Technical Data: **preliminary November 2013**

ArmaFORM PET/W GR: 'green' structural foam core

Polyethylene Therephthalate (Welded)

			GR60	GR80	GR100	GR115
Density	ISO 845	kg/m³	60 (1)	80 (1)	100 (1)	115 (1)
Compression Strength	ASTM D 1621 b	MPa	0,7	0,95	1,5	1,8
Compression Modulus	ASTM D 1621 b ISO 844	MPa MPa	55 35	71 57	105 70	120 80
Shear Strength	ISO 1922	MPa	0,5	0,55	0,7	0,9
Shear Modulus	ISO 1922	MPa	11	18	20	22
Shear Strain	ISO 1922	%	25	15	10	10
Tensile Strength	ASTM C 297	MPa	1,6	2,1	2,4	2,7
Tensile Modulus	ASTM C 297	MPa	60	75	105	120
Thermal Conductivity	EN 12667	W/mK	0,034	0,034	0,034	0,035

Tolerances	**Length**	**Width**	**Diagonal**	**Thickness**
Dimensions (mm) (2)	2.448	1.008	tbc (3)	GR80-GR115: 5–150mm GR60: 10-150 mm
Tolerances (mm) at room temperature	+/- 5	+/- 5	≤ 4	≤100mm: GR80+GR115 +/- 0,5 GR60: +/- 0,7 ≥ 100mm: +/- 1

(1) Tolerances GR80 - GR115: +/- 5 kg/m³; GR60: -5/+10 kg/m³
(2) Standard dimension. Further dimensions on special request.
(3) Depending on length and width combination.
All values are average production figures.
ArmaFORM PET products are CFC / HFC free.

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Divinycell® PR

Technical Data

The high performance sandwich core

Divinycell PR is a thermoplastic sandwich core material manufactured from recycled PET raw material.

Good mechanical strength to low weight makes it suitable for goods transport applications and sandwich panelling.

Mechanical properties Divinycell® PR

Property	Test Procedure	Unit	PR60	PR80	PR100	PR115
Nominal Density	ISO 845	kg/m^3	60	80	100	115
Compressive Strength[1]	ISO 844	MPa	0.7	0.95	1.5	1.8
Compressive Modulus[1]	ASTM D 1621 b	MPa	55	71	105	120
Compressive Modulus[1]	ISO 844	MPa	35	57	70	80
Tensile Strength	ASTM C 297	MPa	1.6	2.1	2.4	2.7
Tensile Modulus	ASTM C 297	MPa	60	75	105	120
Shear Strength	ISO 1922	MPa	0.5	0.55	0.7	0.9
Shear Modulus	ISO 1922	MPa	11	18	20	22
Shear Elongation	ISO 1922	%	25	15	10	10

1. Perpendicular to the plane. All values measured at +23°C

Maximum processing temperature is dependent on time, pressure and processing conditions. Therefore users are advised to contact DIAB Technical Services to confirm that Divinycell PR is compatible with their particular processing parameters.

Divinycell PR is compatible with most commonly used resin systems (polyester, vinyl ester, epoxy and phenolics) including those with high styrene contents. For optimal design of applications used in high operating temperatures in combination with continuous load, please contact DIAB Technical Services for detailed design instructions.

Product Characteristics

- Made of recycled PET bottles
- Good temperature resistance
- Recyclable
- Good thermal conductivity

Applications within

- Goods Transport
- Panelling
- Nacelles

DIAB

www.diabgroup.com

Technical Characteristics Divinycell® PR

Characteristics[1]	Unit	PR60	PR80	PR100	PR115	Test method
Density variation	%	± 5	± 5	± 5	± 5	ISO 845
Thermal conductivity[2]	W/(m-K)	0.034	0.034	0.034	0.034	ISO 12667

1. Typical values are approximate
2. Thermal conductivity at +20°C
3. Measured at different thicknesses, contact DIAB fo more information.

Physical characteristics

Format, color		Unit	PR60	PR80	PR100	PR115
Plain sheets	Length	mm	2448	2448	2448	2448
	Width	mm	1005	1005	1005	1005
GS sheets	Length	mm	1224	1224	1224	1224
	Width	mm	1005	1005	1005	1005
Color			Light green	Light green	Light green	Light green

Other dimensions are available on request.

Disclaimer:
This data sheet may be subject to revision and changes due to development and changes of the material. The data is derived from tests and experience. If not stated as minimum values, the data is average data and should be treated as such. Calculations should be verified by actual tests. The data is furnished without liability for the company and does not constitute a warranty or representation in respect of the material or its use. The company reserves the right to release new data sheets in replacement.

Issued: July 2013 Doc No: PR July 2013 rev2 - SI

The product is made by Armacell

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American Chemistry Council

Lightweight plastic fibers can have added strength but enough 'give' to enhance pedestrian safety

plastics & autos

Lightweight plastic fibers can have added strength but enough 'give' to enhance pedestrian safety

Used with permission, © Lotus

The Lotus Elise incorporates SrPP panels on its exterior to increase passenger and pedestrian safety in addition to a number of its interior features.

- With pedestrian safety measures growing increasingly strict, pedestrian safety components are currently being developed for vehicle application.[1]
- Self-reinforced plastic (polypropylene) is a new engineering process that has been created for use in vehicle hoods to help protect pedestrians in the event of an accident. Though small in size, lightweight and energy absorbent self-reinforced plastic panels are placed strategically where a pedestrian's head might strike the hood of a moving vehicle to help cushion the head and prevent serious injury.[2,3]
- Self-reinforced plastic is created by heating and weaving plastic to stretch and align the molecular chains, making the end product is much stronger than conventional plastic, but without any weight gain.[4,5]
- Engineers performed static deflection tests on a self-reinforced plastic prototype, which withstood the required force load, yet produced greater deflection.[6] This improved deflection indicates that the panel can provide strength on impact, but enough "give" to offer additional protection to pedestrians.
- Automaker Lotus has already used a front access panel made from self-reinforced plastic for its Elise sports car. The Lotus front access panel was found to be 57% lighter than the current production part and passed mechanical and paint durability tests.[7]
- A manufactured brand of self-reinforced plastic is also currently being considered for components such as under-body shields as a replacement for heavier metal shields, as well as potential applications in cosmetic panels and occupant protection.[7]
- To be strong enough for automobile use, conventional composites can be reinforced with glass fiber, carbon fiber or natural materials, which can make recycling more problematic. Self-reinforced plastic, however, uses plastic resin to create a fiber-like entity and as a binding material. This process allows the plastic to actually reinforce itself, which in turn creates a potentially more recyclable material without sacrificing strength.[8,7] Recycling is not always available. Check to see if recycling is available in your area.

Used with permission
Image courtesy Propex Fabrics, Inc.

Polypropylene threads are gathered to create the polypropylene fabric that will be hot compacted into SrPP panels.

Used with permission
Image courtesy NetComposites

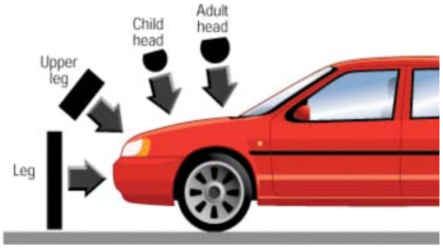
Used with permission, © Lotus

The lightweight Porsche Carrera GT, with its racecar looks and performance, was initially intended to compete in the 24 Hours of LeMans car race.[13]

Additional Information

- Much of the SrPP information comes from UK research program RECYCLE, under the SMMT (Society of Motor Manufacturers and Traders) Foresight Vehicle Initiative, and is available at: http://www.foresightvehicle.org.uk/. RECYCLE was made up of seven UK companies and universities including NetComposites, Lotus Engineering, BI Composites, Propex Fabrics, the University of Warwick, Trauma-Lite, and London Taxis International. The group developed a successful new process for producing SrPP.[8]
- "SrPP products have high impact strengths, making them excellent for areas of [the car relating to] pedestrian safety and passenger protection."[5]
- As a polypropylene plastic, SrPP is corrosion-resistant. It also satisfies standard automotive manufacturing tests for resistance to hydraulic fluids and fuels.[5]
- SrPP is created through a process called "hot compaction," in which polypropylene fabric is selectively melted with heat, which forms a composite consisting of the original, highly oriented material held in place by a melted phase.[9]

Diagram of a Pedestrian Impact



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European New Car Assessment Programme. www.euroncap.com

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Pictures

Lotus Elise: ©Lotus

Polypropylene Threads: http://www.curvonline.com/about/commitment.html#

SrPP Panels: http://www.netcomposites.com/about_us_details.asp?pid=1007&id=1039

SrPP Panels on Lotus Elise: ©Lotus Pedestrian Impact: European New Car Assessment Programme. www.euroncap.com

**For more information, contact Rob Krebs
at rob_krebs@americanchemistry.com
or visit www.plastics-car.com**

American®
Chemistry
Council

Q & A

[AUTOMOTIVE FILM]

GLUE, GLUE METAL, DYED, DYED METAL, GLUE SAFETY, DYED SAFETY, WINDSCREEN FILM

01. Why Solar Control Film?

The solar energy consists of Ultraviolet Ray, Visible Light, Infrared. UV is a major cause of skin cancer and color fading and IR and visible light cause heat up inside of a car. By solar control film, customers can save cooling energy cutting heat coming in. Moreover it can prevent not only skin cancer but also color fading by 99% UV block.

02. What is dyed film?

Dyed film is high quality color stable film by dying its PET material. It prevents interior furniture from color fading by 99% harmful UV block. And it offers you classic look with sophisticated charcoal color film.

03. How do we compare NDFOS Dyed & Dyed metal film with other competitors?

[Heat Shrinking]

It should be taken heat very well on the film to install back window of a car. PET layer, adhesive and hard coating affect heat shrinking. Our product has been based high quality PET layer and technical adhesive know-how so we have equivalent heat shrinking performance as USA manufacturers' product.

[Haze]

NDFOS window films have been enhanced visibility seen through films by using ultra transparent PET material. As a result of this, drivers feel comfortable even with NDFOS window film applied on a glass.

[Fading Out]

Window film based on dyed PET material has 3 to 5 year warranty for color fading out. NDFOS window film has 3 year warranty verified QUV and field test all over the world for color fading out. On the other hand, some Asia dyed manufactures are selling low quality dyed film and it does fade out within 1 year.

[Adhesive]

We put high performance adhesive on NDFOS Window film so there is no adhesive trace when you squeeze and it helps easy installation with fast dry out adhesive. You can distinguish good and low quality of adhesive by smelling, which indicates that adhesive with non smell is supreme adhesive product. Our adhesive has no smell but low quality product has pungent smell.

[Heat Rejection]

HP film is based on metalized PET layer for heat rejection because metal substance can block heat of solar energy. Our window film is equally metalized and has the same heat rejection rate through all range of film. To the contrary, some Asia films have low heat rejection rate and visual barrier caused by unequal metal distribution.

04. What is Dyed metal film?

Dyed metal film can control solar energy by metalized PET that can cut the heat coming from visible light and IR. Dyed metal film can save cooling energy by blocking heat coming inside and has privacy film. Moreover it protects skin cancer and color fading interior by 99% UV block.

05. What's the function of safety film?

Automotive safety film not only has shatterproof function that can protect driver and passenger from shard glass caused by accident but also prevent auto theft. Moreover, it is very effective to block solar energy by protecting UV and IR as window film is.

06. What is difference between Glue safety and Dyed safety film?

The biggest difference between Glue and Dyed safety film is structure of film. Glue safety film has color by putting dye in adhesive between Clear PET of 4MIL thickness and release liner.

---SR
---CLEAR PET
---ADHESIVE+COLOR
---CLEAR PET
---RELEASE LINER

Dyed safety film has color by dyed layer laminating clear PET.

---SR
---CLEAR PET
---DYED PET
---ADHESIVE
---RELEASE LINER

Glue safety film is one of the best seller product and Dyed safety film is being sold as high quality product.

07. How does heat shrinking work?

NDFOS has been steadily putting the best effort to R&D for development of heat shrinking. We are doing installation autonomously for heatshrinking and as a result of having feedback from our business network, we are improving heat shrinking. Our customer has satisfaction with heat shrinking that can fit right for back window of a car. If you would like to have test, feel free to ask sample and follow NDFOS installation instruction

08. What is color fading out?

Each of UV(40%), IR(25%), VL(25%) and etc.(10%) occupy one of reason for color fading out. We put a lot effort in block of UV and IR to prevent color fading. We are trying to meet customer's needs with solar control film that can block 99% of UV and more than 40% of IR. Each film lines have its own warranty terms and we compensate by complain procedure.

09. Why windshield solar control film?

Solar heat coming through windshield should be harmful for excellent driving environment and one of reason to increase cooling cost and to fade out car sheet. Generally, an angle of windshield is lower than side window. As a result, solar heat coming through windshield is much bigger than side window.
Windscreen film not only can save energy by decline of cooling cost but prevent interior fading out. We recommend you to use film with more than 60% of VLT for windscreen for clear outlook.

Target product
High quality windscreen film such as V-KOOL70, 3M Crystalline70, Llumar Air65 are very expensive for every customers. We offer both equivalent level of product and downmarket product to meet all our customers.

Cool Crystal

New! High Performance Automotive Film

Cool Crystal combines the **unbeatable heat rejection** of a lightly metallized film with the **subtle graphite tone** of a smoke shade deep-dyed polyester.

The result? A **high performance** film with high aesthetic appeal that **feels good** and **looks great**.

Color stable and covered by a **lifetime warranty**, **Cool Crystal** retains its protective performance and sleek appearance for **long-lasting impact**.

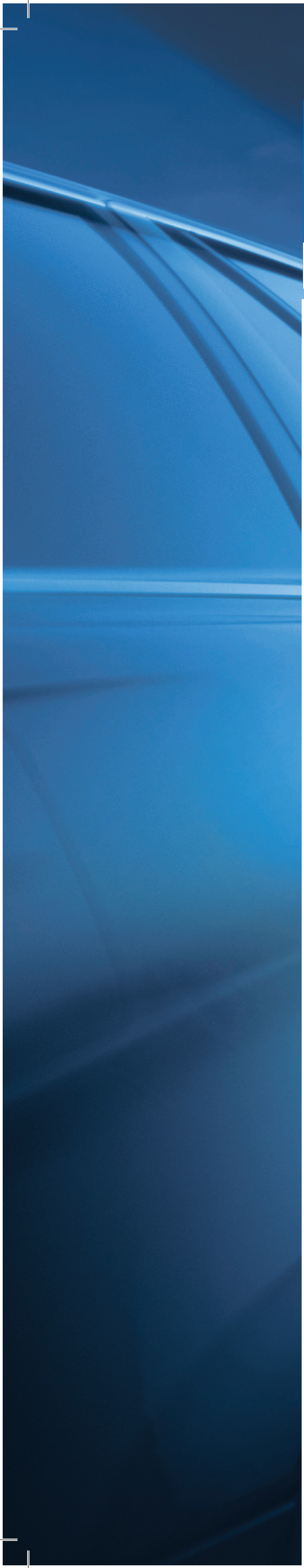
The customer's choice

- Attractive appearance
- Exceptional value
- High heat and glare rejection
- Outstanding UV protection (99%)
- Low visible light reflectance
- No-color-change guarantee
- High privacy (in low VLT)

The dealer's choice

- Superb shrink
- Quick dry
- Lifetime warranty

Hanita Coatings



Cool Crystal

New! High Performance Automotive Film

Good Looks

Five shades of graphite, from 35% to a discreet 04% VLT, to satisfy local legislation and individual taste.

High Performance

Good solar energy rejection combines with low visible light reflectance to ensure a cooler cabin and less glare. Outstanding UV block helps protect skin from sun damage, and interior from fading.

Great Handling

Optimized shrink, reduced drying time and high flexibility guarantee effortless installation.

- Available in 04%, 12%, 20% and 35% VLT
- 20", 30", 40" and 60" width
- For further information contact: **solar@hanitacoatings.com**
  +972 4 985 9919

Optical & Solar Properties	Cool Crystal 04	Cool Crystal 12	Cool Crystal 20	Cool Crystal 35
Visible Light Transmitted	4%	14%	19%	39%
Visible Light Reflected	6%	6%	6%	8%
Ultra Violet Block	99%	99%	99%	99%
Total Solar Energy Reflected	9%	8%	8%	9%
Total Solar Energy Transmitted	25%	28%	30%	40%
Total Solar Energy Absorbed	66%	64%	62%	52%
Shading Coefficient	0.53	0.55	0.57	0.64
Total Solar Energy Rejection	54%	52%	51%	45%
Product code	R058Q04	R058Q12	R058Q20	R058Q35

Performance results are calculated on 1/4" - 6mm glass using NFRC methodology and LBNL Window 5.2 software, and are subject to variations in process conditions within industry standards and are only intended for estimating purposes.

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Hanita Coatings

VIVAK Properties

Physical	Test method	Units	VIVAK PETG
Specific Gravity/Relative Density	ASTM D-792		1.27
Optical Refractive Index	ASTM D-542	nD	1.57
Light Transmission -Total	ASTM D-1003	%	86
Light Transmission - Haze	ASTM D-1003	%	1.0
Water Absorption	ASTM D-570	% By wt	0.2

Mechanical	Test method	Units	VIVAK PETG
Tensile Strength	ASTM D-638	psi	7,700
Tensile Modulus of Elasticity	ASTM D-638	psi	320,300
Flexural Strength	ASTM D-790	psi	11,200
Flexural Modulus of Elasticity	ASTM D-790	psi	310,000
Dielectric Constant	ASTM D-150	@1kHz	2.6
Dielectric Contstant	ASTM D-150	@1mHz	2.4
Dielectric Strength	ASTM D-149	volts/mil	410
Compressive Strength	ASTM D-695	psi	8,000
Shear Strength	ASTM D-732	psi	9,000
Rockwell Hardness	ASTM D-785		R-115

Thermal	Test method	Units	VIVAK PETG
Deflection Temperature 264 psi (1.8 MPa)	ASTM D-648	°F	157
Deflection Temperature 66 psi (0.45 MPa)	ASTM D-648	°F	164
Coefficient of Thermal Expansion - 30 to 30°C	ASTM D-696	in/(in-°F) x 10^{-5}	3.8
Thermal Conductivity	ASTM C-177	BTU-ft/(hr-ft^2	0.13
Flammability (Burning Rate)	ASTM D-635	In/minute	0.06
Flammability	UL 94		HB
Smoke Density Rating	ASTM D-2843	%	53.8
Self-Ignition Temperature	ASTM D-1929	°F	880
Flame Spread Index	ASTM E84		85
Smoke Developed Index	ASTM E84		450
Glasss Transition Temperature	ASTM D-3418	psi	178

Validation Sheet **NL, KIMA 1993, 2-13, mixed**

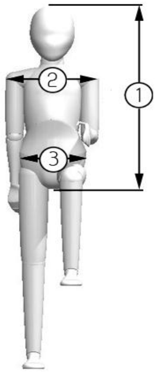
source data: http://dined.io.tudelft.nl/dined/

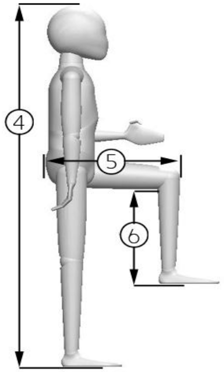
for more information: www.3dhumanmodel.com

Initiated by **Konings & Kappelhoff**
design agency

experts in product design and human interactions

website www.koningskappelhoff.com





dimension number	dimension name
1	sitting height
2	shoulder breadth (bi-deltoid)
3	hip breadth (sitting)
4	stature
5	buttock knee length
6	popliteal height

	KIMA 1993 2-3 Mixed						KIMA 1993 3-4 Mixed						KIMA 1993 4-5 Mixed						KIMA 1993 5-6 Mixed					
	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model
	P05	P05	P50	P50	P95	P95	P05	P05	P50	P50	P95	P95	P05	P05	P50	P50	P95	P95	P05	P05	P50	P50	P95	P95
1	509	466	549	531	590,25	597	534,4	497	574	556	613,6	614	562	528	605	585	644,6	632	592,1	550	635	615	677,9	658
2	217,9	216	241	241	264,1	267	233,2	232	253	253	272,8	274	246	250	268	267	289,45	288	255,25	256	280	280	304,75	304
3	168	168	192	192	215	215	179	179	200	200	220	220	192	192	215	215	238	238	195	195	223	223	251	251
4	857,1	833	933	938	1008,9	1056	938	919	1013	1027	1087,3	1134	1012	993	1084	1103	1155	1200	1083,2	1068	1164	1190	1244,9	1283
5	266	266	299	291	332	332	300	303	331	333	360,7	363	322	323	356	358	389	390	353,35	357	388	391	422,65	429
6	197,6	190	224	223	250,4	241	222	221	253	250	282,7	280	250	249	279	274	308	307	277,3	276	307	303	336,7	334

all dimensions in mm

	KIMA 1993 6-7 Mixed						KIMA 1993 7-8 Mixed						KIMA 1993 8-9 Mixed						KIMA 1993 9-10 Mixed					
	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model
	P05	P05	P50	P50	P95	P95	P05	P05	P50	P50	P95	P95	P05	P05	P50	P50	P95	P95	P05	P05	P50	P50	P95	P95
1	621,1	581	664	645	706,9	687	644	600	689	670	733	712	663,8	631	710	690	756,2	735	684,85	646	736	716	787,15	765
2	270,55	270	292	292	313,45	312	277	277	305	305	333	333	287,95	287	316	315	344,05	344	297,3	297	327	327	356,7	357
3	205	205	231	231	256	256	211	211	243	243	274	274	219	219	250	250	280	280	224	224	261	261	297	297
4	1146,8	1131	1226	1251	1305,2	1355	1196,3	1190	1287	1318	1377,8	1419	1254,2	1253	1340	1374	1425,8	1478	1304,4	1302	1405	1435	1505,7	1547
5	373,05	374	411	412	448,95	492	397,4	400	437	441	476,6	475	418,4	418	458	461	497,6	500	439,45	438	484	482	528,55	520
6	296,65	292	328	327	359,35	361	313,35	306	348	349	382,65	373	335,65	329	367	349	398,35	398	350,05	347	388	379	425,95	429

all dimensions in mm

	KIMA 1993 10-11 Mixed						KIMA 1993 11-12 Mixed						KIMA 1993 12-13 Mixed					
	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model	Source Data	3D Human Model
	P05	P05	P50	P50	P95	P95	P05	P05	P50	P50	P95	P95	P05	P05	P50	P50	P95	P95
1	703,9	670	760	742	816,1	793	718,6	689	778	758	837,4	811	737	703	801	776	865	839
2	310	310	343	343	376	376	318	318	351	351	384	384	325	325	361	361	397	398
3	234	234	277	277	320	320	242	242	286	286	329	329	248	248	295	295	342	342
4	1355,5	1365	1466	1506	1576,6	1619	1395,2	1408	1509	1551	1622,9	1673	1435,3	1445	1564	1593	1692,7	1731
5	464,8	466	511	513	557,2	553	477,85	480	529	528	580,15	575	496,55	496	551	549	605,45	601
6	365,75	368	407	409	448,25	442	379,75	380	421	422	462,25	461	441,8	390	488	431	534,2	475

all dimensions in mm

Note: for this model the dimensions of the individual body parts were implemented. The validation shows the combined dimensions and the deviation form the source data.
Note: hip breath values differ in standing and sitting position. The sitting hip breath has been chosen because the Kima models are regularly used for child seat development.

PowerLAN™ Master Gateway Battery Management Controller With PowerPump™ Cell Balancing Technology

Check for Samples: bq78PL116

FEATURES

- **bq78PL116 Designed for Managing 3- to 16-Series-Cell Battery Systems**
  - **Support for LCD and Electronic Paper Displays or EPDs**
  - **Configurable for 11-A, 26-A, or 110-A Operating Currents**
- **Systems With More Than Four Series Cells Require External bq76PL102 Dual-Cell Monitors**
- **SmartSafety Features:**
  - **Prevention: Optimal Cell Management**
  - **Diagnosis: Improved Sensing of Cell Problems**
  - **Fail Safe: Detection of Event Precursors**
- **Rate-of-Change Detection of All Important Cell Characteristics:**
  - **Impedance**
  - **Cell Temperature**
- **PowerPump Technology Transfers Charge Efficiently From Cell to Cell During All Operating Conditions, Resulting in Longer Run Time and Cell Life**
  - **Includes User-Configurable PowerPump Cell-Balancing Modes**
- **High-Resolution 18-Bit Integrating Delta-Sigma Coulomb Counter for Precise Charge-Flow Measurements and Gas Gauging**
- **Multiple Independent Δ-Σ ADCs: One-per-Cell Voltage, Plus Separate Temperature, Current, and Safety**
- **Simultaneous, Synchronous Measurement of Pack Current and Individual Cell Voltages**
- **Very Low Power Consumption**
  - **< 400 μA Active, < 185 μA Standby, < 85 μA Ship, and < 1 μA Undervoltage Shutdown**
- **Accurate, Advanced Temperature Monitoring of Cells and MOSFETs With up to 4 Sensors**
- **Fail-Safe Operation of Pack Protection Circuits: Up to Three Power MOSFETs and One Secondary Safety Output (Fuse)**
- **Fully Programmable Voltage, Current, Balance, and Temperature-Protection Features**
- **External Inputs for Auxiliary MOSFET Control**
- **Smart Battery System 1.1 Compliant via SMBus**

APPLICATIONS

- **Portable Medical Instruments and Test Equipment**
- **Mobility Devices (E-Bike)**
- **Uninterruptible Power Supplies and Hand-Held Tools**

DESCRIPTION

The bq78PL116 master gateway battery controller is part of a complete Li-Ion control, monitoring, and safety solution designed for large series cell strings.

The bq78PL116 along with bq76PL102 PowerLAN™ dual-cell monitors provide complete battery-system control, communications, and safety functions for a structure of three up to 16 series cells. This PowerLAN system provides simultaneous, synchronized voltage and current measurements using one A/D per-cell technology. This eliminates system-induced noise from measurements and allows the precise, continuous, real-time calculation of cell impedance under all operating conditions, even during widely fluctuating load conditions.

PowerPump technology transfers charge between cells to balance their voltage and capacity. Balancing is possible during all battery modes: charge, discharge, and rest. Highly efficient charge-transfer circuitry nearly eliminates energy loss while providing true real-time balance between cells, resulting in longer run-time and improved cycle life.

PowerLAN, PowerPump, bqWizard are trademarks of Texas Instruments.
All other trademarks are the property of their respective owners.

DESCRIPTION (CONTINUED)

Temperature is sensed by up to 4 external sensors and one on-chip sensor. This permits accurate temperature monitoring of each cell individually. Firmware is then able to compensate for the temperature-induced effects on capacity, impedance, and OCV on a cell-by-cell basis, resulting in superior charge/ discharge and balancing control.

External MOSFET control inputs provide user- definable direct hardware control over MOSFET states. Smart control prevents excessive current through MOSFET body diodes. Auxiliary inputs can be used for enhanced safety and control in large multicell arrays.

The bq78PL116 is completely user-configurable, with parametric tables in flash memory to suit a variety of cell chemistries, operating conditions, safety controls, and data reporting needs. It is easily configured using the supplied bqWizard™ graphical user interface (GUI). The device is fully programmed and requires no algorithm or firmware development.

The bq78PL116 pin functions of LED1/SEG1–LED5/SEG5, PSH/BP/TP, and FIELD support LED, LCD, and electronic paper displays (EPDs). The user can configure the bq78PL116 for the desired display type.

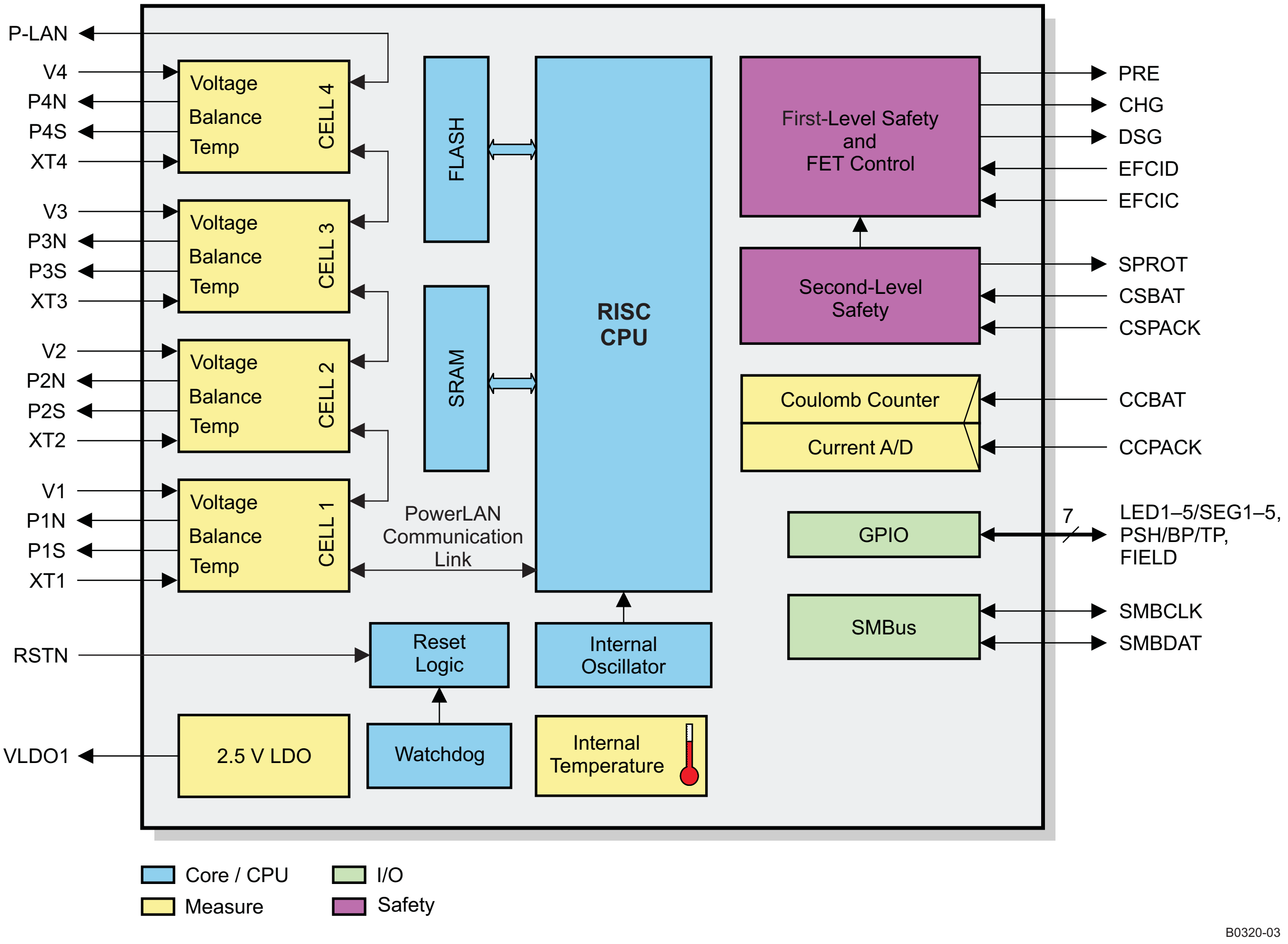


Figure 1. BQ78PL116 Internal Block Diagram

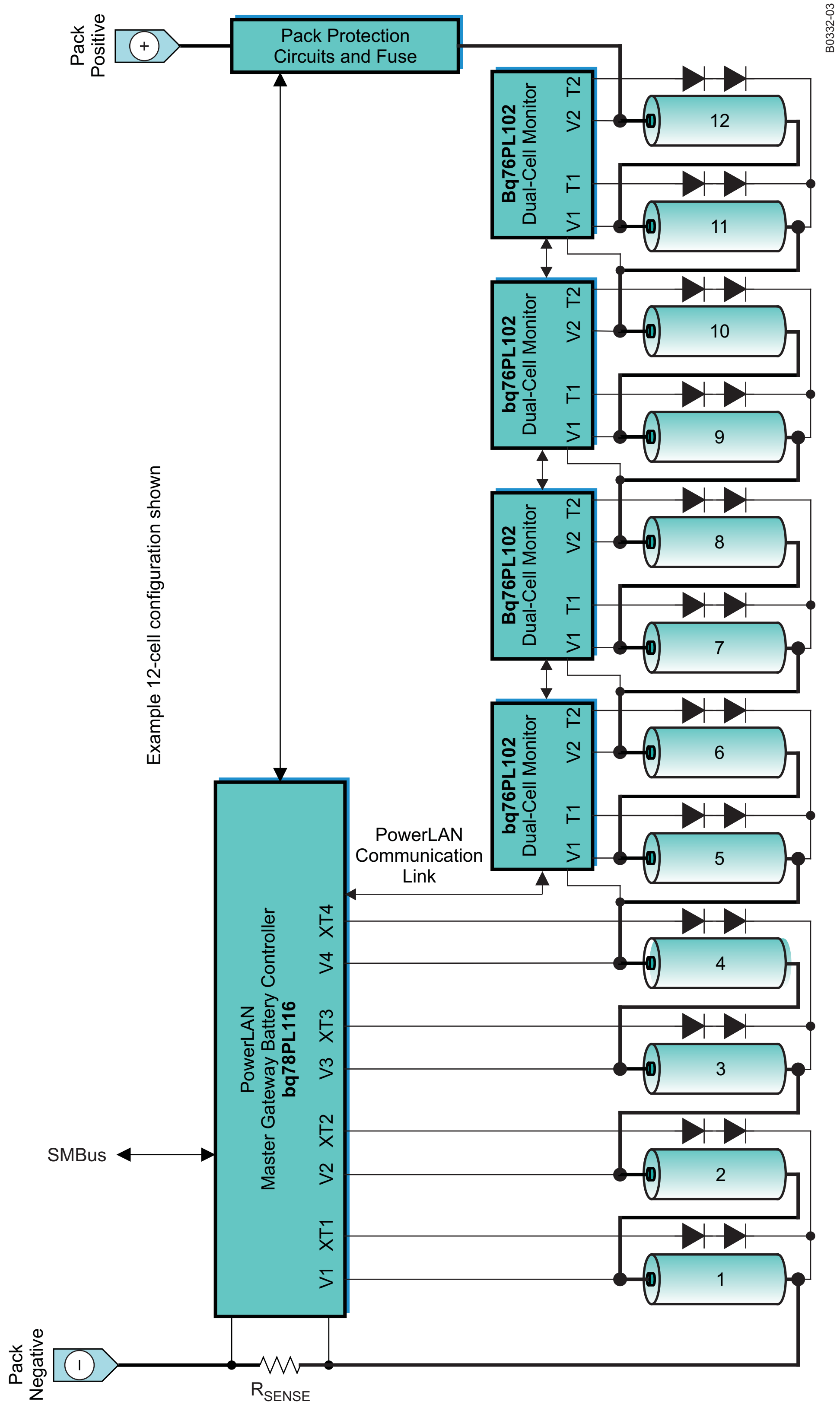


Figure 2. Example bq78PL116 System Implementation (12 Cells)

Table 1. ORDERING INFORMATION

Product	Cell Configuration[1]	Package	Package Designator	Temperature Range	Ordering Number	Quantity, Transport Media
bq78PL116	3 to 16 series cells	QFN-48, 7-mm × 7-mm	RGZ	–40°C to 85°C	bq78PL116RGZT	250, tape and reel
					bq78PL116RGZR	2500, tape and reel

(1) For configurations consisting of more than four series cells, additional bq76PL102 parts must be used.

AVAILABLE OPTIONS

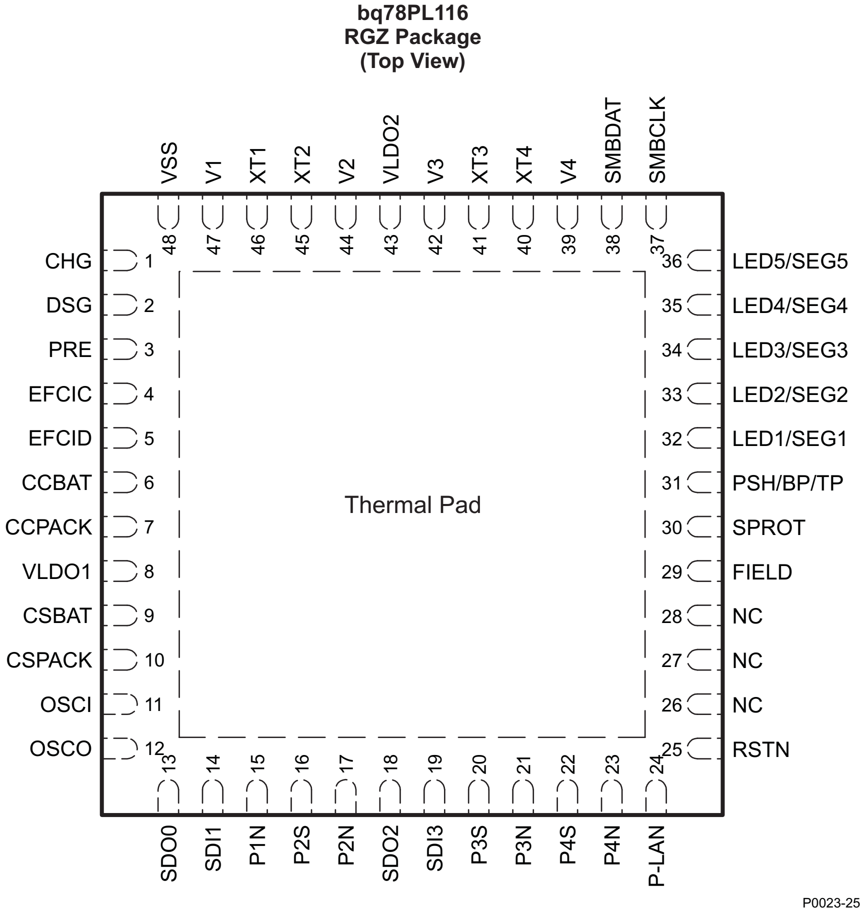


Figure 3. bq78PL116 Pinout

bq78PL116 TERMINAL FUNCTIONS

NAME	NO.	TYPE[1]	DESCRIPTION
CCBAT	6	IA	Coulomb counter input (sense resistor), connect to battery negative
CCPACK	7	IA	Coulomb counter input (sense resistor), connect to pack negative
CHG	1	O	Charge MOSFET control (active-high, low opens MOSFET)
CSBAT	9	IA	Current sense input (safety), connect to battery negative
CSPACK	10	IA	Current sense input (safety), connect to pack negative
DSG	2	O	Discharge MOSFET control (active-high, low opens MOSFET)
EFCIC	4	I	External charge MOSFET control input
EFCID	5	I	External discharge MOSFET control input

(1) Types: I = Input, IA = Analog input, IO = Input/Output, O = Output, P = Power

bq78PL116 TERMINAL FUNCTIONS (continued)

NAME	NO.	TYPE[(1)]	DESCRIPTION
FIELD	29	O	EPD field segment
LED1/SEG1	32	O	LED1 – open-drain, active-low, LCD and EPD segment 1
LED2/SEG2	33	O	LED2 – open-drain, active-low, LCD and EPD segment 2
LED3/SEG3	34	O	LED3 – open-drain, active-low, LCD and EPD segment 3
LED4/SEG4	35	O	LED4 – open-drain, active-low, LCD and EPD segment 4
LED5/SEG5	36	O	LED5 – open-drain, active-low, LCD and EPD segment 5
N/C	26, 27	IO	Connect 1-MΩ resistor to VSS
N/C	28	O	No connect
OSCI	11	I	External oscillator input (no connect, internal oscillator used)
OSCO	12	O	External oscillator output (no connect, internal oscillator used)
P1N	15	O	Charge-balance gate drive, cell 1 north
P2N	17	O	Charge-balance gate drive, cell 2 north
P2S	16	O	Charge-balance gate drive, cell 2 south
P3N	21	O	Charge-balance gate drive, cell 3 north
P3S	20	O	Charge-balance gate drive, cell 3 south
P4N	23	O	Charge-balance gate drive, cell 4 north
P4S	22	O	Charge-balance gate drive, cell 4 south
P-LAN	24	IO	PowerLAN I/O to external bq76PL102 nodes
PRE	3	O	Precharge MOSFET control (active-high)
PSH/BP/TP	31	IO	Pushbutton detect for LED display, LCD backplane, EPD top plane and charge pump
RSTN	25	I	Device reset, active-low
SDI1	14	I	Connect to SDO0 via a capacitor
SDI3	19	I	Internal PowerLAN connection – connect to SDO2 through a 0.01-μF capacitor
SDO0	13	O	Requires 100-kΩ pullup resistor to VLDO1
SDO2	18	O	Internal PowerLAN connection – connect to SDI3 through a 0.01-μF capacitor
SMBCLK	37	IO	SMBus clock signal
SMBDAT	38	IO	SMBus data signal
SPROT	30	O	Secondary protection output, active-high (FUSE)
V1	47	IA	Cell-1 positive input
V2	44	IA	Cell-2 positive input
V3	42	IA	Cell-3 positive input
V4	39	IA	Cell-4 positive input
VLDO1	8	P	Internal LDO-1 output, bypass with 10-μF capacitor to VSS
VLDO2	43	P	Internal LDO-2 output, bypass with 10-μF capacitor to V2
VSS	48	IA	Cell-1 negative input
XT1	46	IA	External temperature-sensor-1 input
XT2	45	IA	External temperature-sensor-2 input
XT3	41	IA	External temperature-sensor-3 input
XT4	40	IA	External temperature-sensor-4 input
–	–	P	Thermal pad. Connect to VSS

ABSOLUTE MAXIMUM RATINGS[1]

over operating free-air temperature range (unless otherwise noted)

		RANGE	UNITS
T_A	Operating free-air temperature (ambient)	–40 to 85	°C
T_{stg}	Storage temperature	–65 to 150	°C
V4	Voltage range with respect to V3	–0.5 to 5.0	V
V3	Voltage range with respect to V2	–0.5 to 5.0	V
V2	Voltage range with respect to V1	–0.5 to 5.0	V
V1	Voltage range with respect to VSS	–0.5 to 5.0	V
EFCIC, EFCID	Voltage range with respect to VSS	–0.5 to 5.0	V
LED1/SEG1—LED5/SEG5	Voltage on I/O pin with respect to VSS	–0.5 to 5.0	V
SMBCLK, SMBDAT	Voltage range with respect to VSS	–0.5 to 6.0	V
VLDO1	Voltage with respect to VSS	3.0	V
VLDO2	Voltage range with respect to V2	3.0	V
RSTN	Voltage range with respect to VSS	–0.5 to VLDO1 + 0.5	V
FIELD, SPROT, PSH/BP/TP	Voltage range with respect to VSS	–0.5 to VLDO1 + 0.5	V
CCBAT, CCPACK, CSBAT, CSPACK	Voltage range with respect to VSS	–0.5 to VLDO1 + 0.5	V
CHG, DSG, PRE	Voltage range with respect to VSS	–0.5 to VLDO1 + 0.5	V
OSCI, OSCO	Voltage with respect to VSS	–0.5 to VLDO1 + 0.5	V
XT1, XT2	Voltage with respect to VSS	–0.5 to VLDO1 + 0.5	V
SDO0	Voltage range with respect to VSS	–0.5 to VLDO1 + 0.5	V
XT3, XT4	Voltage range with respect to V2	–0.5 to VLDO2 + 0.5	V
SDO2, SDI3, P-LAN	Voltage range with respect to V2	–0.5 to VLDO2 + 0.5	V
SDO0, SDI1	Voltage range with respect to VSS	–0.5 to V1 + 0.5	V
P1N, P2S, P2N	Voltage range with respect to VSS	–0.5 to V1 + 0.5	V
P3S, P3N, P4S, P4N	Voltage range with respect to V2	–0.5 to V3 + 0.5	V
PRE, CHG, DSG, SPROT, FIELD, PSH/BP/TP	Current source/sink	20	mA
LED1/SEG1–LED5/SEG5	Current source/sink	20	mA
VLDO1, VLDO2	Current source/sink	20	mA
ESD tolerance	JEDEC, JESD22-A114 human-body model, R = 1500 Ω, C = 100 pF	2	kV
Lead temperature, sodlering	Total time < 3 seconds	300	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

RECOMMENDED OPERATING CONDITIONS

over operating free-air temperature range (unless otherwise noted)

			MIN	NOM	MAX	UNIT
V_{SUP}	Supply voltage—V1, V2, V3, V4	All cell voltages equal, four-cell operation	2.5	3.6	4.5	V
		All cell voltages equal, three-cell operation (V3 = V4)	2.8	3.6	4.5	
$V_{Startup}$	Minimum startup voltage—V1, V2, V3, V4	All cell voltages equal	2.9			V
V_{IN}	Input cell voltage range—V(n+1) – V(n), n = 1, 2, 3, 4		0		4.5	V
C_{VLDO1}	VLDO 1 capacitor—VLDO1		2.2	10	47	µF
C_{VLDO2}	VLDO 2 capacitor—VLDO2		2.2	10	47	µF
C_{Vn}	Cell-voltage capacitor—Vn		1			µF

ELECTRICAL CHARACTERISTICS

T_A = –40°C to 85°C (unless otherwise noted)

DC Characteristics

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
I_{DD}	Operating-mode current (at V2)	Acrtive mode, cells = 3.6 V		400		µA
I_{STBY}	Standby-mode current (at V2)	SMBCLK = SMBDAT = VSS, I_{BAT} = 0, cells = 3.6 V		185		µA
I_{SHIP}	Ship-mode current (at V2)	SMBCLK = SMBDAT = VSS, I_{BAT} = 0, cells = 3.6 V		85		µA
I_{ECUV}	Extreme cell undervoltage shutdown current	All cells < 2.7 V and any cell < ECUV set point			1	µA
V_{OL}	SPROT, LEDEN, PSH/BP/TP(bq78PL116), FIELD(bq78PL116)	I_{OL} < 4 mA	0		0.5	V
V_{OH} (1)	SPROT, LEDEN, PSH/BP/TP(bq78PL116), FIELD(bq78PL116)	I_{OH} < –4 mA	V_{LDO1} – 0.1			V
V_{IL}	SPROT, LEDEN, PSH/BP/TP(bq78PL116), FIELD(bq78PL116)				0.25 V_{LDO1}	V
V_{IH}	SPROT, LEDEN, PSH/BP/TP(bq78PL116), FIELD(bq78PL116)		0.75 V_{LDO1}			V

(1) Does not apply to SMBus pins.

Voltage-Measurement Characteristics

T_A = –40°C to 85°C (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Measurement range		2.75		4.5	V
Resolution			<1		mV
Accuracy (1)	25°C		±3	±7	mV
	0°C to 60°C		±10		
Measurement temperature coefficient		160	180	200	µV/°C

(1) Voltage measurement calibrated at factory

Current-Sense Characteristics

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Measurement range	Hardware gain = 9	–0.112		0.1	V
Measurement range (SENSE1)	10-mΩ sense resistor (1)	–11.2		10	A
Measurement range (SENSE2)	3-mΩ sense resistor (hardware gain = 13)	–25.8		25.8	A
Measurement range (SENSE3)	1-mΩ sense resistor (2)	–112		100	A
Input offset	T_A = 25°C		±50		µV
Offset drift	T_A = 0°C to 60°C		0.5		µV/°C
Resolution	Hardware gain = 9		10		µV
Full-scale error (3)	T_A = 25°C	±0.1%			
Full-scale error drift	T_A = 0°C to 60°C	50			PPM/°C

(1) Default setting
(2) Measurement range beyond ±32,768 mA requires the use of an SBData IPScale Factor.
(3) After calibration. Accuracy is dependent on system calibration and temperature coefficient of sense resistor.

Coulomb-Count Characteristics(1) (2)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Resolution			5		nVh
Intergral nonlinearity			0.008%		
Snap-to-zero (deadband)			±100(3)		µV

(1) Shares common input with current-sense section (CCBAT, CCPACK)
(2) After calibration. Accuracy is dependent on system calibration and temperature.
(3) Corresponds to ±10 mA with 10-mΩ sense resistor

Current-Sense (Safety) Characteristics(1)

over free-air temperature range (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Measurement range		–0.312		0.312	V
Minimum threshold setting			25	42	mV
Accuracy(1)	Short-circuit detection	–20		20	mV
	Overcurrent detection, charge and discharge	–4		4	
Resolution	Short-circuit detection		10		mV
	Overcurrent detection, charge and discharge		1.25		
Duration	Short-circuit detection	0.1		3.2	ms
	Overcurrent detection, charge and discharge	0.9		106	

(1) After calibration. Accuracy is dependent on system calibration and temperature coefficient of sense resistor.

Internal Temperature-Sensor Characteristics(1)

over free-air temperature range (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Measurement range		–30		85	°C
Resolution			0.1		°C
Accuracy(1)	0° to 85°		±2		°C

(1) After calibration. Accuracy is dependent on system calibration.

LDO Voltage Characteristics(1)

over free-air temperature range (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{LDO1}	LDO1 operating voltage, referenced to VSS	Load = –200 µA	2.425	2.5	2.575	V
V_{LDO2}	LDO2 operating voltage, referenced to V2	Load = –2 mA	2.425	2.5	2.575	V

(1) After calibration. Accuracy is dependent on system calibration.

External Temperature-Sensor Characteristics

over free-air temperature range (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Measurement range		–40		90	°C
Resolution			0.2		°C
Accuracy(1)	25°		±2		°C
	0° to 85°		±2		
Source current		30	50	70	µA

(1) After calibration. Accuracy is dependent on system calibration.

SMBus Characteristics(1)

over free-air temperature range (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{IL}	Input low voltage		0		0.8	V
V_{IH}	Input high voltage		2.1		5.5	V
V_{OL}	Output low voltage	350-µA sink current	0		0.4	V
C_L	Capacitance, each I/O pin				10	pF
f_{SCL}	SCLK nominal clock frequency	T_A = 25°C	10	100	100	kHz
R_{PU} (2)	Pullup resistors for SCLK, SDATA	V_{BUS} 5 V nominal	13.3		45.3	kΩ
		V_{BUS} 3 V nominal	2.4		6.8	

(1) SMBus timing and signals meet the SMBus 2.0 specification requirements under normal operating conditions. All signals are measured with respect to PACK-negative.

(2) Pullups are typically implemented external to the battery pack and are selected to meet SMBus requirements.

PowerLAN Characteristics(1)(2)(3)

over free-air temperature range (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
C_L	Load capacitance	SDI1, SDI3, SDO0, SDO2, P-LAN			100	pF
V_{IH}	Input logic high	SDI1	0.8 VLDO1			V
		SDI3	0.8 VLDO2			
V_{OH}	Output logic high	SDO0, SDO2	0.9 VLDO1			V
		P-LAN	0.9 VLDO2			
V_{IL}	Input logic low	SDI1			0.2 VLDO1	V
		SDI3			0.2 VLDO2	
V_{OL}	Output logic low	SDO0, SDO2			0.1 VLDO1	V
		P-LAN			0.1 VLDO2	
$t_{r(I)}$	Input rise time	SDI1, SDI3			500	ns
$t_{f(I)}$	Input fall time	SDI1, SDI3			500	ns
$t_{r(O)}$	Output rise time	SDO0, SDO2, P-LAN		30	50	ns
$t_{f(O)}$	Output fall time	SDO0, SDO2, P-LAN		30	50	ns

(1) Values specified by design and are over the full input voltage range and the maximum load capacitance.

(2) The SDI and SDO pins are ac-coupled from the cell circuits downstream and upstream, respectively. The limits specified here are the voltage transitions which must occur within the SDI and SDO rise-and fall-time specifications.

(3) Coupling capacitor between PowerLAN pins is 1000 pF. This value is specified by design.

PowerPump Characteristics(1)

over free-air temperature range (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{OH}	High drive, P2S	I_{OUT} = –10 μA	0.9 V1			V
V_{OL}	Low drive, P2S	I_{OUT} = 200 μA			0.1 V1	V
V_{OH}	High drive, P1N, P2N	I_{OUT} = –200 μA	0.9 V1			V
V_{OL}	Low drive, P1N, P2N	I_{OUT} = 10 μA			0.1 V1	V
V_{OH}	High drive, P3S, P4S	I_{OUT} = –10 μA	0.9 V1			V
V_{OL}	Low drive, P3S, P4S	I_{OUT} = 200 μA			0.1 V1	V
V_{OH}	High drive, P3N, P4N	I_{OUT} = –200 μA	0.9 V1			V
V_{OL}	Low drive, P1N, P2N	I_{OUT} = 10 μA			0.1 V1	V
I_{OH}	Source current, P2S, P3S, P4S	V_{OH} = V1 – 0.8 V	250			μA
I_{OL}	Sink current, P1N, P2N, P3N, P4N	VOH = V1 + 0.2 V	–250			μA
t_r	Signal rise time	C_{Load} = 300 pF			100	ns
t_f	Signal FET fall time	C_{Load} = 300 pF			100	ns
f_P	Frequency			204.8		kHz
D	PWM duty cycle	P1N, P2N, P3N, P4N		33%		
		P2S, P3S, P4S		67%(2)		

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(1) All parameters representative of a typical cell voltage of 3.6 V.

(2) Effective duty cycle is 33%. PxS pins are P-channel drives and MOSFET on-time is (1 – D).

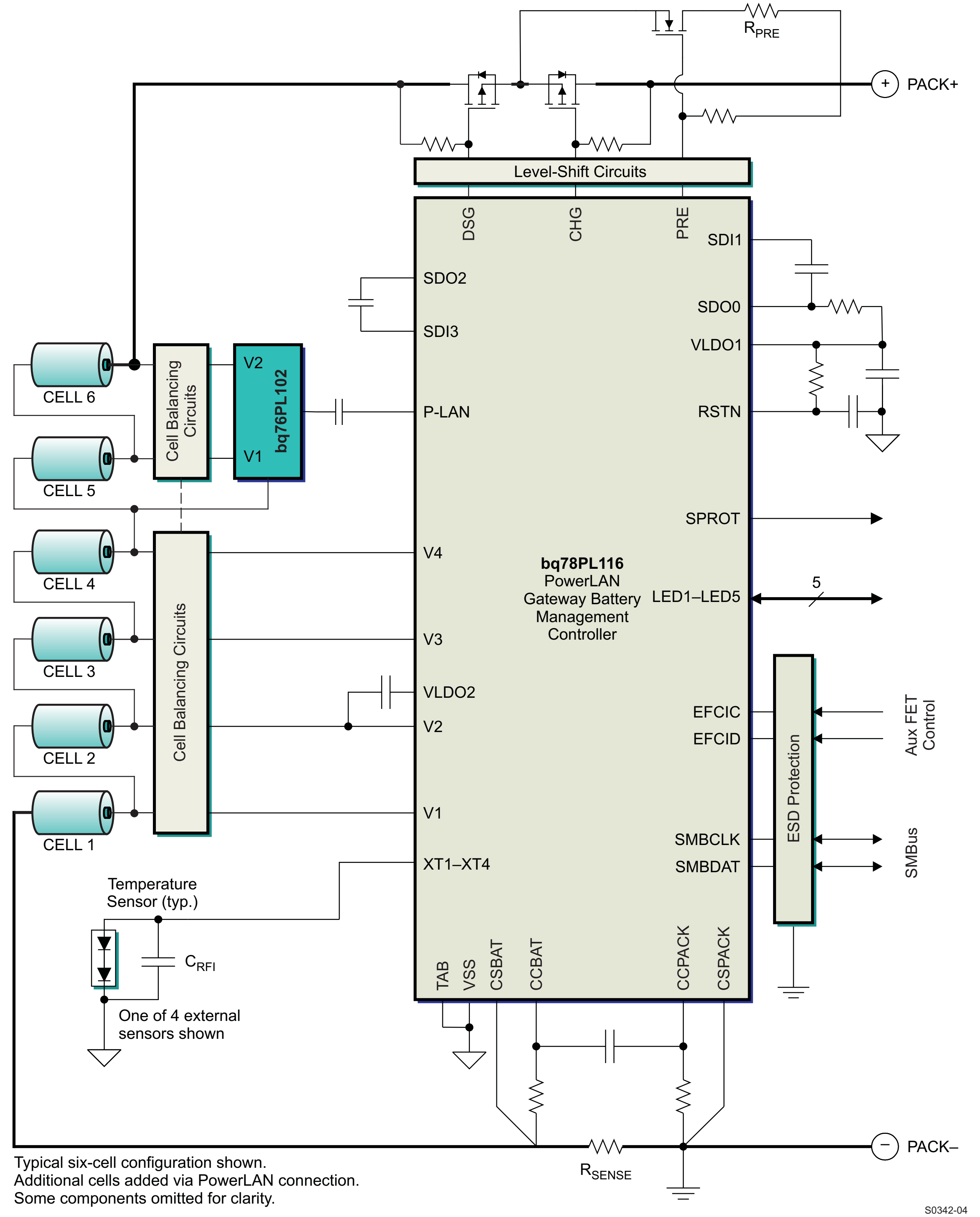

Figure 4. bq78PL116 Simplified Example Circuit Diagram

FEATURE SET

Primary (First-Level) Safety Features

The bq78PL116 implements a breadth of system protection features which are easily configured by the customer. First-level protections work by controlling the MOSFET switches. These include:

- Battery cell over/undervoltage protection
- Pack over/undervoltage protection
- Charge and discharge overcurrent protection
- Short-circuit protection
- External MOSFET control inputs (EFCIx) with programmable polarity
- Up to four external temperature inputs for accurate cell and MOSFET monitoring
- Watchdog timer protection
- Brownout detection and protection against extreme pack undervoltage

Secondary (Second-Level) Safety Features

The bq78PL116 can detect more serious system faults and activate the SPROT pin, which can be used to open an in-line chemical fuse to permanently disable the pack. Secondary optional features include

- Fully independent of first-level protections
- SmartSafety algorithms for early detection of potential faults
  - Temperature abnormalities (extremes, rate of change)
  - Cell imbalance exceeds safety limits
  - Impedance rise due to cell or weld strap fault
- MOSFET failure or loss of MOSFET control
- Safety overvoltage, pack and cell
- Safety overtemperature, limits for both charge and discharge
- Safety overcurrent, charge and discharge
- Failed current measurement, voltage measurement, or temperature measurement

Charge Control Features

- Meets SMBus 1.1 and Smart Battery System (SBS) Specification 1.1 requirements
- Active cell balancing using patented PowerPump technology, which eliminates unrecoverable capacity loss due to normal cell imbalance
- Simultaneous, synchronous measurement of all cell voltages in a pack
- Simultaneous, synchronous measurement of pack current with cell voltages
- Reports target charging current and/or voltage to an SBS Smart Charger
- Reports the chemical state-of-charge for each cell and pack
- Supports precharging and zero-volt charging with separate MOSFET control
- Programmable, Chemistry-specific parameters
- Fault reporting

Gas Gauging

- The bq78PL116 accurately reports battery cell and pack state-of-charge (SOC). No full charge/discharge cycle is required for accurate reporting.
- State-of-charge is reported via SMBus and optional display.
- 18-bit integrating delta-sigma ADC coulomb counter

Display Types

- The bq78PL116 drives a three- to five-segment LED display in response to a pushbutton (LEDEN) input signal. Each LED pin can sink up to 10 mA.
- The bq78PL116 drives a three- to five-segment static liquid-crystal display.
- The bq78PL116 drives a three- to five-segment electronic paper display. An external 15-V voltage source is required. E Ink Corporation supplies this type of display.

The display type is selected via the parameter set.

Lifetime Logging (Readable via SMBus)

- Lifetime delivered ampere-hours
- Last discharge average
- Lifetime maximum power
- Maximum/minimum temperature
- Maximum/minimum pack voltage
- Maximum/minimum cell voltage in a pack
- Maximum charge and discharge currents

Power Modes

- **Normal Mode:** The bq78PL116 performs measurements and calculations, makes decisions, and updates internal data approximately once per second. *All safety circuitry is fully functional in this mode.*
- **Standby Mode:** The bq78PL116 performs as in normal mode, but at a dramatically reduced rate to lower power consumption at times when the host computer is inactive or the battery system is not being used. *All safety circuitry remains fully functional in this mode.*
- **Ship Mode:** The bq78PL116 disables (opens) all the protection MOSFETs, and continues to monitor temperature and voltage, but at a reduced measurement rate to dramatically lower power consumption. Environmental data is saved in flash as a part of the historical record. *Safety circuitry is disabled in this mode*. The device does not enter this power state as a part of normal operation; it is intended for use after factory programming and test. Entry occurs only after a unique SMBus command is issued. Exit occurs when the SMBus lines return to an active state.
- **Extreme Cell Undervoltage (ECUV) Shutdown Mode:** In this mode, the bq78PL116 draws minimal current and the charge and discharge protection MOSFETs are disabled (opened). The precharge MOSFET remains enabled when a charge voltage is present. *Safety circuitry is disabled in this mode*. The device does not enter this mode as a part of normal operation; it enters this state during extreme cell undervoltage conditions (ECUV). The ECUV threshold is programmable between 2.5 V and 2.8 V for even series cell applications and 2.7 V to 2.8 V for odd series cell applications.

STATE	OVERCURRENT PROTECTION	ENTRY CONDITION	EXIT CONDITION
Active	Fully active	Normal operation as determined by firmware	Firmware directed to the following operating modes
Standby	Fully active	No load current flowing for predetermined time	Load activity
Ship	Not active	Protected SMBus command	SMBus becomes active
Extreme cell undervoltage	Not active (precharge enabled)	Enabled when Vcell < ECUV	Vcell charge above ECUV recovery threshold (2.9 V/cell typical)

OPERATION

The bq78PL116 battery-management controller serves as a master controller for a Li-Ion battery system consisting of up to 16 cells in series. Any number of cells may be connected in parallel; other system or safety issues limit the number of parallel cells. The bq78PL116 provides extraordinarily precise state-of-charge gas gauging along with first- and second-level pack safety functions. Voltage and current measurements are performed synchronously and simultaneously for all cells in the system, allowing a level of precision not previously possible in battery management. Temperature is measured by up to four additional external temperature sensors. Coulomb counting is captured continuously by a dedicated 18-bit integrating delta-sigma ADC in the bq78PL116. The CPU in the bq78PL116 is also responsible for system data calculations and communicating parameters via the SMBus interface.

PowerLAN Communication Link

PowerLAN technology is Texas Instruments' patented serial network and protocol designed specifically for battery management in a multicell system environment. The PowerLAN link is used to initiate and report measurements of cell voltage and temperature, and control cell balancing. The bq78PL116 serves as the master controller of the PowerLAN link and can interface to multiple bq76PL102 dual-cell battery monitors, which measure and balance additional cells. The bq78PL116 monitors the first three or four cells, and bq76PL102s can be added to monitor more series cells.

The PowerLAN link isolates voltages from adjacent bq76PL102 devices to permit high-voltage stack assembly without compromising precision and accuracy. The PowerLAN link is expandable to support up to 16 cells in series. Each bq76PL102 handles voltage and temperature measurements, as well as balancing for two cells. The PowerLAN link provides high ESD tolerance and high immunity to noise generated by nearby digital circuitry or switching currents. Each bq76PL102 has both a PowerLAN input and PowerLAN output: Received data is buffered and retransmitted, permitting high numbers of nodes without loss of signal fidelity. Signals are capacitor-coupled between nodes, providing dc isolation.

Safety

Unique in the battery-management controller market, the bq78PL116 simultaneously measures voltage and current using independent and highly accurate delta-sigma ADCs. This technique removes virtually all systemic noise from measurements, which are made during all modes of battery operation: charge, discharge, and rest. The bq78PL116 also directs all connected bq76PL102 dual-cell battery monitors to measure each cell voltage simultaneously with the bq78PL116 measurements. Battery impedance and self-discharge characteristics are thus measured with an unprecedented level of accuracy in real time. The bq78PL116 applies this precise information to SmartSafety algorithms to detect certain anomalies and conditions which may be indicative of internal cell faults, before they become serious problems.

The bq78PL116 uses its enhanced measurement system to detect system faults including cell under- and overvoltage, cell under- and overtemperature, system overvoltage, and system overcurrent. First-level safety algorithms first attempt to open the MOSFET safety switches. If this fails, second-level safety algorithms activate the SPROT output, normally used to open a fuse and provide permanent, hard protection for the systems. External MOSFET control inputs with programmable polarity can also be used to operate the safety MOSFETs under control of user supplied circuitry. The bq78PL116 continuously monitors these inputs. If any MOSFET fails to open when commanded; the 2^{nd} level safety algorithms also activate the SPROT output. All first- and second-level safety algorithms have fully programmable time delays to prevent false triggering.

Cell Balancing

Patented PowerPump cell balancing technology drastically increases the useful life of battery packs by eliminating the cycle life fade of multi-cell packs due to cell imbalance. PowerPump technology efficiently transfers charge from cell to cell, rather than simply bleeding off charging energy as heat as is typically done with resistive-bleed balancing circuits. Balancing is configurable and may be performed during any battery operational modes: charge, discharge, or rest. Compared to resistive bleed balancing, virtually no energy is lost as heat. The actual balance current is externally scalable and can range from 10 mA to 1 A (100 mA typical) depending on component selection and system or cell requirements.

A variety of techniques, such as simple terminal voltage, terminal voltage corrected for impedance and temperature effects, or state-of-charge balancing, is easily implemented by the bq78PL116. By tracking the balancing required by individual cells, overall battery safety is enhanced, often allowing early detection of soft shorts or other cell failures. Balancing is achieved between all cells within the pack as dynamically determined by the bq78PL116.

The bq78PL116 supports the following configurable cell-balancing features:

- Turbo-pump mode. When enabled, this allows 60%–70% pump availability when there are no active safety events and current is not flowing. While in turbo-pump mode, temperature rate-of-rise features are not available.
- Option to disable cell balancing during discharge
- Option to disable cell balancing during charge
- Test mode operation that allows for convenient production-line testing of PowerPump circuitry

Outputs

Charge Control

The CHG and PRE outputs are ordinarily used to drive MOSFET transistors controlling charge to the cell stack. Charge or precharge mode is selected based on the present cell voltage compared to the user-definable cell precharge, undervoltage, and temperature thresholds. When below these limits, the PRE signal is active and the CHG signal is inactive. This turns on the precharge MOSFET and is used to charge a depleted system through a current-limiting series resistor. When all cell voltages are above the limit and the temperature is above the charge temperature minimum, then the CHG output also becomes active and enables the charge MOSFET to turn on, providing a high-current path between charger and battery cells.

The CHG and PRE MOSFET control outputs are both disabled (low) when any cell reaches the safety cutoff limit or temperature threshold. During active charging modes (and above cell voltage thresholds), the discharge MOSFET is also enabled to avoid excessive heating of the body diode. Similarly, the charge MOSFET is active during discharge, provided current flow is in the correct direction and no safety violations are present.

The CHG and PRE outputs are intended to drive buffer transistors acting as inverting level shifters.

Discharge Control

The DSG output operates similarly to control-system discharging. It is enabled (high) by default. If a cell voltage falls below a programmable threshold, or excessive current or other safety related fault is sensed, the DSG output is disabled (low) to prevent damage to the cells.

All facets of safely charging and discharging the cell stack are controlled by user-definable parameters which provide precise control over MOSFET states. Both system and cell over- and undervoltage limits are provided, as well as programmable hysteresis to prevent oscillation. Temperature and current thresholds are also provided, each with independent timers to prevent nuisance activations.

The DSG output is intended to drive a buffer transistor acting as an inverting level-shifter.

Display

The bq78PL116 shows state-of-charge indication on LED, static liquid crystal, and electronic paper displays or EPDs in a bar-graph-type format. The parameter set allows selection of display type and configuration. PSH/BP/TP is a multifunction pin. In LED display mode, PSH serves as an input that monitors for closure of a state-of-charge indicator (SOCi) push-button switch. In LCD mode, this pin is used to drive the LCD backplane. In EPD mode, this pin drives the top plane common signal of the display.

In LED display mode, the signals LED1/SEG1–LED5/SEG5 are current-sinking outputs designed to drive low-current LEDs.

In LCD and EPD modes, the LED1/SEG1–LED5/SEG5 pins drive the active segments through external buffer transistors. In EPD mode, the FIELD pin drives the display background field.

Electronic paper displays require an external power supply, typically 15 V, to power the display. In EPD, mode the bq78PL116 strobes the display outputs for a user- programmable period of milliseconds to drive an external voltage multiplier or charge pump to the required display supply voltage. The display segments are then updated in a manner that ensures the required 0-Vdc segment voltage offset is maintained and keeps the external power supply at its nominal voltage.

Inputs

Current Measurement

Current is monitored by four separate ADCs. All use the same very low-value sense resistor, typically 10, 3, or 1 milliohms in series with the pack negative connection. CCBAT and CCPACK connections to the sense resistor use an R/C filter for noise reduction. (CSBAT and CSPACK are direct connections used for secondary safety). When configured to use a 1-milliohm sense resistor, the maximum available pack capacity increases to 327 Ah from 32.7 Ah.

A 14-bit delta-sigma ADC is used to measure current flow accurately in both directions. The measurements are taken simultaneously and synchronously with all the cell voltage measurements, even those cells measured by bq76PL102 dual-cell battery monitors.

Coulomb Counting

A dedicated coulomb counter is used to measure charge flow with 18-bit precision in both directions by a calibrated, integrating delta-sigma ADC. This allows the bq78PL116 to keep very accurate state-of-charge (SOC) information and battery statistics. A small deadband is applied to further reduce noise effects. The coulomb counter is unique in that it continues to accumulate (integrate) current flow in either direction even as the rest of the internal microcontroller is placed in a very low power state, further lowering power consumption without compromising system accuracy.

Safety Current

Two additional ADCs are used to directly monitor for overcurrent or short-circuit current conditions, independently of the internal function. This provides a direct and rapid response to insure pack integrity and safe operation by opening the appropriate MOSFETs. These functions are implemented in hardware, and do not require firmware for functionality.

Voltage Measurement

Voltage measurement is performed by four independent delta-sigma ADCs which operate simultaneously and are triggered synchronously so that all voltages are read at precisely the same moment. The bq78PL116 coordinates the attached bq76PL102 dual-cell battery monitors so they also perform their cell voltage measurements in sync with the bq78PL116 voltage and current measurements. Voltage measurements are converted with better than 1 mV of resolution, providing superior accuracy. One-ADC-per-cell technology means that voltage is also measured simultaneously with current, permitting accurate, real-time cell impedance calculation during all operating conditions. This technique also provides greatly enhanced noise immunity and filtering of the input signal without signal loss.

Temperature Measurement

XT1–XT4 are dedicated temperature-sensor inputs. Each external sensor consists of a low-cost silicon diode (dual diode in one package is recommended) and capacitor combination. The bq78PL116 can report all four of these temperatures individually. The bq78PL116 firmware uses the internal temperature sensor of the device for board temperature measurements.

EFCIx

The external MOSFET control inputs are for user control of MOSFETs based on external circuitry and conditions. The polarity of the input signal is user-programmable. These pins can be used to force the protection MOSFETs to an OFF state.

COMMUNICATIONS

SMBus

The bq78PL116 uses the industry-standard Smart Battery System’s two-wire System Management Bus (SMBus) communications protocol for all external communication. SMBus version 1.1 is supported by the bq78PL116, and includes clock stretching, bus fault time-out detection, and optional packet error checking (PEC). For additional information, see the www.smbus.org and www.sbs-forum.org Web sites.

Smart Battery Data (SBData)

The bq78PL116 supports Smart Battery System's (SBS) Smart Battery Data Specification 1.1. See the SBS/SMBus site at www.sbs-forum.org for further information regarding these specifications.

This SBS Data (SBData) specification defines read/write commands for accessing data commonly required in laptop computer applications. The commands are generic enough to be useful in most applications.

The bq78PL116 provides a wealth of data beyond the standard set of SBData (0x00 - 0x23) through Extended SBData Commands. See the following table for a listing of the SBData commands and the default set of Extended SBData (0x3C - 0x58). SBData command locations 0x80 and 0x81 are used to implement some of the features unique to the bq78PL116. Refer to the bq78PL116 Technical Reference Manual Document for additional details on compliance to SBData and how to take advantage of the data and controls specific to bq78PL116.

THERMAL PAD

The large pad on the bottom of the package is square, located in the center, and is 5.3 ±0.05 mm per side.

SBS Standard Data Parameter List (Abridged)[1]

Command	Data Type	Description
00	R/W word (unsigned)	Manufacturer Access
01	R/W word (unsigned)	Remaining Capacity Alarm Level
02	R/W word (unsigned)	Remaining Time Alarm Level
03	R/W word (unsigned)	Battery Mode
04	R/W word (unsigned)	At Rate value used in AtRate calculations – NOT SUPPORTED
05	Read word (unsigned)	At Rate Time to Full – NOT SUPPORTED
06	Read word (unsigned)	At Rate Time to Empty – NOT SUPPORTED
07	Read word (Boolean)	At Rate OK – NOT SUPPORTED
08	Read word (unsigned)	Pack Temperature (maximum of all individual cells)
09	Read word (unsigned)	Pack Voltage (sum of individual cell readings)
0A	Read word (unsigned)	Pack Current
0B	Read word (unsigned)	Average Pack Current
0C	Read word (unsigned)	Max Error
0D	Read word (unsigned)	Relative State of Charge
0E	Read word (unsigned)	Absolute State of Charge
0F	Read word (unsigned)	Remaining Pack Capacity
10	Read word (unsigned)	Full Charge Capacity
11	Read word (unsigned)	Run Time to Empty
12	Read word (unsigned)	Average Time to Empty
13	Read word (unsigned)	Average Time to Full
14	Read word (unsigned)	Charging Current
15	Read word (unsigned)	Charging Voltage
16	Read word (unsigned)	Battery Status
17	Read word (unsigned)	Cycle Count
18	Read word (unsigned)	Design Capacity
19	Read word (unsigned)	Design Voltage
1A	Read word (unsigned)	Specification Information
1B	Read word (unsigned)	Manufacture Date
1C	Read word (unsigned)	Serial Number
1D–1F	Reserved	
20	Read block (string)	Pack Manufacturer Name (31 characters maximum)
21	Read block (string)	Pack Device Name (31 characters maximum)
22	Read block (string)	Pack Chemistry
23	Read block (string)	Manufacturer Data
24–2E	Reserved	
2F	R/W Block	Optional Manufacturer Function 5
30–3B	Reserved	
3C	R/W word (unsigned)	Optional Manufacturer Option 4 (Vcell 1)
3D	R/W word (unsigned)	Optional Manufacturer Option 3 (Vcell 2)
3E	R/W word (unsigned)	Optional Manufacturer Option 2 (Vcell 3)
3F	R/W word (unsigned)	Optional Manufacturer Option 1 (Vcell 4)
40	R/W word (unsigned)	Extended Data (Vcell 5)
41	R/W word (unsigned)	Extended Data (Vcell 6)
42	R/W word (unsigned)	Extended Data (Vcell 7)
43	R/W word (unsigned)	Extended Data (Vcell 8)
44	R/W word (unsigned)	Extended Data (Vcell 9)

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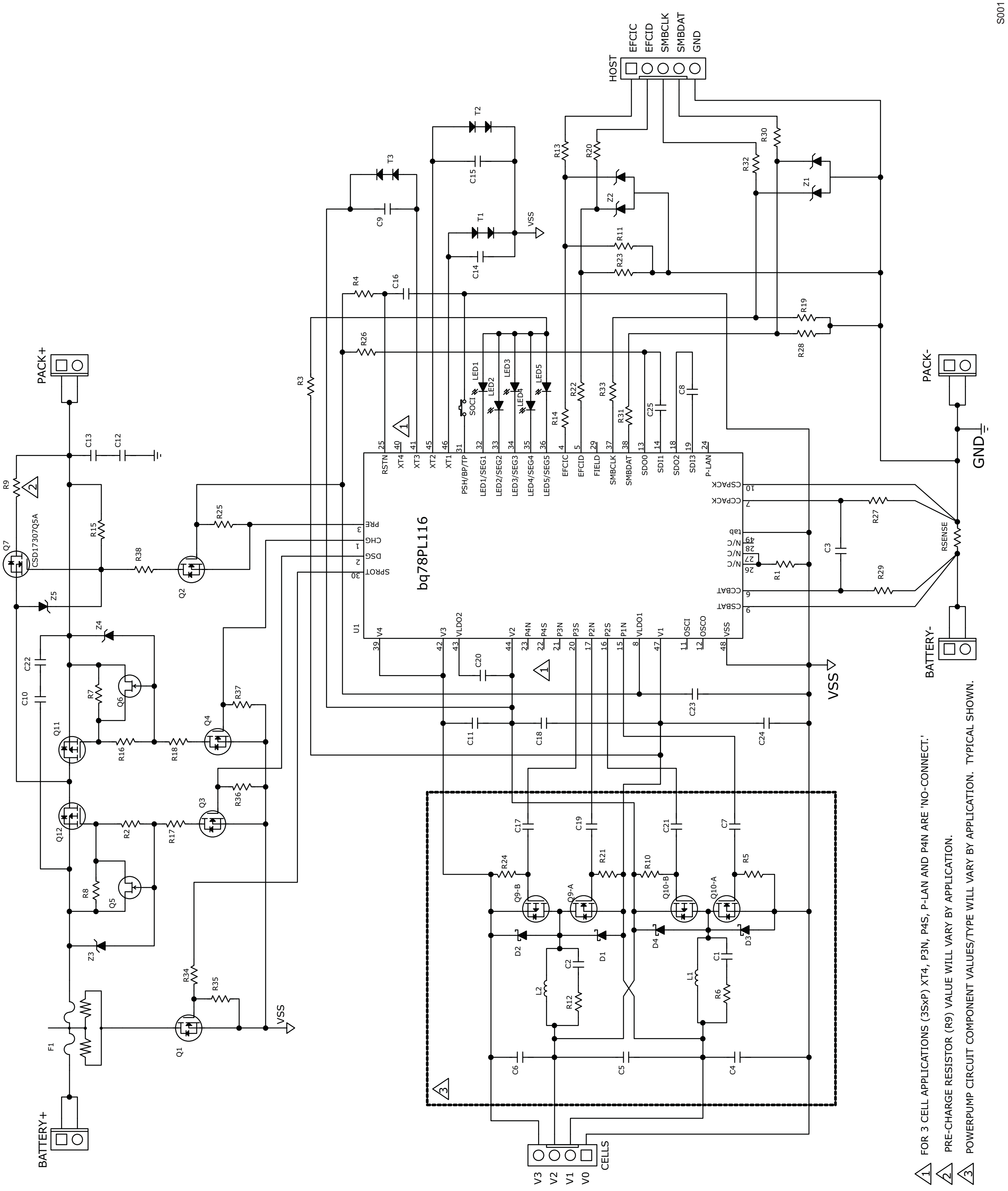
(1) Parameters 0x00–0x3F are compatible with the SBDATA specification.

Command	Data Type	Description
45	R/W word (unsigned)	Extended Data (Vcell 10)
46	R/W word (unsigned)	Extended Data (Vcell 11)
47	R/W word (unsigned)	Extended Data (Vcell 12)
48	R/W word (unsigned)	Extended Data (Vcell 13)
49	R/W word (unsigned)	Extended Data (Vcell 14)
4A	R/W word (unsigned)	Extended Data (Vcell 15)
4B	R/W word (unsigned)	Extended Data (Vcell 16)
4C	R/W word (unsigned)	Extended Data (Temp 0 – Intenal)
4D	R/W word (unsigned)	Extended Data (Temp 1 – Extenal)
4E	R/W word (unsigned)	Extended Data (Temp 2 – Extenal)
4F	R/W word (unsigned)	Extended Data (Temp 3 – Extenal)
50	R/W word (unsigned)	Extended Data (Temp 4 – Extenal)
51	R/W word (unsigned)	Extended Data (Safety Status)
52	R/W word (unsigned)	Extended Data (Permanent Fail Status)
53	R/W word (unsigned)	Extended Data (Charge Status)
54	R/W word (unsigned)	Extended Data (Lifetime Maximum Pack Voltage)
55	R/W word (unsigned)	Extended Data (Lifetime Maximum Cell Voltage)
56	R/W word (unsigned)	Extended Data (Lifetime Maximum Charge Current)
57	R/W word (unsigned)	Extended Data (Lifetime Maximum Discharge Current)
58	R/W word (unsigned)	Extended Data (Lifetime Maximum Temperature)
80	R/W word (unsigned)	Extended Command (Device Status)
81	R/W word (unsigned)	Extended Command (Device Command)

REFERENCE SCHEMATICS



1 FOR 3 CELL APPLICATIONS (3SxP) XT4, P3N, P4S, P-LAN AND P4N ARE 'NO-CONNECT.'

2 PRE-CHARGE RESISTOR (R9) VALUE WILL VARY BY APPLICATION.

3 POWERPUMP CIRCUIT COMPONENT VALUES/TYPE WILL VARY BY APPLICATION. TYPICAL SHOWN.

Figure 5. Typical 3S Application Schematic

Table 2. Bill of Materials for 3S Application

Qty	Reference	Value	Description	Size	Manufacturer	Mfg Part No.
5	C10 C12-13 C16 C22	0.1uF	Capacitor SMT Ceramic X7R +/-10% 50V	603	Standard	Standard
5	C11 C18 C20 C23-24	10uF	Capacitor SMT Ceramic X5R +/-10% 6.3V	603	Standard	Standard
3	C1-3	0.01uF	Capacitor SMT Ceramic X7R +/-10% 25V	603	Standard	Standard
3	C4-6	22uF	Capacitor SMT Ceramic Y5V +/-20% 10V	805	Standard	Standard
4	C7 C17 C19 C21	3300pF	Capacitor SMT Ceramic X7R +/-10% 50V	603	Standard	Standard
5	C8-9 C14-15 C25	1000pF	Capacitor SMT Ceramic X7R +/-10% 50V	603	Standard	Standard
12	R1 R7-8 R11 R15 R19 R23 R25 R28 R36-38	1.0M	Resistor SMT 1/10W +/-5%	603	Standard	Standard
2	R17-18	30K	Resistor SMT 1/10W +/-5%	603	Standard	Standard
2	R2 R16	200K	Resistor SMT 1/10W +/-5%	603	Standard	Standard
2	R26 R35	100K	Resistor SMT 1/10W +/-5%	603	Standard	Standard
2	R27 R29	4.7K	Resistor SMT 1/10W +/-5%	603	Standard	Standard
11	R3 R6 R12-14 R20 R22 R30-33	100	Resistor SMT 1/10W +/-5%	603	Standard	Standard
2	R4 R34	10K	Resistor SMT 1/10W +/-5%	603	Standard	Standard
4	R5 R10 R21 R24	20K	Resistor SMT 1/10W +/-5%	603	Standard	Standard
1	R9	100	Resistor SMT +/-5% 1W	603	Standard	Standard
1	RSENSE	0.01	Resistor SMT +/-1% 1W +/-100ppm/°C	2512	Standard	Standard
4	D1-4	Vf=385mV	Schottky Rectifier Diode 20V IFSM>2A	SOD-123	Standard	Standard
2	L1-2	4.7uH	Inductor SMT Shielded Isat=2.0A	4.9mm x 4.9mm x 2.0mm	Taiyo Yuden	NRS5020T4R7MMGJ
5	LED1-5		Green LED	603	Standard	Standard
1	SOCI	50mA	Momentary Pushbutton		Standard	Standard
3	T1-3		Dual Diode (Series Arrangement)	SOT-23	Fairchild	MMBD4148SE
4	Q1-4		N-Channel MOSFET 2.5Vgs rated, Vds>30V	SOT-23	Infineon	BSS138N
2	Q5-6	Vdg = -40V	N-Channel JFET Idss>0.2mA, Vgs<-1.5V	SOT-23	Fairchild	MMBFJ201
1	Q7	9.7 mOhm RDSon	MOSFET N-Channel SMT 30Vds	SON 5mm x 6mm	Texas Instruments	CSD17307Q5A
2	Q9-10		MOSFET N/P Complementary Pair	6-TSOP	Alpha & Omega	AO6604

Table 2. Bill of Materials for 3S Application (continued)

Qty	Reference	Value	Description	Size	Manufacturer	Mfg Part No.
2	Q11-12		MOSFET P-Channel SMT -30VDS	SOIC-8	Fairchild	FDS6673
1	U1		PowerLAN Master Gateway Battery Management Controller	QFN48	Texas Instruments	bq78PL116RGZR
3	Z1-2 Z5	5.6V	Common Anode Zener Diode Pair 300mW	SOT-23	Standard	Standard
2	Z3-4	12V	Zener Diode 500mW	SOD-123	Diodes, Inc	BZT52C12-13-F
1	F1	12 Amp	Chemical Fuse For 2-3 Cells In Series		Sony	SFH-1212A
4	BATTERY+ BATTERY- PACK+ PACK-		2 Pin Connector		Standard	Standard
1	CELLS		4 Pin Connector		Standard	Standard
1	HOST		5 Pin Connector		Standard	Standard

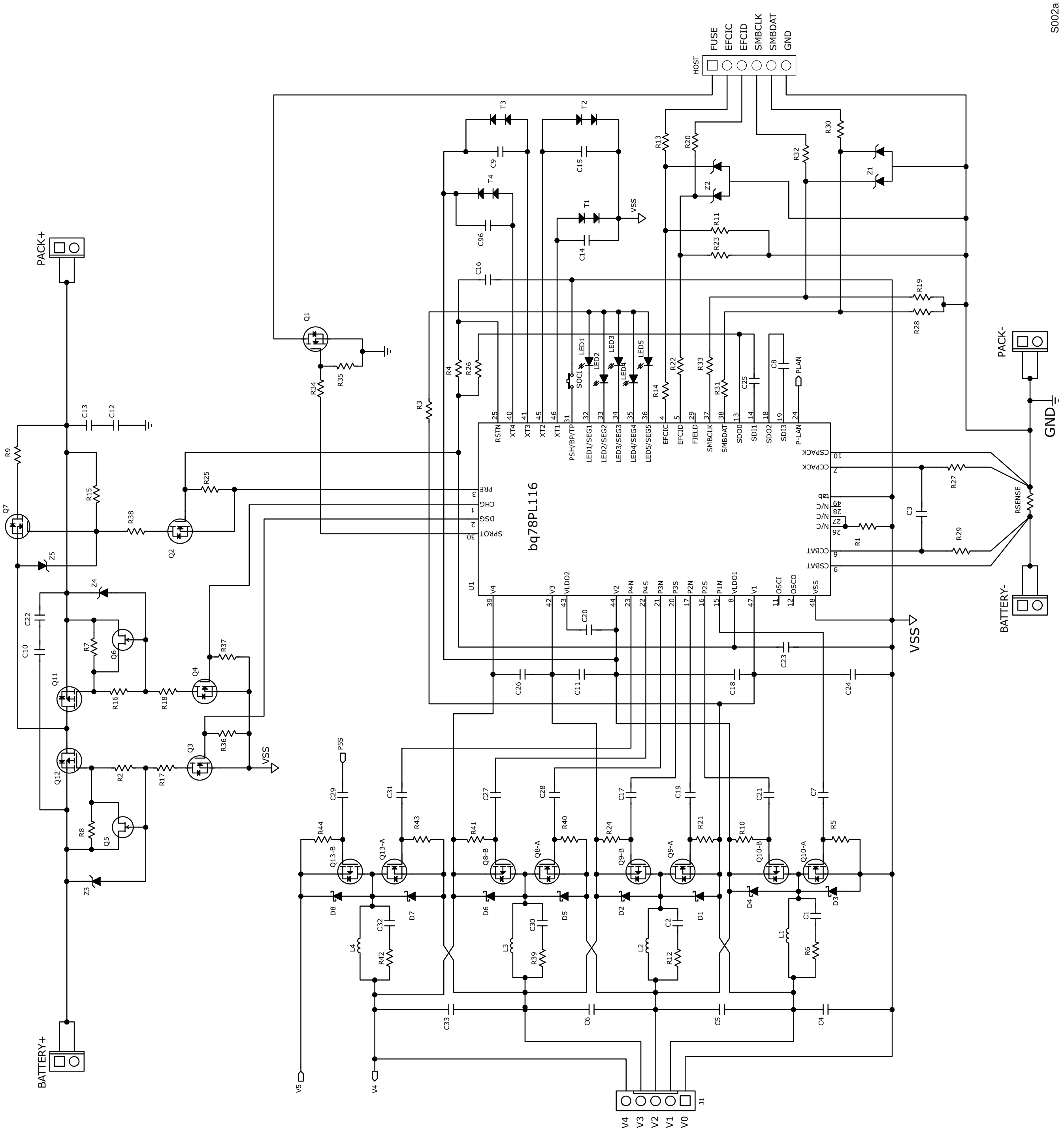


Figure 6. Typical 16S Application Circuit – bq78PL116 and FETs (Sheet 1 of 4)

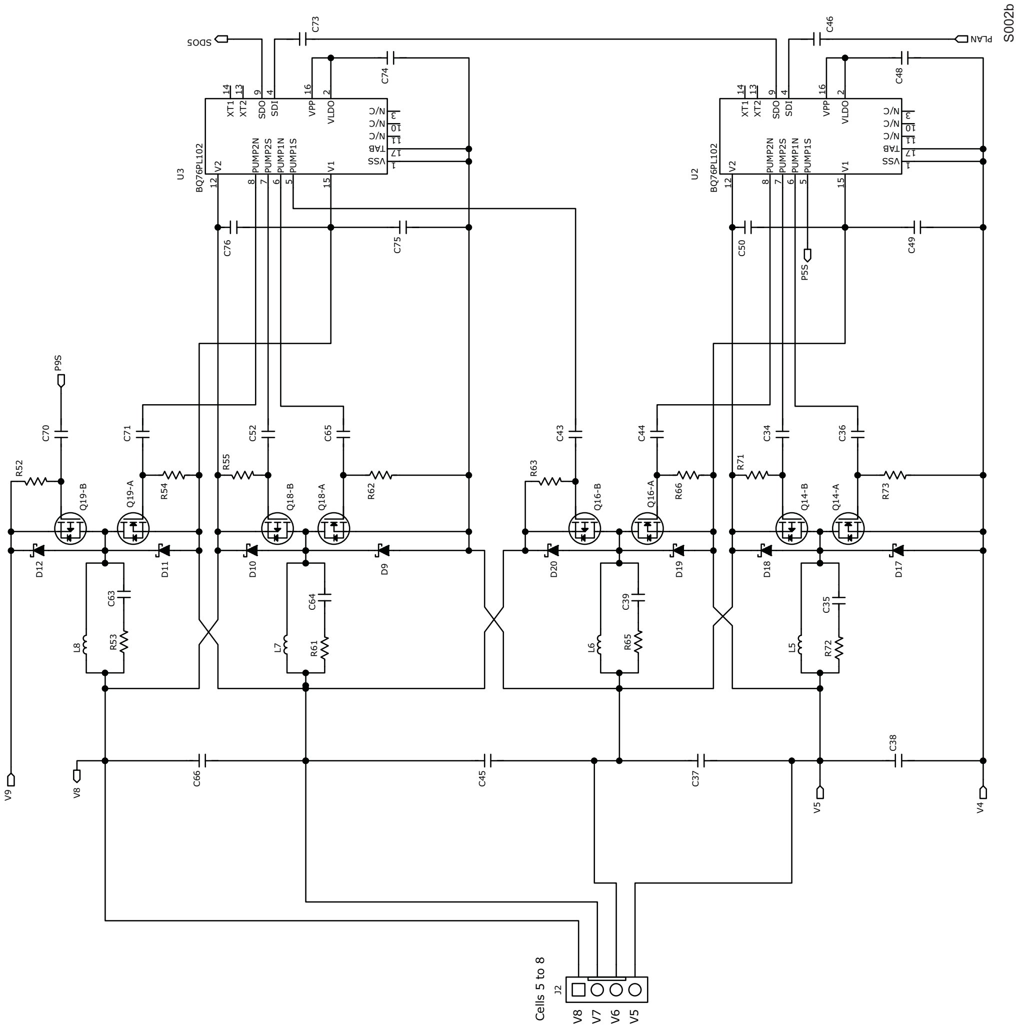


Figure 7. Typical 16S Application Circuit – bq76PL102 for Cells 5–8 (Sheet 2 of 4)

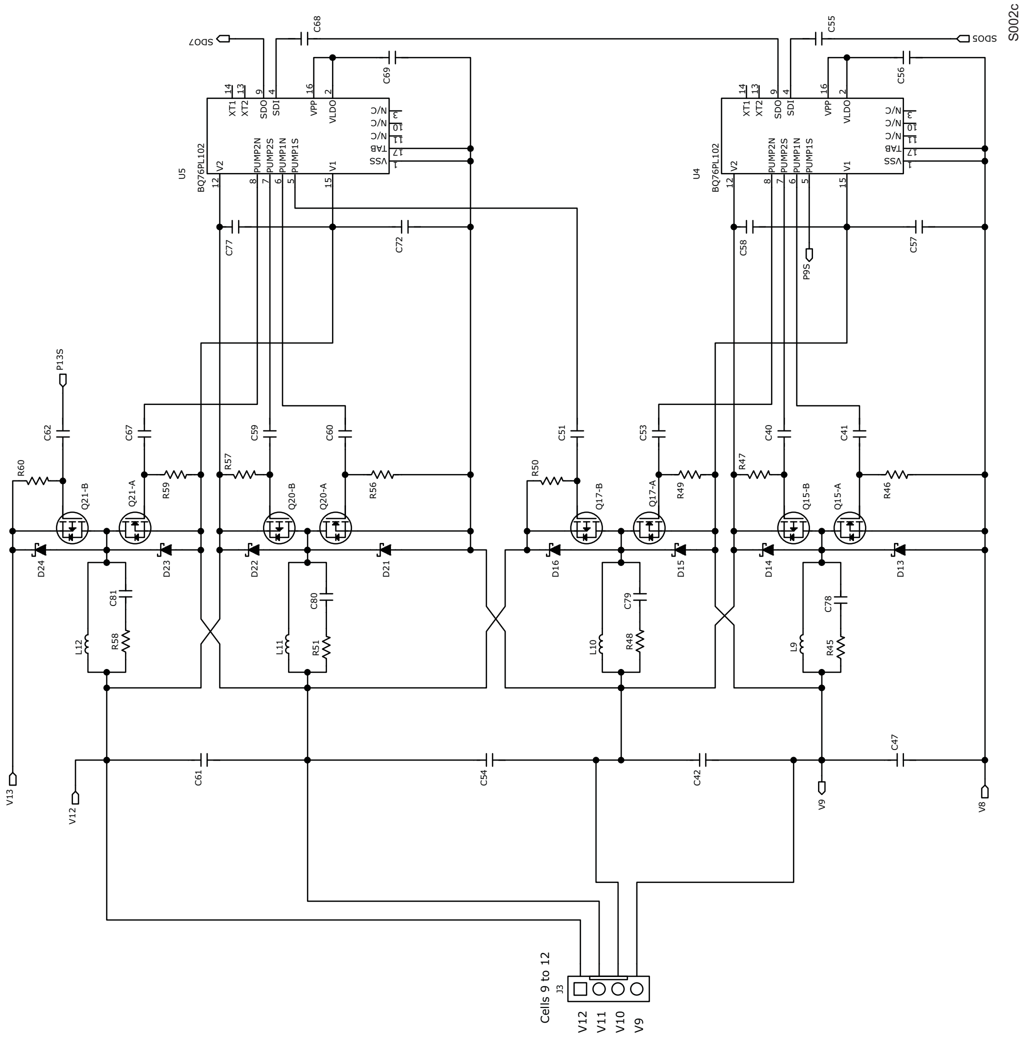


Figure 8. Typical 16S Application Circuit – bq76PL102 for Cells 9–12 (Sheet 3 of 4)

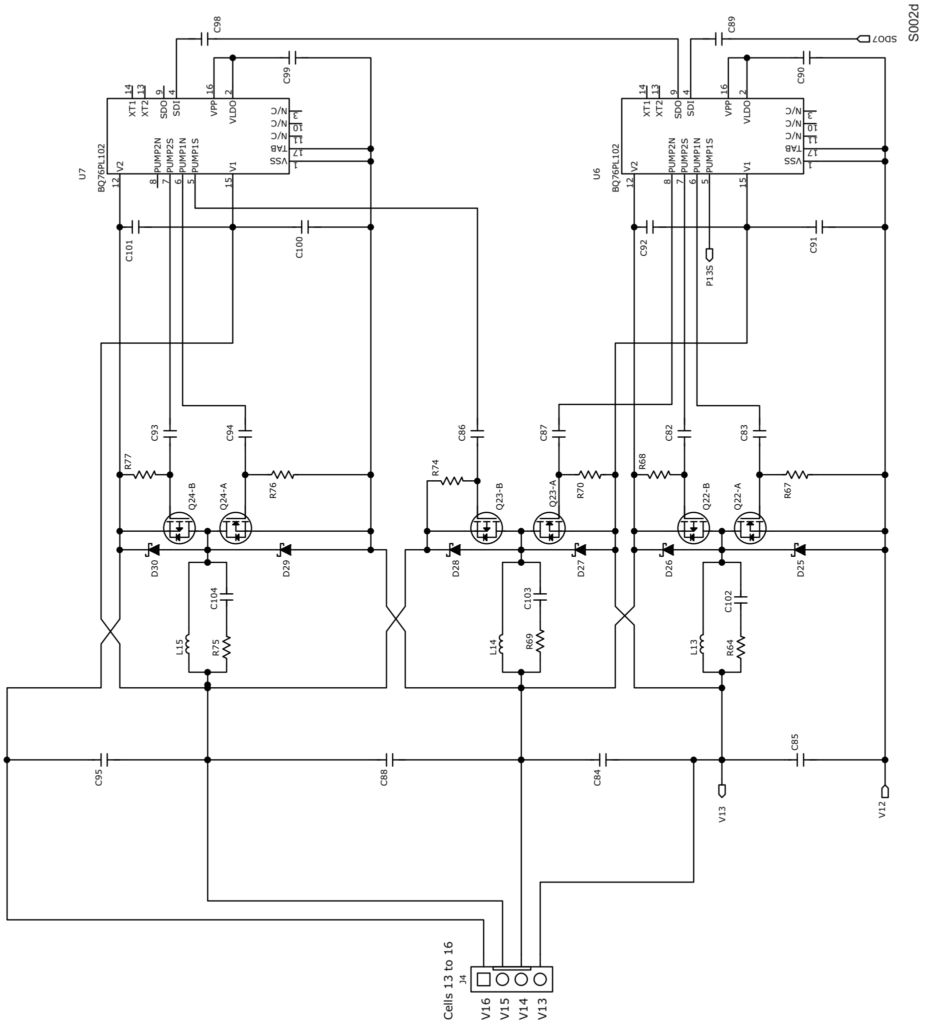


Figure 9. Typical 16S Application Circuit – bq76PL102 for Cells 13–16 (Sheet 4 of 4)

Table 3. Bill of Materials for 16S Application

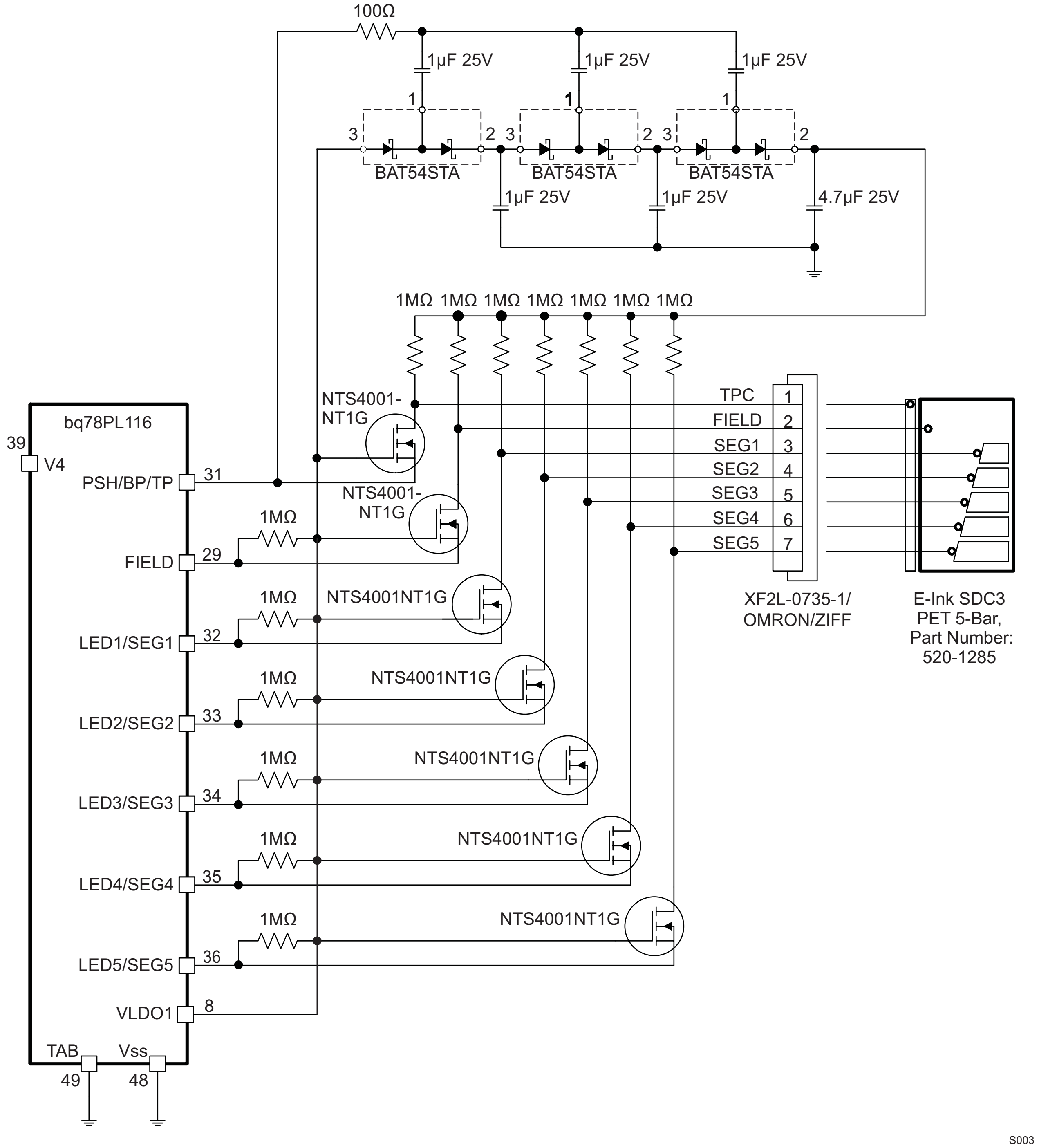
Qty	Reference	Value	Description	Size	Manufacturer	Mfg Part No.
6	U2-7	QFN-16	PowerLAN Dual Cell Monitor	QFN16	Texas Instruments	bq76PL102RGTT
1	U1	QFN-48	PowerLAN Master Gateway Battery Management Controller	QFN48	Texas Instruments	bq78PL116RGZR
24	C11 C18 C20 C23-24 C26 C48-50 C56-58 C69 C72 C74-77 C90-92 C99-101	10uF	Capacitor SMT Ceramic X5R +/-10% 6.3V	603	Standard	Standard
16	C1-3 C30 C32 C35 C39 C63-64 C78-81 C102-104	0.01uF	Capacitor SMT Ceramic X7R +/-10% 25V	603	Standard	Standard
12	C8-9 C14-15 C25 C46 C55 C68 C73 C89 C96 C98	1000pF	Capacitor SMT Ceramic X7R +/-10% 50V	603	Standard	Standard
5	C10 C12-13 C16 C22	0.1uF	Capacitor SMT Ceramic X7R +/-10% 50V	603	Standard	Standard

Table 3. Bill of Materials for 16S Application (continued)

Qty	Reference	Value	Description	Size	Manufacturer	Mfg Part No.
30	C7 C17 C19 C21 C27-29 C31 C34 C36 C40-41 C43-44 C51-53 C59-60 C62 C65 C67 C70-71 C82-83 C86-87 C93-94	3300pF	Capacitor SMT Ceramic X7R +/-10% 50V	603	Standard	Standard
16	C4-6 C33 C37-38 C42 C45 C47 C54 C61 C66 C84-85 C88 C95	22uF	Capacitor Ceramic SMT Y5V +/-20% 10V	805	Standard	Standard
24	R3 R6 R12-14 R20 R22 R30-33 R39 R42 R45 R48 R51 R53 R58 R61 R64-65 R69 R72 R75	100	Resistor SMT 1/10W +/-5%	603	Standard	Standard
2	R4 R34	10K	Resistor SMT 1/10W +/-5%	603	Standard	Standard
2	R26 R35	100K	Resistor SMT 1/10W +/-5%	603	Standard	Standard
12	R1 R7-8 R11 R15 R19 R23 R25 R28 R36- 38	1.0M	Resistor SMT 1/10W +/-5%	603	Standard	Standard
30	R5 R10 R21 R24 R40-41 R43-44 R46-47 R49-50 R52 R54-57 R59-60 R62-63 R66- 68 R70-71 R73-74 R76-77	20K	Resistor SMT 1/10W +/-5%	603	Standard	Standard
2	R2 R16	200K	Resistor SMT 1/10W +/-5%	603	Standard	Standard
2	R17-18	30K	Resistor SMT 1/10W +/-5%	603	Standard	Standard
1	R9	3K	Resistor SMT +/-5% 1W	603	Standard	Standard
2	R27 R29	4.7K	Resistor SMT 1/10W +/-5%	603	Standard	Standard
1	RSENSE	0.01	Resistor SMT +/-1% 1W +/-100ppm/°C	2512	Standard	Standard
15	L1-15	4.7uH	Inductor SMD Shielded Isat=2.0A	4.9mm x 4.9mm x 2.0mm	Taiyo Yuden	NRS5020T4R7MMGJ
4	Q1-4	Vds > 80V	N-Channel MOSFET, 2.5Vgs Rated	SOT-23	Standard	Standard
2	Q5-6	Idss=0.2 to 1.0mA	General Purpose N-Channel JFET Amplifier	SOT-23	Fairchild	MMBFJ201
1	Q7	100 Vds	MOSFET N-Channel 20Vgs	D2PAK	Standard	Standard
15	Q8-10 Q13-24	+/-8Vgs	MOSFET N/P Complementary Pair	6-TSOP	Alpha & Omega	AO6604
2	Q11-12	-100 Vds	MOSFET P-Channel 20Vgs	D2PAK	Standard	Standard
30	D1-30	500mA	Schottky Rectifier Diode 20V	SOD-123	Fairchild	MBR0520L
4	T1-4		Dual Diode	SOT-23	Fairchild	MMBD4148SE
5	LED1-5	Green/25 mA	Green Diffused LED 1.6mm x 0.8mm SMT	603	Standard	Standard

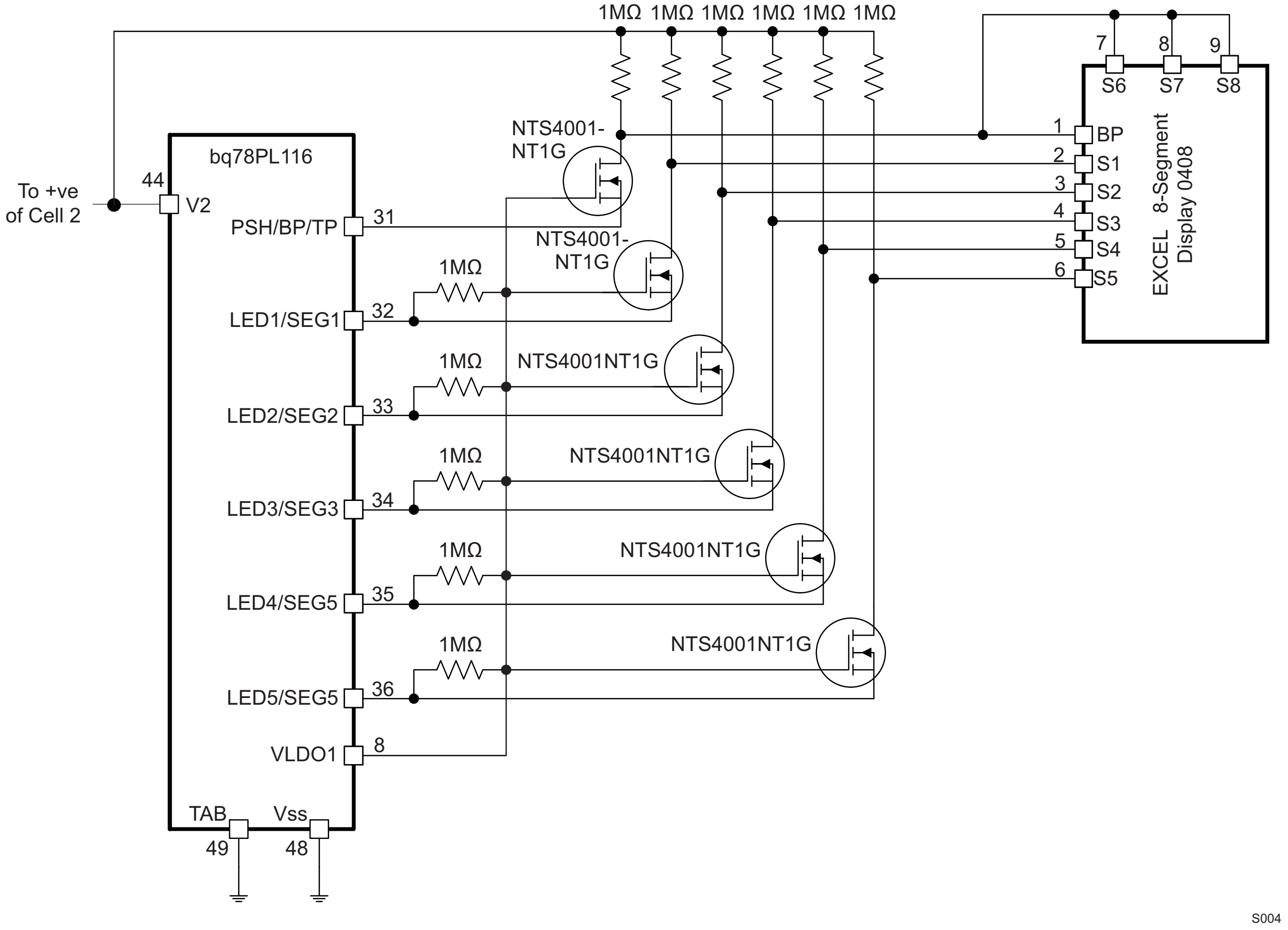
Table 3. Bill of Materials for 16S Application (continued)

Qty	Reference	Value	Description	Size	Manufacturer	Mfg Part No.
2	Z1 Z2	5.6VDC	Common Anode Zener Diode Pair 300mW	SOT-23	Standard	Standard
3	Z3-5	500mW	Zener Diode 500mW 12V	SOD-123	Standard	Standard
1	SOCI	50mA	Tactile Momentary Pushbutton Thru-Hole		Standard	Standard
1	HOST		Header	6 Position	Standard	Standard
1	J1	1.0 Amp	Header	5 Position	Standard	Standard
3	J2-4	3.0A	Header	4 Position	Standard	Standard
4	BATTERY+ BATTERY- PACK+ PACK-	30 Amps	Header	2 Position	Standard	Standard



NOTE: For reference only. Actual display used may require different operating voltage. Consult with display vendor.

Figure 10. Reference Schematic (Electronic-Paper Display Connections)



NOTE: For reference only. Actual display used may require different operating voltage. Consult with display vendor.

Figure 11. Reference Schematic (LCD Connections)

REVISION HISTORY

Changes from Revision A (October 2010) to Revision B	Page
• Revised PowerLAN Characteristics table	9
• Changed Ah values in Current Measurement paragraph	16

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)	Op Temp (°C)	Top-Side Markings (4)	Samples
BQ78PL116RGZR	NRND	VQFN	RGZ	48	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR	-40 to 85	78PL116 BQ	
BQ78PL116RGZT	NRND	VQFN	RGZ	48	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR	-40 to 85	78PL116 BQ	

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) Only one of markings shown within the brackets will appear on the physical device.

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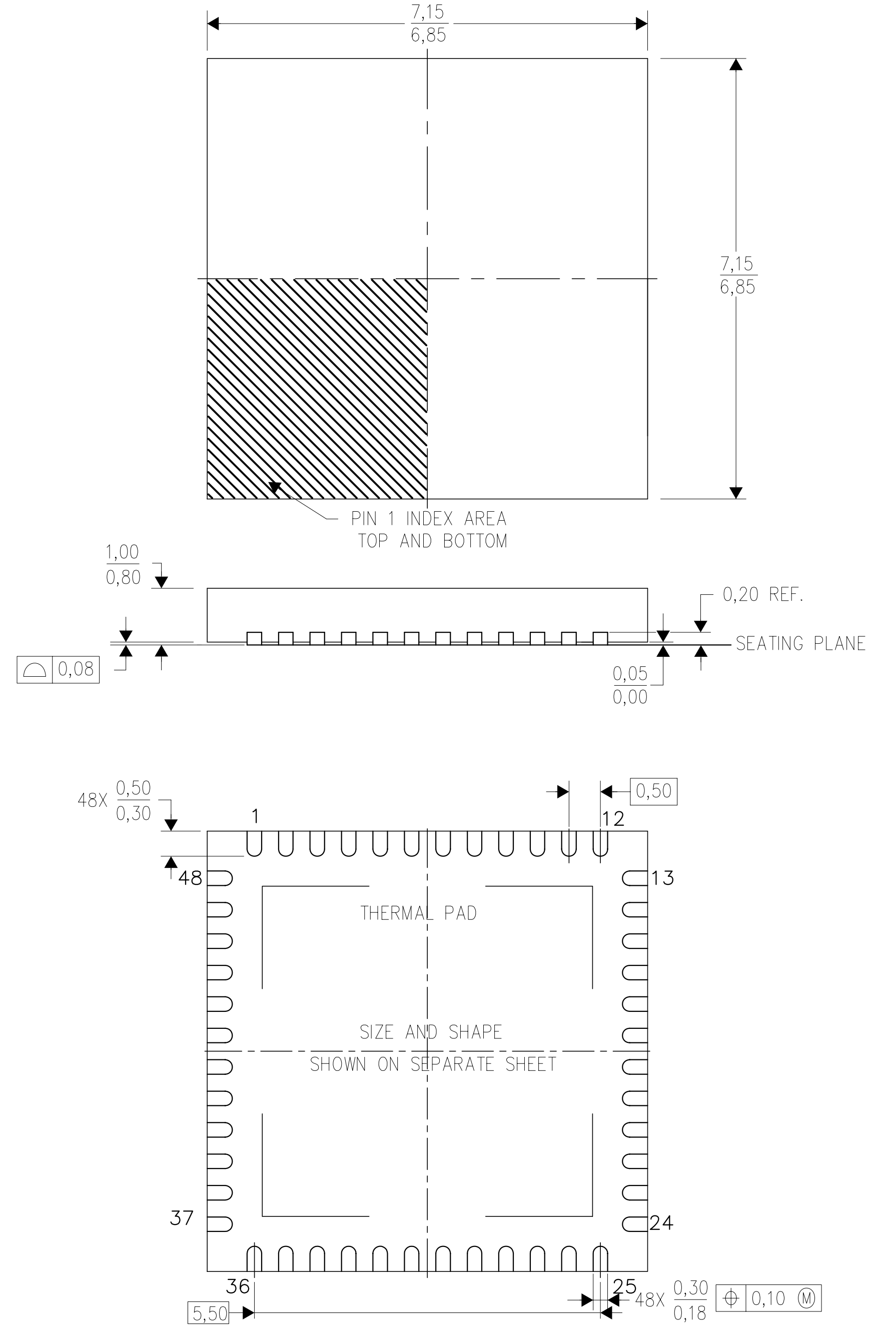
RGZ (S–PVQFN–N48) PLASTIC QUAD FLATPACK NO–LEAD



NOTES:
- A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M–1994.
- B. This drawing is subject to change without notice.
- C. Quad Flatpack, No–leads (QFN) package configuration.
- D. The package thermal pad must be soldered to the board for thermal and mechanical performance.
- E. See the additional figure in the Product Data Sheet for details regarding the exposed thermal pad features and dimensions.
- F. Falls within JEDEC MO–220.

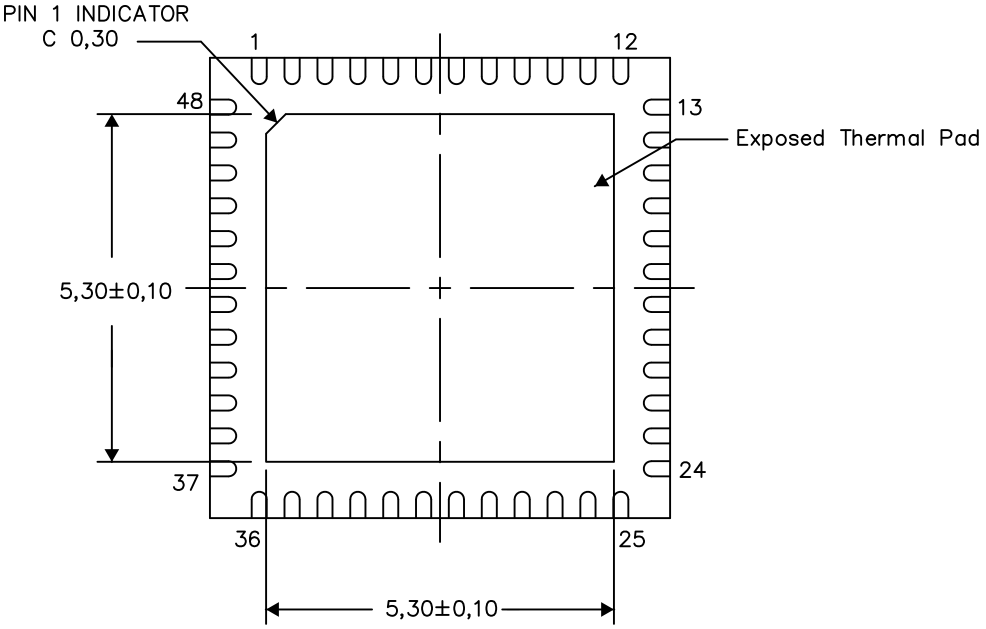
RGZ (S–PVQFN–N48) PLASTIC QUAD FLATPACK NO–LEAD

THERMAL INFORMATION

This package incorporates an exposed thermal pad that is designed to be attached directly to an external heatsink. The thermal pad must be soldered directly to the printed circuit board (PCB). After soldering, the PCB can be used as a heatsink. In addition, through the use of thermal vias, the thermal pad can be attached directly to the appropriate copper plane shown in the electrical schematic for the device, or alternatively, can be attached to a special heatsink structure designed into the PCB. This design optimizes the heat transfer from the integrated circuit (IC).

For information on the Quad Flatpack No–Lead (QFN) package and its advantages, refer to Application Report, QFN/SON PCB Attachment, Texas Instruments Literature No. SLUA271. This document is available at www.ti.com.

The exposed thermal pad dimensions for this package are shown in the following illustration.



Bottom View

Exposed Thermal Pad Dimensions

4206354–9/T 03/13

NOTE: All linear dimensions are in millimeters

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National Semiconductor

May 3, 2011

LM5050-1

High Side OR-ing FET Controller

General Description

The LM5050-1 High Side OR-ing FET Controller operates in conjunction with an external MOSFET as an ideal diode rectifier when connected in series with a power source. This ORing controller allows MOSFETs to replace diode rectifiers in power distribution networks thus reducing both power loss and voltage drops.

The LM5050-1 controller provides charge pump gate drive for an external N-Channel MOSFET and a fast response comparator to turn off the FET when current flows in the reverse direction. The LM5050-1 can connect power supplies ranging from +5V to +75V and can withstand transients up to +100V.

Features

- Wide Operating Input Voltage range, V_{IN}: 5V to 75V
- +100 Volt transient capability
- Charge pump gate driver for external N-Channel MOSFET
- Fast 50ns response to current reversal
- 2A peak gate turn-off current
- Minimum V_{DS} clamp for faster turn-off
- Package: TSOT-6 (Thin SOT23-6)

Applications

- Active OR-ing of Redundant (N+1) Power Supplies

Typical Application Circuits

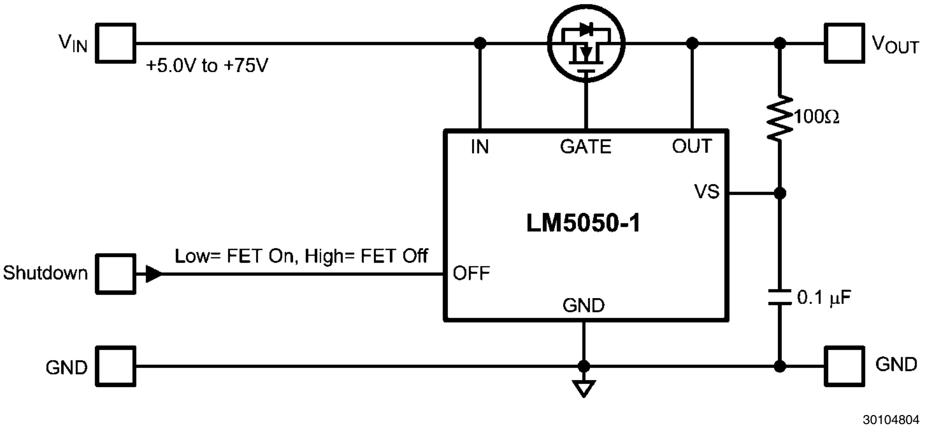


FIGURE 1. Full Application

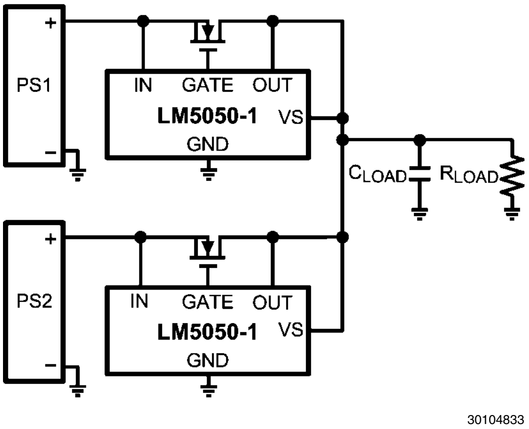
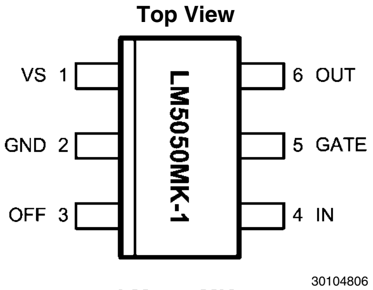


FIGURE 2. Typical Redundant Supply Configuration

Connection Diagram



LM5050MK-1
TSOT-6 Package
NS Package Number MK06A

Ordering Information

Order Number	Package Type	Supplied As
LM5050MK-1	TSOT-6	1000 units Tape and Reel
LM5050MKX-1	TSOT-6	3000 units Tape and reel

Pin Descriptions

Pin #	Name	Function
1	VS	The main supply pin for all internal biasing and an auxiliary supply for the internal gate drive charge pump. Typically connected to either V_{OUT} or V_{IN}, a separate supply can also be used.
2	GND	Ground return for the controller
3	OFF	A logic high state at the OFF pin will pull the GATE pin low and turn off the external MOSFET.
4	IN	Voltage sense connection to the external MOSFET Source pin.
5	GATE	Connection to the external MOSFET Gate.
6	OUT	Voltage sense connection to the external MOSFET Drain pin.

Absolute Maximum Ratings (*Note 1*)

IN, OUT Pins to Ground (*Note 4*)	-0.3V to 100V
GATE Pin to Ground (*Note 4*)	-0.3V to 100V
VS Pin to Ground	-0.3V to 100V
OFF Pin to Ground	-0.3V to 7V
Storage Temperature Range	–65°C to 150°C
ESD (HBM) (*Note 2*)	±2 kV
Peak Reflow Temperature (*Note 3*)	260°C, 30sec

Operating Ratings (*Note 1*)

IN, OUT, VS Pins	5.0V to 75V
OFF Pin	0.0V to 5.5V
Junction Temperature Range (T_J)	–40°C to +125°C

Electrical Characteristics

Limits in standard type are for T_J = 25°C only; limits in **boldface type** apply over the operating junction temperature (T_J) range of -40°C to +125°C. Minimum and Maximum limits are guaranteed through test, design, or statistical correlation. Typical values represent the most likely parametric norm at T_J = 25°C, and are provided for reference purposes only. Unless otherwise stated the following conditions apply: V_{IN} = 12.0V, V_{VS} = V_{IN}, V_{OUT} = V_{IN}, V_{OFF} = 0.0V, C_{GATE}= 47 nF, and T_J = 25°C.

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
VS Pin						
V_{VS}	Operating Supply Voltage Range	-	**5.0**	-	**75.0**	V
I_{VS}	Operating Supply Current	V_{VS}= 5.0V, V_{IN} = 5.0V V_{OUT} = V_{IN} - 100 mV	-	75	**105**	µA
		V_{VS}= 12.0V, V_{IN} = 12.0V V_{OUT} = V_{IN} - 100 mV	-	100	**147**	
		V_{VS}= 75.0V, V_{IN} = 75.0V V_{OUT} = V_{IN} - 100 mV	-	130	**288**	
IN Pin						
V_{IN}	Operating Input Voltage Range	-	**5.0**	-	**75.0**	V
I_{IN}	IN Pin current	V_{IN} = 5.0V V_{VS}= V_{IN} V_{OUT} = V_{IN} - 100 mV GATE = Open	**32**	190	**305**	µA
		V_{IN} = 12.0V to 75.0V V_{VS}= V_{IN} V_{OUT} = V_{IN} - 100 mV GATE = Open	**233**	320	**400**	
OUT Pin						
V_{OUT}	Operating Output Voltage Range	-	**5.0**	-	**75.0**	V
I_{OUT}	OUT Pin Current	V_{IN} = 5.0V to 75.0V V_{VS}= V_{IN} V_{OUT} = V_{IN} - 100 mV	-	3.2	**8**	µA
GATE Pin						
$I_{GATE(ON)}$	Gate Pin Source Current	V_{IN} = 5.0V V_{VS} = V_{IN} V_{GATE} = V_{IN} V_{OUT} = V_{IN} - 175 mV	**12**	30	**41**	µA
		V_{IN} = 12.0V to 75.0V V_{VS} = V_{IN} V_{GATE} = V_{IN} V_{OUT} = V_{IN} - 175 mV	**20**	32	**41**	
V_{GS}	V_{GATE} - V_{IN} in Forward Operation (*Note 7*)	V_{IN} = 5.0V V_{VS} = V_{IN} V_{OUT} = V_{IN} - 175 mV	**4.0**	7	**9.0**	V
		V_{IN} = 12.0V to 75.0V V_{VS} = V_{IN} V_{OUT} = V_{IN} - 175 mV	**9.0**	12	**14.0**	

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
$t_{GATE(REV)}$	Gate Capacitance Discharge Time at Forward to Reverse Transition See *Figure 3*	C_{GATE} = 0 (*Note 5*)	-	25	**85**	ns
		C_{GATE} = 10 nF (*Note 5*)	-	60	-	
		C_{GATE} = 47 nF (*Note 5*)	-	180	**350**	
$t_{GATE(OFF)}$	Gate Capacitance DischargeTime at OFF pin Low to High Transition See *Figure 4*	C_{GATE} = 47 nF (*Note 6*)	-	486	-	ns
$I_{GATE(OFF)}$	Gate Pin Sink Current	$V_{GATE} = V_{IN} + 3V$ $V_{OUT} > V_{IN}$ + 100 mV t ≤ 10ms	**1.8**	2.8	-	A
$V_{SD(REV)}$	Reverse V_{SD} Threshold $V_{IN} < V_{OUT}$	$V_{IN} - V_{OUT}$	**-41**	-28	**-16**	mV
$\Delta V_{SD(REV)}$	Reverse V_{SD} Hysteresis		-	10	-	mV
$V_{SD(REG)}$	Regulated Forward V_{SD} Threshold $V_{IN} > V_{OUT}$	V_{IN} = 5.0V $V_{VS} = V_{IN}$ $V_{IN} - V_{OUT}$	**1**	19	**37**	mV
		V_{IN} = 12.0V $V_{VS} = V_{IN}$ $V_{IN} - V_{OUT}$	**4.4**	22	**37**	
OFF Pin						
$V_{OFF(IH)}$	OFF Input High Threshold Voltage	$V_{OUT} = V_{IN}$-500 mV V_{OFF} Rising	-	1.56	**1.75**	V
$V_{OFF(IL)}$	OFF Input Low Threshold Voltage	$V_{OUT} = V_{IN}$ - 500 mV V_{OFF} Falling	**1.10**	1.40	-	
ΔV_{OFF}	OFF Threshold Voltage Hysteresis	$V_{OFF(IH)} - V_{OFF(IL)}$	-	155	-	mV
I_{OFF}	OFF Pin Internal Pull-down	V_{OFF} = 4.5V	**3.0**	5	**7.0**	µA
		V_{OFF} = 5.0V	-	8	-	

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur, including in-operability and degradation of device reliability and/or performance. Functional operation of the device and/or non-degradation at the Absolute Maximum Ratings or other conditions beyond those indicated in the Recommended Operating Conditions is not implied. Operating Range conditions indicate the conditions at which the device is functional and the device should not be operated beyond such conditions. For guaranteed specifications and conditions, see the Electrical Characteristics table.

Note 2: The Human Body Model (HBM) is a 100 pF capacitor discharged through a 1.5 kΩ resistor into each pin. Applicable test standard is JESD-22-A114-C.

Note 3: For soldering specifications see the LM5050-1 Product Folder at www.national.com, general information at www.national.com/analog/packaging/, and reflow information at www.national.com/ms/MS/MS-SOLDERING.pdf .

Note 4: The GATE pin voltage is typically 12V above the IN pin voltage when the LM5050-1 is enabled (i.e. OFF Pin is Open or Low, and $V_{IN} > V_{OUT}$). Therefore, the Absolute Maximum Rating for the IN pin voltage applies only when the LM5050-1 is disabled (i.e. OFF Pin is logic high), or for a momentary surge to that voltage since the Absolute Maximum Rating for the GATE pin is also 100V

Note 5: Time from V_{IN}-V_{OUT} voltage transition from 200 mV to -500 mV until GATE pin voltage falls to V_{IN} + 1V. See *Figure 3*

Note 6: Time from V_{OFF} voltage transition from 0.0V to 5.0V until GATE pin voltage falls to V_{IN} + 1V. See *Figure 4*

Note 7: Measurement of V_{GS} voltage (i.e. $V_{GATE} - V_{IN}$) includes 1 MΩ in parallel with C_{GATE}.

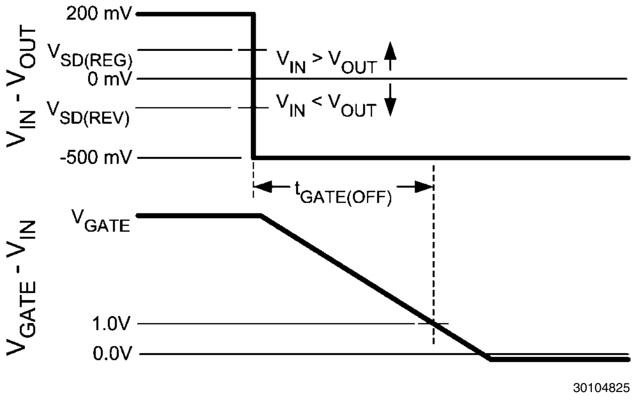


FIGURE 3. Gate Off Timing for Forward to Reverse Transition

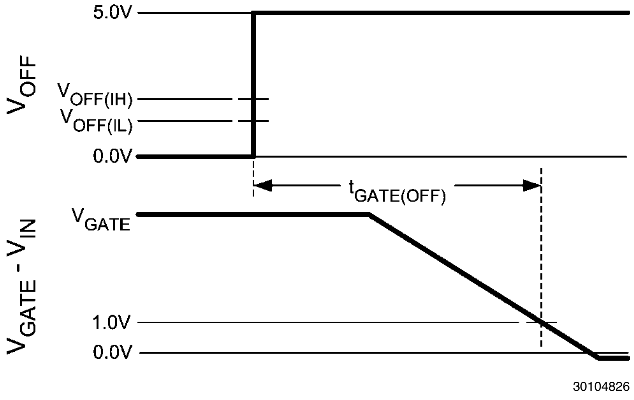
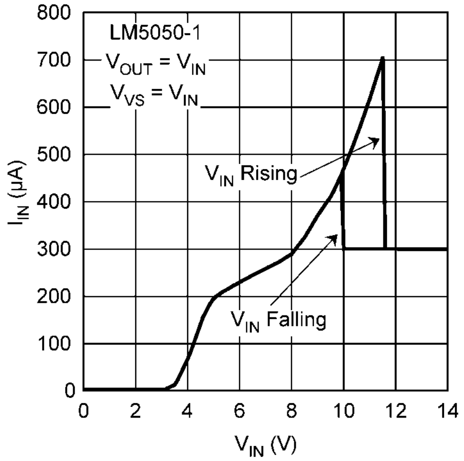


FIGURE 4. Gate Off Timing for OFF pin Low to High Transition

Typical Performance Characteristics

Unless otherwise stated: V_{VS} = 12V, V_{IN} = 12V, V_{OFF} = 0.0V, and T_J = 25°C

I_{IN} vs V_{IN}



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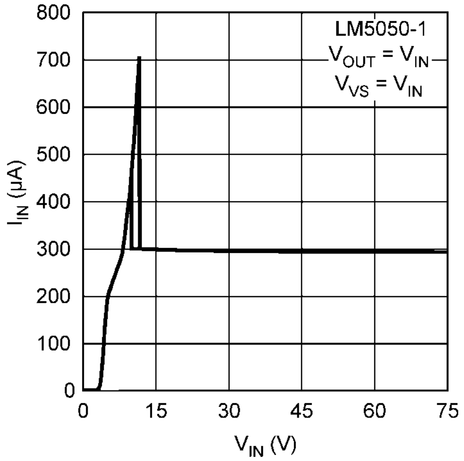
I_{IN} vs V_{IN}



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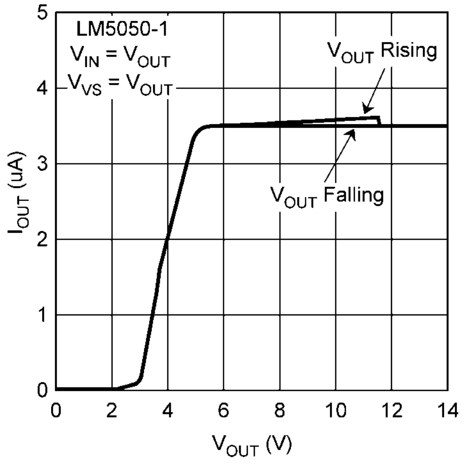
I_{OUT} vs V_{OUT}



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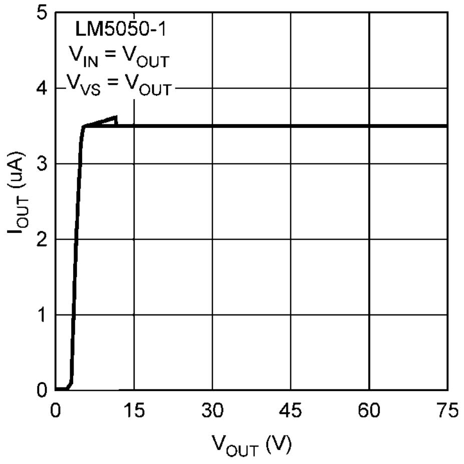
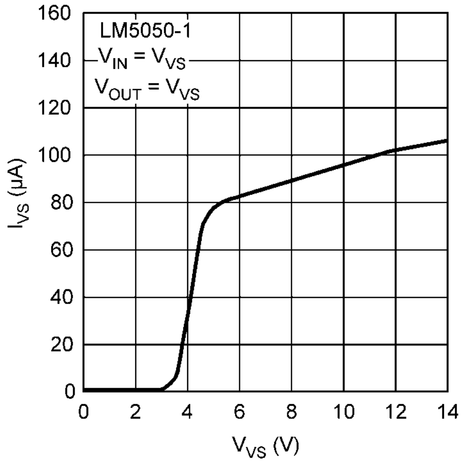
I_{OUT} vs V_{OUT}



30104820

I_{VS} vs V_{VS}



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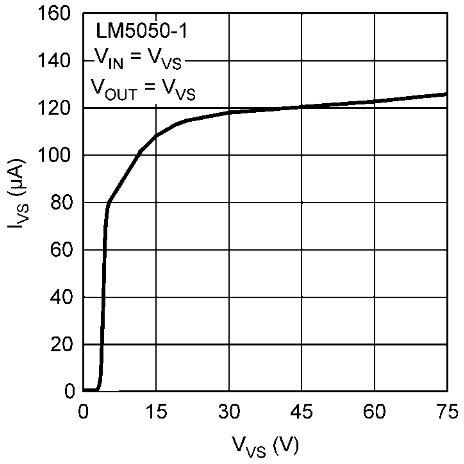
I_{VS} vs V_{VS}



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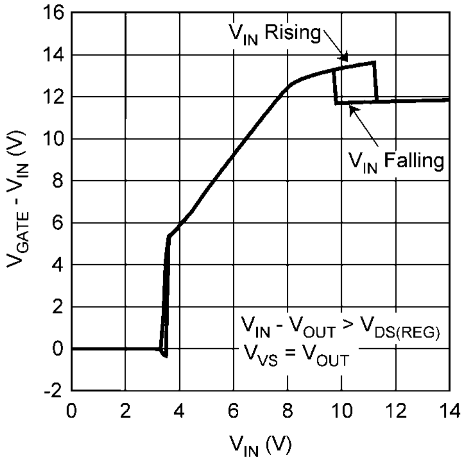
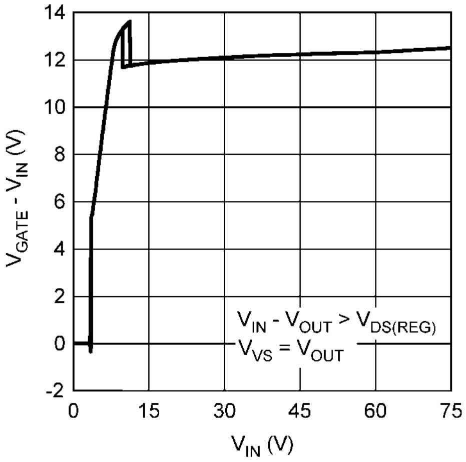
(V_{GATE} - V_{IN}) vs V_{IN}, V_{VS} = V_{OUT}



30104811

(V_{GATE} - V_{IN}) vs V_{IN}, V_{VS} = V_{OUT}



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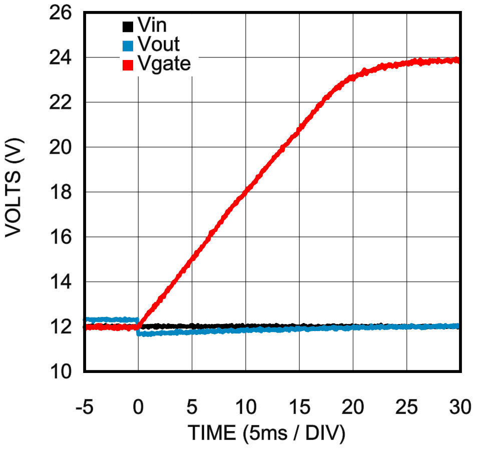
Forward C_{GATE} Charge Time, C_{GATE} = 47 nF



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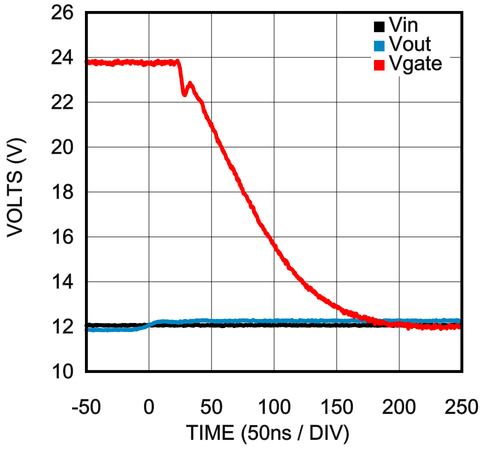
Reverse C_{GATE} Discharge, C_{GATE} = 47 nF



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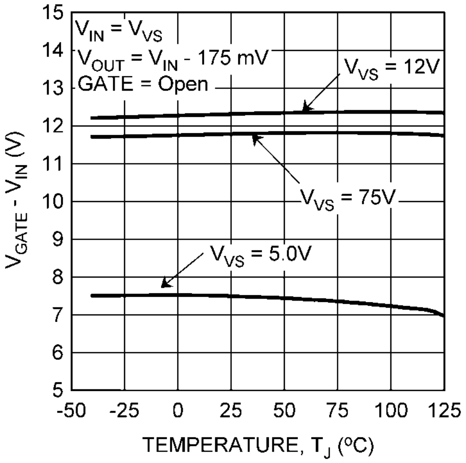
V_{GATE} - V_{IN} vs Temperature



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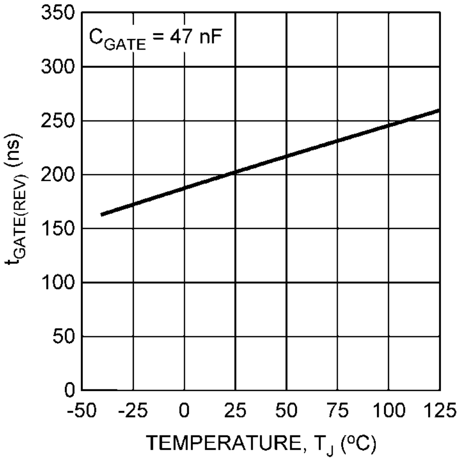
$t_{GATE(REV)}$ vs Temperature



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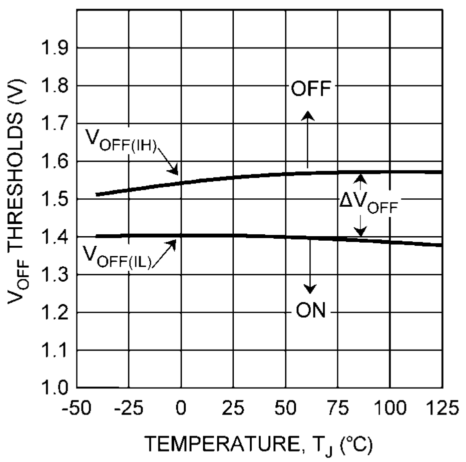
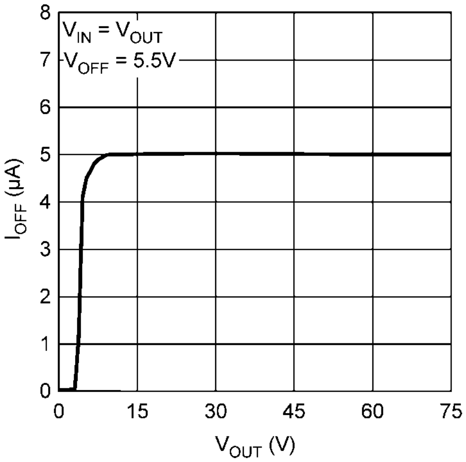
OFF Pin Thresholds vs Temperature



30104827

OFF Pin Pull-Down vs Temperature



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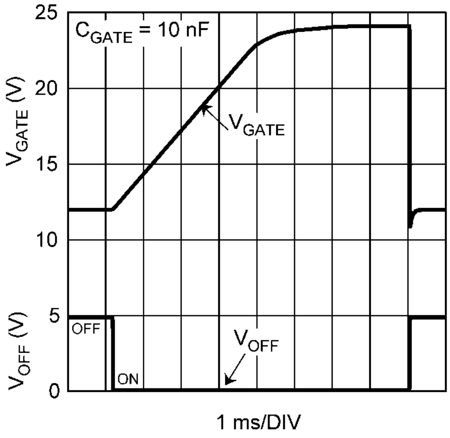
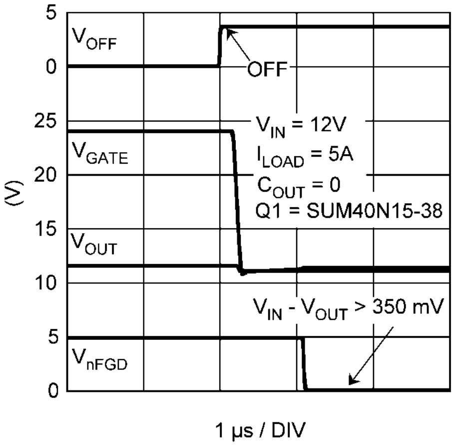
C_{GATE} Charge and Discharge vs OFF Pin



30104815

OFF Pin, On to Off Transition



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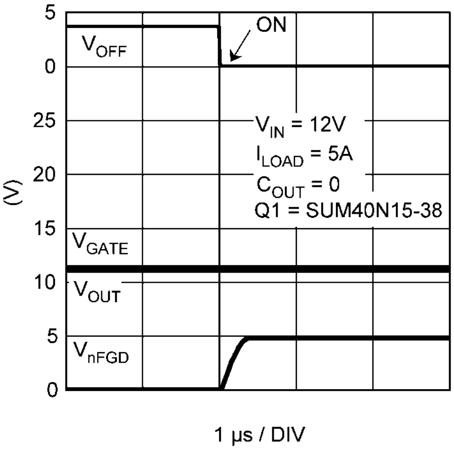
OFF Pin, Off to On Transition



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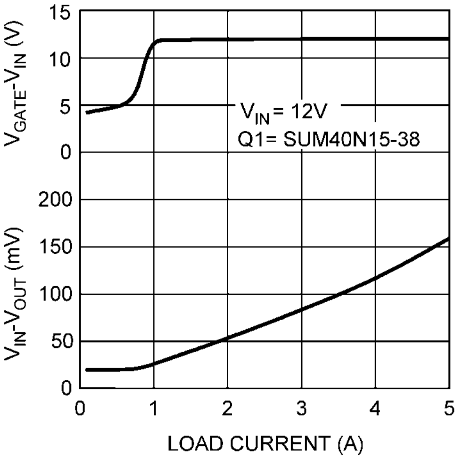
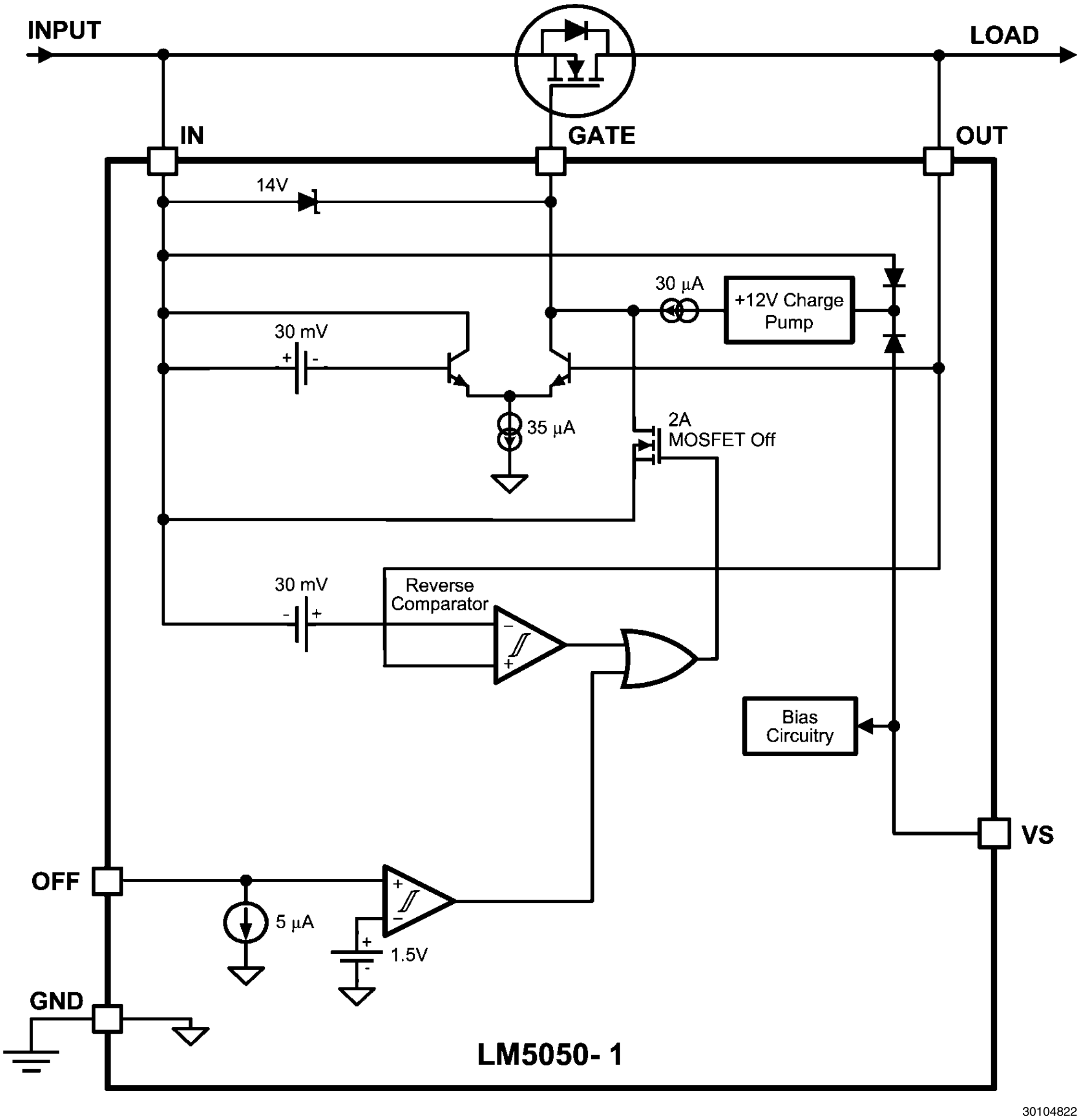
GATE Pin vs ($R_{DS(ON)}$ x I_{DS})



30104818

Block Diagram



Applications Information

FUNCTIONAL DESCRIPTION

Systems that require high availability often use multiple, parallel-connected redundant power supplies to improve reliability. Schottky OR-ing diodes are typically used to connect these redundant power supplies to a common point at the load. The disadvantage of using OR-ing diodes is the forward voltage drop, which reduces the available voltage and the associated power losses as load currents increase. Using an N-channel MOSFET to replace the OR-ing diode requires a small increase in the level of complexity, but reduces, or eliminates, the need for diode heat sinks or large thermal copper area in circuit board layouts for high power applications.

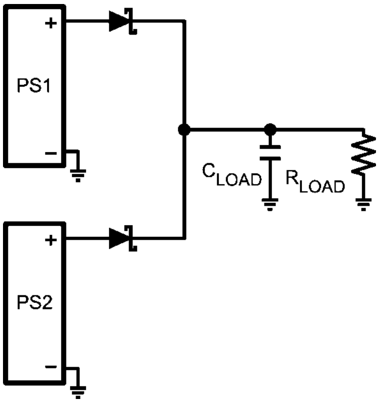


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FIGURE 5. OR-ing with Diodes

The LM5050-1 is a positive voltage (i.e. high-side) OR-ing controller that will drive an external N-channel MOSFET to replace an OR-ing diode. The voltage across the MOSFET source and drain pins is monitored by the LM5050-1 at the IN and OUT pins, while the GATE pin drives the MOSFET to control its operation based on the monitored source-drain voltage. The resulting behavior is that of an ideal rectifier with source and drain pins of the MOSFET acting as the anode and cathode pins of a diode respectively.

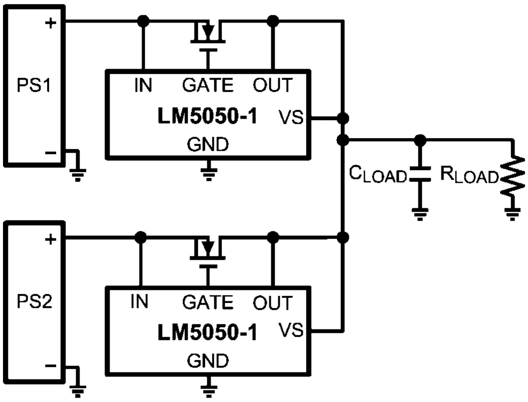

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FIGURE 6. OR-ing with MOSFETs

IN, GATE AND OUT PINS

When power is initially applied, the load current will flow from source to drain through the body diode of the MOSFET. The resulting voltage across the body diode will be detected at the LM5050-1 IN and OUT pins which then begins charging the MOSFET gate through a 32 µA (typical) charge pump current source . In normal operation, the gate of the MOSFET is charged until it reaches the clamping voltage of the 12V GATE to IN pin zener diode internal to the LM5050-1.

The LM5050-1 is designed to regulate the MOSFET gate- to -source voltage if the voltage across the MOSFET source and drain pins falls below the $V_{SD(REG)}$ voltage of 22 mV (typical).

If the MOSFET current decreases to the point that the voltage across the MOSFET falls below the $V_{SD(REG)}$ voltage regulation point of 27 mV (typical), the GATE pin voltage will be decreased until the voltage across the MOSFET is regulated at 22 mV. If the drain-to-source voltage is greater than $V_{SD(REG)}$ voltage the gate-to-source will increase, eventually reaching the 12V GATE to IN zener clamp level.

If the MOSFET current reverses, possibly due to failure of the input supply, such that the voltage across the LM5050-1 IN and OUT pins is more negative than the $V_{SD(REV)}$ voltage of -28 mV (typical), the LM5050-1 will quickly discharge the MOSFET gate through a strong GATE to IN pin discharge transistor.

If the input supply fails abruptly, as would occur if the supply was shorted directly to ground, a reverse current will temporarily flow through the MOSFET until the gate can be fully discharged. This reverse current is sourced from the load capacitance and from the parallel connected supplies. The LM5050-1 responds to a voltage reversal condition typically within 25 ns. The actual time required to turn off the MOSFET will depend on the charge held by gate capacitance of the MOSFET being used. A MOSFET with 47 nF of effective gate capacitance can be turned off in typically 180 ns. This fast turn off time minimizes voltage disturbances at the output, as well as the current transients from the redundant supplies.

VS PIN

The LM5050-1 VS pin is the main supply pin for all internal biasing and an auxiliary supply for the internal gate drive charge pump.

For typical LM5050-1 applications, where the input voltage is above 5.0V, the VS pin can be connected directly to the OUT pin. In situations where the input voltage is close to, but not less than, the 5.0V minimum, it may be helpful to connect the VS pin to the OUT pin through an RC Low-Pass filter to reduce the possibility of erratic behavior due to spurious voltage spikes that may appear on the OUT and IN pins. The series resistor value should be low enough to keep the VS voltage drop at a minimum. A typical series resistor value is 100Ω. The capacitor value should be the lowest value that produces acceptable filtering of the voltage noise.

Alternately, it is possible to operate the LM5050-1 with V_{IN} values less than 1V if the VS pin is powered from a separate supply. This separate VS supply must be between 5.0V and 75V. See *Figure 9*.

OFF PIN

The OFF pin is a logic level input pin that is used to control the gate drive to the external MOSFET. The maximum operating voltage on this pin is 5.5V.

When the OFF pin is high, the MOSFET is turned off (independent of the sensed IN and OUT voltages). In this mode, load current will flow through the body diode of the MOSFET. The voltage difference between the IN pin and OUT pins will be approximately 700 mV if the MOSFET is operating normally through the body diode.

The OFF pin has an internal pull-down of 5 µA (typical). If the OFF function is not required the pin may be left open or connected to ground.

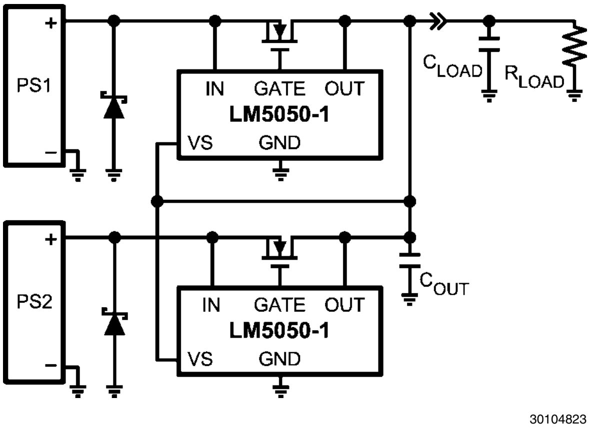


FIGURE 7.

SHORT CIRCUIT FAILURE OF AN INPUT SUPPLY

An abrupt zero ohm short circuit across the input supply will cause the highest possible reverse current to flow while the internal LM5050-2 control circuitry discharges the gate of the MOSFET. During this time, the reverse current is limited only by the $R_{DS(ON)}$ of the MOSFET, along with parasitic wiring resistances and inductances. Worst case instantaneous reverse current would be limited to:

$$I_{D(REV)} = (V_{OUT} - V_{IN}) / R_{DS(ON)}$$

The internal Reverse Comparator will react, and will start the process of discharging the Gate, when the reverse current reaches:

$$I_{D(REV)} = V_{SD(REV)} / R_{DS(ON)}$$

When the MOSFET is finally switched off, the energy stored in the parasitic wiring inductances will be transferred to the rest of the circuit. As a result, the LM5050-2 IN pin will see a negative voltage spike while the OUT pin will see a positive voltage spike. The IN pin can be protected by diode clamping the pin to GND in the negative direction. The OUT pin can be protected with a TVS protection diode, a local bypass capacitor, or both. In low voltage applications, the MOSFET draintosource breakdown voltage rating may be adequate to protect the OUT pin (i.e. $V_{IN} + V_{(BR)DSS(MAX)} < 75V$), but most MOSFET datasheets do not guarantee the maximum breakdown rating, so this method should be used with caution.

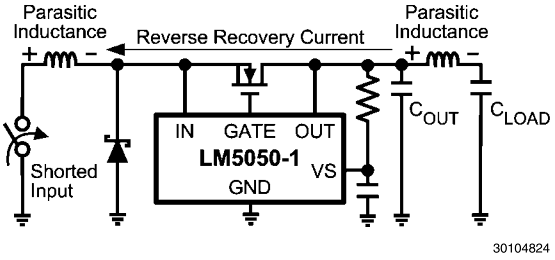


FIGURE 8.

MOSFET Selection

The important MOSFET electrical parameters are the maximum continuous Drain current I_D, the maximum Source current (i.e. body diode) I_S, the maximum drain-to-source voltage $V_{DS(MAX)}$, the gate-to-source threshold voltage $V_{GS(TH)}$, the drain-to-source reverse breakdown voltage $V_{(BR)DSS}$, and the drain-to-source On resistance $R_{DS(ON)}$.

The maximum continuous drain current, I_D, rating must exceed the maximum continuous load current. The rating for the maximum current through the body diode, I_S, is typically rated the same as, or slightly higher than the drain current, but body diode current only flows while the MOSFET gate is being charged to $V_{GS(TH)}$.

$$\text{Gate Charge Time} = Q_g / I_{GATE(ON)}$$

The maximum drain-to-source voltage, $V_{DS(MAX)}$, must be high enough to withstand the highest differential voltage seen in the application. This would include any anticipated fault conditions.

The drain-to-source reverse breakdown voltage, $V_{(BR)DSS}$, may provide some transient protection to the OUT pin in low voltage applications by allowing conduction back to the IN pin during positive transients at the OUT pin.

The gate-to-source threshold voltage, $V_{GS(TH)}$, should be compatible with the LM5050-1 gate drive capabilities. Logic level MOSFETs, with $R_{DS(ON)}$ rated at $V_{GS(TH)}$ at 5V, are recommended, but sub-Logic level MOSFETs having $R_{DS(ON)}$ rated at $V_{GS(TH)}$ at 2.5V, can also be used. Standard level MOSFETs, with $R_{DS(ON)}$ rated at $V_{GS(TH)}$ at 10V, are not recommended.

The dominate MOSFET loss for the LM5050-1 active OR-ing controller is conduction loss due to source-to-drain current to the output load, and the $R_{DS(ON)}$ of the MOSFET. This conduction loss could be reduced by using a MOSFET with the lowest possible $R_{DS(ON)}$. However, contrary to popular belief, arbitrarily selecting a MOSFET based solely on having low $R_{DS(ON)}$ may not always give desirable results for several reasons:

1) Reverse transition detection. Higher $R_{DS(ON)}$ will provide increased voltage information to the LM5050 Reverse Comparator at a lower reverse current level. This will give an earlier MOSFET turn-off condition should the input voltage become shorted to ground. This will minimize any disturbance of the redundant bus.

2) Reverse current leakage. In cases where multiple input supplies are closely matched it may be possible for some small current to flow continuously through the MOSFET drain to source (i.e. reverse) without activating the LM5050 Reverse Comparator. Higher $R_{DS(ON)}$ will reduce this reverse current level.

3) Cost. Generally, as the $R_{DS(ON)}$ rating goes lower, the cost of the MOSFET goes higher.

Selecting a MOSFET with an $R_{DS(ON)}$ that is too large will result in excessive power dissipation. Additionally, the MOSFET gate will be charged to the full value that the LM5050 can provide as it attempts to drive the Drain to Source voltage down to the $V_{SD(REG)}$ of 22 mV typical. This increased Gate charge will require some finite amount of additional discharge time when the MOSFET needs to be turned off.

As a guideline, it is suggest that RDS(ON) be selected to provide at least 22 mV, and no more than 100 mV, at the nominal load current.

$$(22\text{ mV} / I_D) \le R_{DS(ON)} \le (100\text{mV} / I_D)$$

The thermal resistance of the MOSFET package should also be considered against the anticipated dissipation in the MOSFET in order to ensure that the junction temperature (T_J) is reasonably well controlled, since the $R_{DS(ON)}$ of the MOSFET increases as the junction temperature increases.

$$P_{DISS} = I_D^2 \times (R_{DS(ON)})$$

Operating with a maximum ambient temperature ($T_{A(MAX)}$) of 35°C, a load current of 10A, and an $R_{DS(ON)}$ of 10 mΩ, and desiring to keep the junction temperature under 100°C, the maximum junction-to-ambient thermal resistance rating (θ_{JA}) would need to be:

$$\theta_{JA} \leq (T_{J(MAX)} - T_{A(MAX)})/(I_D^2 \times R_{DS(ON)})$$

$$\theta_{JA} \leq (100°C - 35°C)/(10A \times 10A \times 0.01\Omega)$$

$$\theta_{JA} \leq 65°C/W$$

Typical Applications

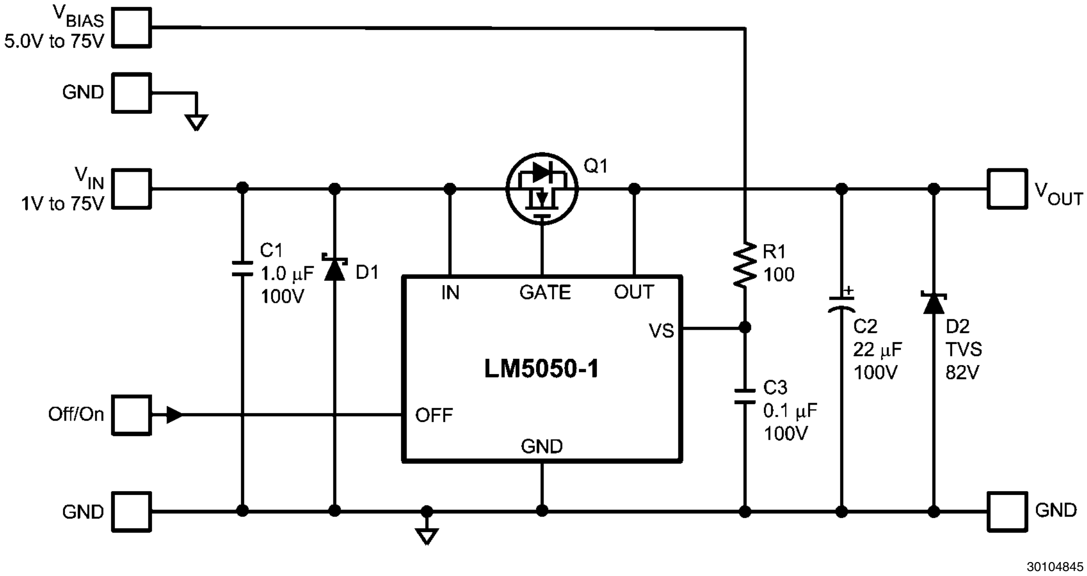


FIGURE 9. Using a Separate VS Supply For Low Vin Operation

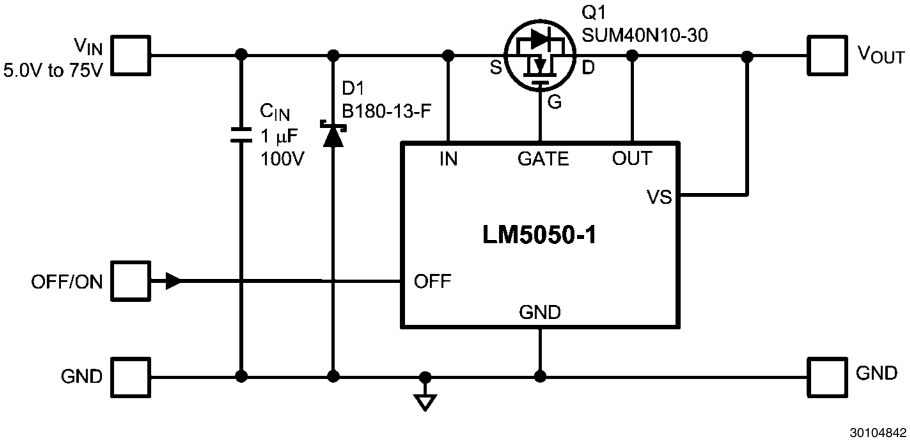


FIGURE 10. Basic Application with Input Transient Protection

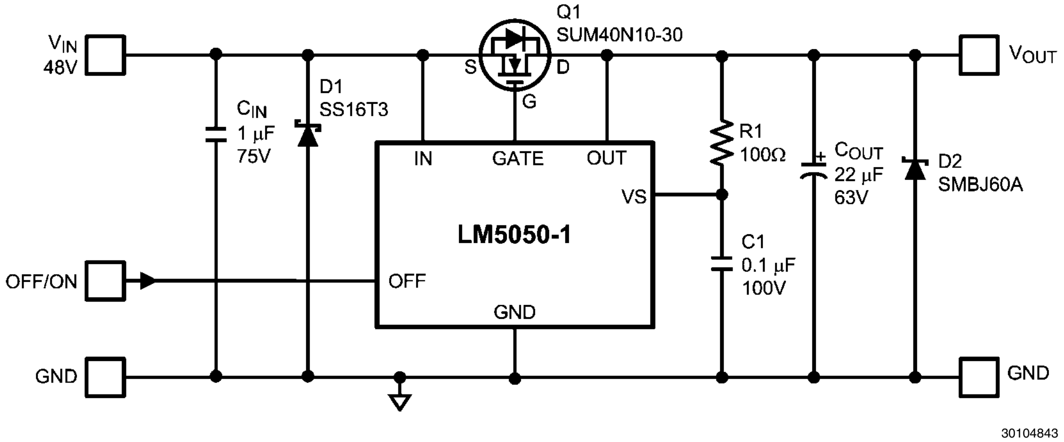


FIGURE 11. Typical Application with Input and Output Transient Protection

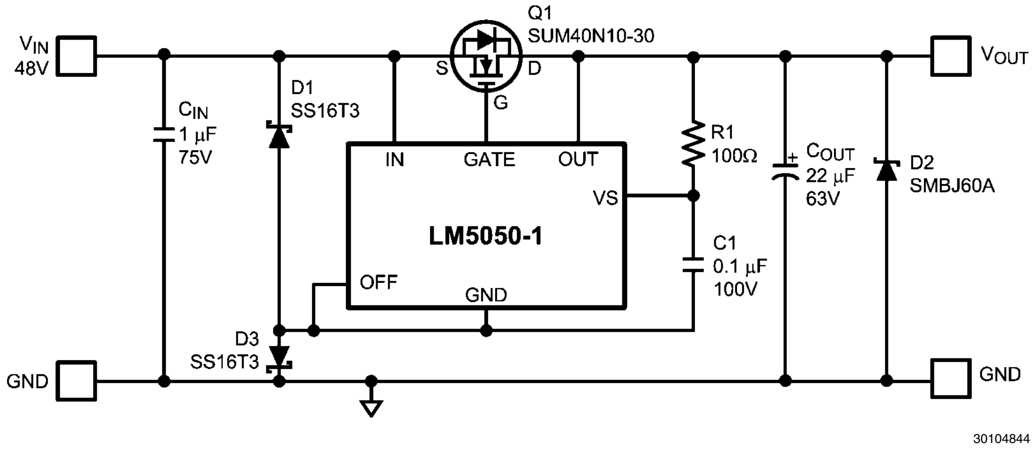
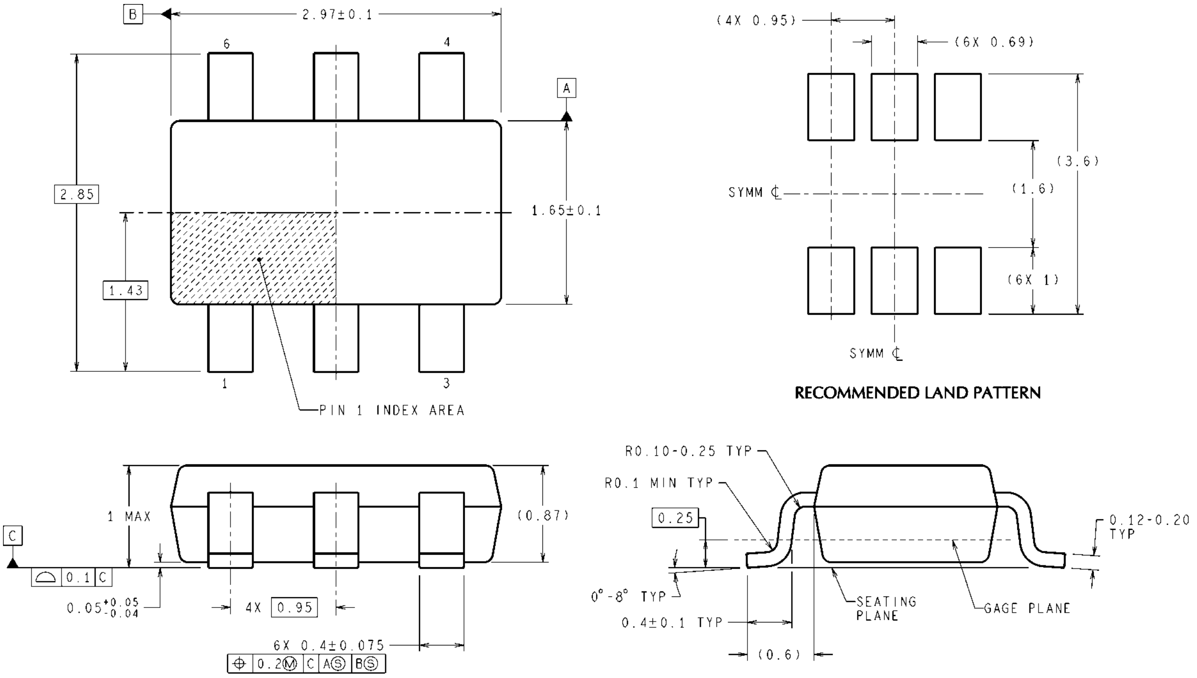


FIGURE 12. +48V Application with Reverse Input Voltage (V_{IN} = -48V) Protection

Physical Dimensions inches (millimeters) unless otherwise noted



DIMENSIONS ARE IN MILLIMETERS

MK06A (Rev E)

6-Lead TSOT Package
NS Package Number MK06A

Notes

Notes

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LDOs	www.national.com/ldo	Quality and Reliability	www.national.com/quality
LED Lighting	www.national.com/led	Feedback/Support	www.national.com/feedback
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Protective Vents

SCREW-IN VENTS

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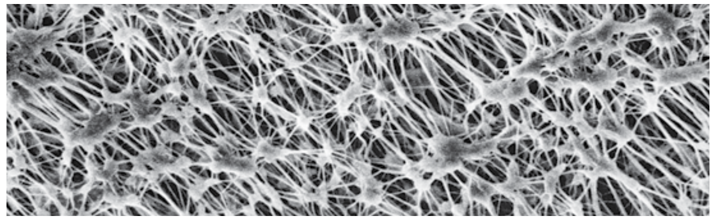
The GORE™ Membrane is:

- chemically inert
- non-shedding
- UV-resistant
- temperature-resistant



Gore's expanded PTFE membrane magnified 40,000 times.

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Protective Vents

SCREW-IN VENTS

Increase your equipment's durability in harsh environments

Venting for Protection

Outdoor enclosures are continuously exposed to harsh environments such as rainstorms, dust, sand and high winds. During changing environmental conditions, pressure can build inside a sealed enclosure, putting stress on seals. Over time stress causes seals to fail, which allows water, corrosive liquids, salt and particulates to enter the enclosure and damage the internal electronics.

With proven performance for more than 20 years, GORE® Protective Vents are the leading solution for protecting your sensitive electronics. These vents equalize pressure and reduce condensation by allowing air to flow freely into and out of sealed enclosures. At the same time, they provide a durable barrier to protect the electronics from contaminants. The result — improved reliability, increased safety and longer product life for your sealed electronic devices.

Venting Solution for any Application

Available in a variety of sizes, designs and constructions, GORE® Screw-In Vents meet the challenges of any application. The screw-in design is engineered specifically to withstand the mechanical stress of rugged environments, and many provide full product traceability with 100 percent online quality control, including individual laser marking. The specific vent solution for an application depends on the housing material and size:

- The standard series — GORE® PolyVent M12x1 and M12x1.5 — is suitable for housings with various wall thicknesses that may or may not require a counter nut.
- Meeting the same requirements as the standard series, the GORE® PolyVent M12x1.5 HA has the added benefit of providing high airflow.
- As proven by its EX-approval rating, the GORE® Metal Vent delivers added durability to provide robust protection and performance in extreme conditions.
- Engineered specifically to maintain high airflow in large outdoor enclosures with volumes that exceed 200 liters, the GORE® PolyVent XL meets the most rigorous industry standards — even the solar resistance IEC 62108 standard.

Realize the Benefits of GORE® Screw-In Vents:

- **Increased safety** from rugged screw-in construction with a durable O-ring that ensures stability and security
- **Easy installation** to ensure safe, durable performance in any application
- **Durable protection** against water, salts and corrosive liquids even after liquid immersion
- **Longer product life** with durable vent that is temperature-resistant, hydrolytically stable, and UV-resistant

Protective Vents

SCREW-IN VENTS

Product Information


NEW

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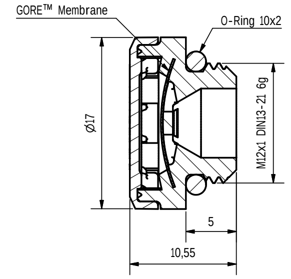
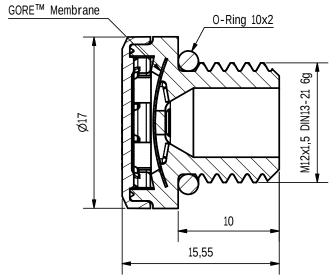
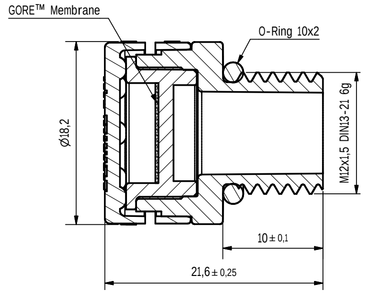
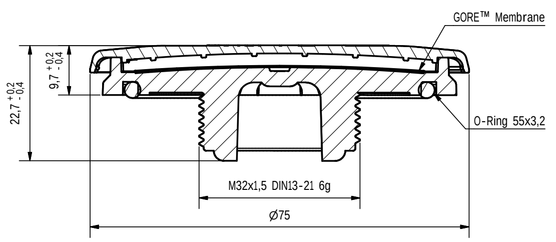
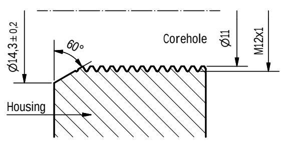
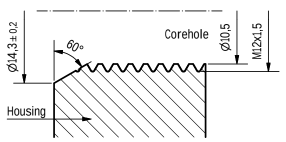
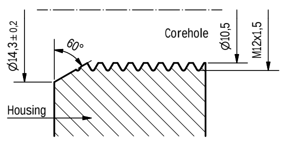
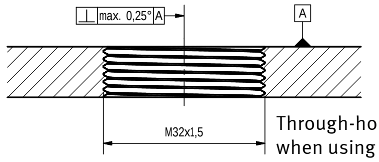
Part Number	**PMF100318 (black) / PMF100319 (grey)**	**PMF100320 (black) / PMF100321 (grey)**	**PMF100391 (black) / PMF100392 (grey)**	**PMF100519 (black) / PMF100520 (grey)**	**PMF100444**	**PMF200542**
Product Performance						
Water entry pressure	›0.6 bar / 30 sec	›0.6 bar / 30 sec	›0.3 bar / 30 sec	›0.3 bar / 30 sec	›0.3 bar / 30 sec	› 0.3 bar / 30 sec
Typical airflow	450 ml / min (dp = 70 mbar)	450 ml / min (dp = 70 mbar)	2500 ml / min (dp = 70 mbar)	2000 ml / min (dp = 70 mbar)	1700 ml / min (dp = 70 mbar)	16 l / min (dp = 12 mbar)
Product Characteristics						
Laminate: membrane / backing material	ePTFE / Polyester (PET)	ePTFE / Polyester (PET)	ePTFE / Polyester (PET)	ePTFE / Polyester (PET)	ePTFE / Polyester (PET)	ePTFE / Polyester (PET)
Laminate: membrane characteristic	Oleophobic	Oleophobic	Hydrophobic	Oleophobic	Oleophobic	Oleophobic
Housing material	Polyamide (PA6)	Polyamide (PA6)	Polyamide (PA6)	Polyamide (PA6)	Aluminum zinc alloy with nickel, copper coating	Polycarbonate (PC)
Color of housing material similar to	Black: RAL 9011 / Grey: RAL 7035	Black: RAL 9011 / Grey: RAL 7035	Black: RAL 9011 / Grey: RAL 7035	Black: RAL 9011 / Grey: RAL 7035	Metallic	Grey: RAL 7035
O-Ring material	Silicone 60 Shore A	Silicone 60 Shore A	Silicone 60 Shore A	Silicone 60 Shore A	Silicone 60 Shore A	Silicone 60 Shore A, UL94-V0
Wrench size	16 mm	16 mm	16 mm	16 mm	18 mm	70 mm
Installed height	5.6 mm	5.6 mm	5.6 mm	5.6 mm	11.5 mm	9.7 mm
Accessory parts (incl. part number)	n/a	Plastic backing nut, grey (M10510-009)	Plastic backing nut, grey (M10510-009)	Plastic backing nut, grey (M10510-009)	Metal backing nut (M10510-008)	Plastic backing nut, grey (M10510-010)
Design and Dimensions						
						
Recommended Installation						
• Install on a flat, vertical housing surface where water or other contaminants will not pool. • Orient the membrane so that it faces the external environment.	 Recommended torque: 0.6 – 0.8 Nm	Recommended torque: 0.6 – 0.8 Nm		Through-hole diameter when using a backing nut: 12.2 ± 0.1 mm	 Recommended torque: 0.6 – 1.2 Nm	 Recommended torque: 5 Nm Through-hole diameter when using a backing nut: 33 ± 0.5 mm

ENVIRONMENTAL PERFORMANCE

GORE® Screw-In Vents have been tested by independent laboratories and meet these performance standards. Results for the new GORE® PolyVent XL will be available as soon as the independent testing is completed.

All certificates are available upon request.

✓ = passed

✓ Ingress Protection Testing

Vent protection against ingress of particulates and water

- **IEC 529, 2nd**
  - IP66
  - IP67
  - IP68 (tested for extended immersion: 2 meters for 1 hour)
  - IP69k

✓ Temperature Testing

Vent durability in a range of temperatures

- **IEC 60068-2-1** (low temperature of -40 °C)
- **IEC 60068-2-2** (high temperature of +125 °C)
- **IEC 60068-2-14** (cycling temperatures between -40 °C and +125 °C)

✓ Humidity Testing

Vent durability in hot, humid environments

METHOD:

- **IEC 600-2-78**

TEST CONDITIONS:

- 85 °C
- 85% relative humidity
- 1,000 hours

✓ Salt Fog Testing

Vent resistance to salty environments

METHODS:

- **IEC 60068-2-11** (salt fog)
- **IEC 60068-2-52** (cyclic salt fog)

✓ Corrosive Gas Testing

Vent durability in corrosive gas environment (e.g., NO_x, SO_x, H_2S, Cl_x)

METHOD:

- **GR-3108-CORE**

✓ Fungus Testing

Vent resistance to growth of fungus

METHOD:

- **ASTM G-21**

✓ Flammability and UV Resistance Testing

Housing body and cap resistance to flames and ultraviolet light

METHOD:

- **UL 94-V0 f1**

✓ Explosion Testing (Metal Vent only)

Durability in explosive environment

METHOD:

- **Council Directive 94/9 / EC ATEX (95)**
  - I M2 Ex e I
  - II 2G Ex e II
  - II 1D

✓ Solar Industry Testing (Polyvent XL only)

Durability in solar applications

METHODS:

- **IEC 62108 10.8** (humidity freeze – high temperature / humidity followed by freezing temperature)
- **IEC 62108 10.9** (hail impact)

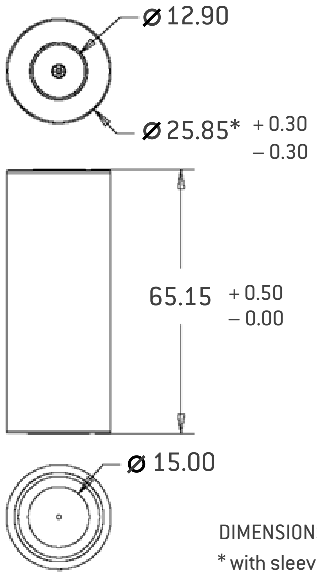
Nanophosphate® High Power Lithium Ion Cell
ANR26650*m1*-B

KEY FEATURES AND BENEFITS

- Excellent abuse tolerance and superior cycle life from A123's patented Nanophosphate® lithium ion chemistry
- High power with over 2,600 W/kg and 5,800 W/L, 10 seconds, 50% SOC
- High usable energy over a wide state of charge (SOC) range

ANR26650*m1*-B Cell Specifications

Cell Dimensions (mm)	ø26 x 65
Cell Weight (g)	76
Cell Capacity (nominal/minimum, Ah)	2.5/2.4
Voltage (nominal, V)	3.3
Internal Impedance (1kHz AC typical, mΩ)	6
HPPC 10 Sec Discharge Pulse Power 50% SOC	200 W
Recommended Standard Charge Method	1C to 3.6V CCCV, 45 min
Recommended Fast Charge Method to 80% SOC	4C to 3.6V CC, 12 min
Maximum Continuous Discharge (A)	70
Maximum Pulse Discharge (10 seconds, A)	120
Cycle Life at 10C Discharge, 100% DOD	>1,000 cycles
Operating Temperature	-30°C to 55°C
Storage Temperature	-40°C to 60°C



DIMENSIONS IN MM
* with sleeve 25.96 +/- 0.50 mm

APPLICATIONS

Transportation

Advanced energy storage for electric drive vehicles

Commercial

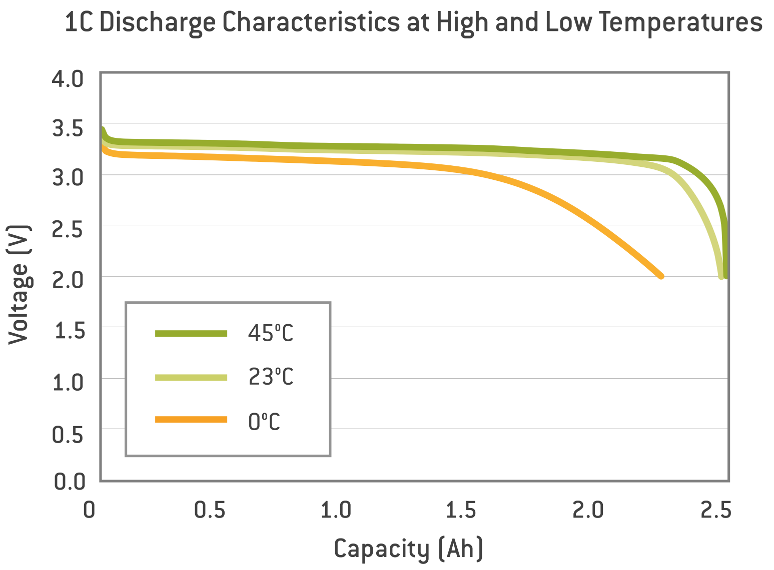
Enabling next-generation commercial products

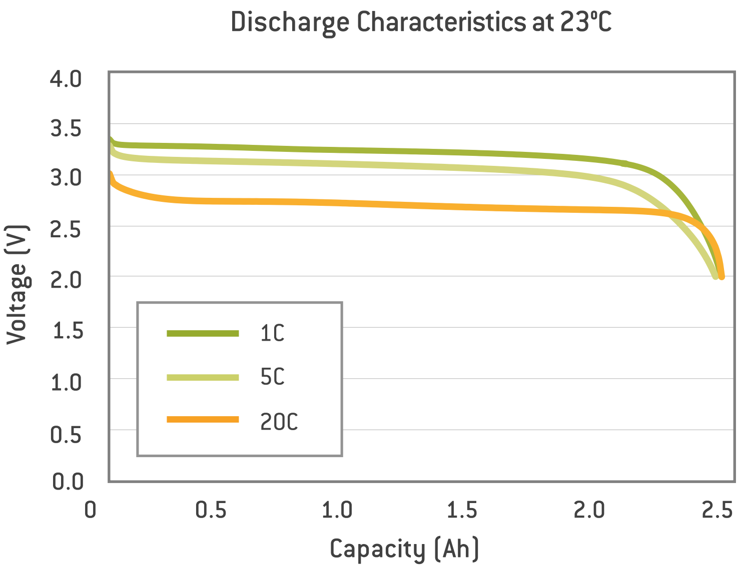
Electric Grid

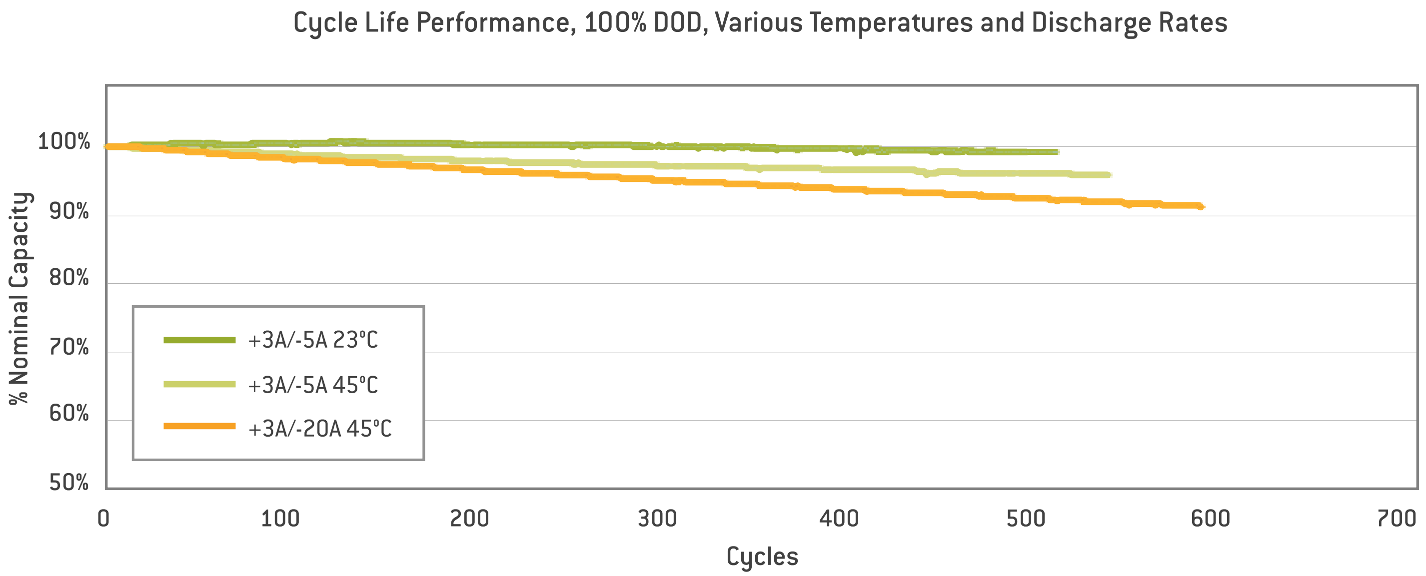
Dynamic energy solutions for a smarter grid

Nanophosphate® High Power Lithium Ion Cell

ANR26650m1-B







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A123 SYSTEMS

USER DOCUMENTATION

Date: February, 2013

Document #:493005-001E

Cylindrical Battery Pack Design, Validation, and Assembly Guide

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Tables

Chapter 1

About this document

Purpose of this document

This manual provides information on designing and validating battery packs with A123 Systems Nanophosphate® cells. It is not intended to cover all aspects of proper battery pack design, or make design recommendations. This guide is primarily focused on outlining the unique aspects of A123 Systems' cells to account for when designing a battery pack. A123 Systems recommends obtaining and studying relevant documentation from the appropriate sources before starting a project. This document should not be used in association with any cells not provided by A123 Systems.

NOTICE Anyone involved in the design, use, or manufacture of A123 Systems cells should read and understand this document.

⚠ DANGER **This document is not a comprehensive set of instructions to assist audiences in building battery packs. Designing, validating and assembling battery packs is potentially dangerous to personnel and property; therefore, it should only be attempted with a complete understanding of all aspects of proper battery pack design and construction, which is outside the scope of this document. A123 Systems is not responsible for any battery pack designs developed by any party other than A123 Systems. Anyone involved in building a battery pack with A123 cells must have the training and experience necessary to safely handle the cells and prevent accidental short circuits and arc flashes.**

Chapter 2

Possible Dangers Involved With Handling Cells and Battery Packs

A123 Systems' cells are highly stable and abuse tolerant; however, handling a battery pack remains potentially dangerous to personnel and property, and should only be attempted with a complete understanding of all aspects of proper battery pack construction. The dangers involved in building a battery pack include those described in the following sections.

- Thermal Events
- Short Circuits
- Arc Flashes
- High Voltage

Thermal Events

Proper battery pack design is essential to allow the safety features of A123 Systems' cells to function as designed.As a safety feature, overheating A123 cells vent gases to relieve dangerous pressure buildup to disperse into the environment. However, an improperly designed battery pack can prevent the gases from safely dispersing, or prevent the cells from venting altogether.

⚠ DANGER Adding an ignition source to improperly-vented gases can create a dangerous thermal event. You **must** ventilate these expelled gasses from the environment itself after the gases are vented from the cell itself.

While A123 cells normally vent gases to relieve dangerous pressure buildup caused by heat or excessive voltage, extreme situations may cause the cells to violently eject their contents (the layers of anode and cathode material within the battery).

For example, the heat generated by overcharging, overdischarging, or excessively cycling an 18650,26650, or 32113 cell will destroy the cell, and it can damage a poorly designed enclosure or other surrounding components of a battery pack. This document highlights some recommendations on the pack's physical and electrical design which can mitigate these dangers.

Short Circuits

⚠ DANGER

Because A123 cells offer relatively high-power potential, an improperly designed battery pack may allow short circuits with dangerous levels of current.

Arc Flashes

⚠ DANGER

A poor battery pack design may increase the chances of an arc flash. An arc flash caused by a short circuit involving both high voltage and high current, emits extremely high intensity visible and ultra violet light with the potential to damage property while causing blindness and burns to personnel.

High Voltage

⚠ DANGER

Assembling a battery pack involves combining cells in serial or parallel to achieve higher voltages and currents, respectively. As the voltage and current involved increase, so does the danger to personnel assembling the battery pack. Without the proper training, experience, tools and personal protective equipment (PPE), handling high voltage battery packs may result in personnel injury or death.

Chapter 3

Transportation and Storage

This chapter includes the following sections:

NOTICE

This document does not constitute legal advice or training. This document is not intended to substitute for training that may be required by laws and industry standards applicable to you. You should seek your own advice on laws and relevant industry standards applicable to the transportation and storage of dangerous goods prior to transporting or storing A123 batteries or cells.

Transporting Batteries

Transporting dangerous goods is regulated internationally by the International Civil Aviation Organization (ICAO) Technical Instructions and corresponding International Air Transport Association (IATA) Dangerous Goods Regulations and the International Maritime Dangerous Goods (IMDG) Code. In the United States, transportation of these batteries is regulated by the Hazardous Materials Regulations (HMR), which is found at Title 49 of the Code of Federal Regulations, Sections 100-185. All of these regulations that govern the transport of rechargeable lithium ion (including lithium ion polymer) cells and batteries (which are classified dangerous goods) are based on the UN Recommendations on the Transport of Dangerous Goods Model Regulations.

All energy storage systems (ESS), or components thereof, containing lithium ion chemistry must meet the test criteria set forth in the UN "Recomendations on the Transport of Dangerous Goods, Manual of Tests and Criteria", chapter 38.3 (known as UN 38.3) in order to be shipped in PG II packaging.

Other laws and regulatory requirements may apply depending upon your location. It is your obligation to become familiar with and adhere to the laws and regulatory requirements as they apply to you.

Overview of the Shipping Process

The following tables shows a brief overview of the steps typically required to ship a product that includes lithium ion both internationally and in the U.S.

Step Number	Process Step	Comments
1	Design the Battery.	Design the battery to ensure it will pass UN Manual of Tests and Criteria.
2	Test the Cell or Battery. Refer to "UN Test Types", below.	Perform UN testing T1-T8.
3	Obtain UN certified packaging.	All Class 9 Dangerous Goods (DG) must be shipped in UN certified packaging.
4	Packaging the cell or Battery.	Pack per regulations and close per packaging manufacturer's instructions.
5	Marking and labeling. Refer to "Lithium Ion UN Numbers", below.	Insure that packaging container has all the required labeling.
6	Fill out proper shipping documentation.	Complete shipper's declaration for dangerous goods, airway bill, and so on.
7	Ship the package.	Ensure that shipping company can ship dangerous goods and that an MSDS and any Competent Authority Approval accompanies the package.

UN Test Types

The UN Manual of Tests and Criteria Section 38.3 consists of the following tests:

- Test T.1: Altitude Simulation
- Test T.2: Thermal Test
- Test T.3: Vibration
- Test T.4: Shock
- Test T.5: External Short Circuit Test
- Test T.6: Impact (Cell only)
- Test T.7: Overcharge
- Test T.8: Forced Discharge (Cell only)

Lithium Ion Numbers

The following lists the proper shipping name for ithium ion/metal batteries as well as the corresponding UN and US number:

- UN 3480: Lithium ion batteries
- UN 3481: Lithium ion batteries packed with equipment
- UN 3481: Lithium ion batteries contained in equipment
- US 3090: Lithium metal batteries
- US 3091: Lithium metal batteries packed with equipment
- US 3091: Lithium metal batteries contained in equipment

Requirements for Excepted and Regulated Cells and Batteries

Cells and battery packs have transportation and packaging requirements based on their watt hours.

Individual **cells** with with not more 20 Wh are excepted from regulated Class 9 requirements. Cells exceeding 20 Wh are regulated as Class 9.

Battery packs with not more 100 Wh are excepted. Batteries exceeding 100 Wh regulated as Class 9.

Determining the Nominal Watt Hour Ratings of Cells and Batteries

To determine the nominal watt hours of a cell, multiply the nominal voltage (volts) of the cell by the cell's nominal capacity (amp hours).

- *Nominal Watt hours (Wh) of the cell = Nominal Voltage of the cell (V) x Nominal Capacity of the cell (Ah)*

To determine the nominal watt hours of a battery, multiply the number of cells by the equation above. That is, the number of cells multiplied by their nominal voltage and then by their nominal capacity. Typically, individual A123 Systems cells do not exceed the 20 watt hour threshold.

For example, this formula is as follows for A123 Systems cell battery values:

- *Nominal Watt hours of a battery (Wh) = Number of cells x Nominal Voltage of a cell (V) x Nominal Capacity of a cell (Ah)*

Determining Watt Hour Ratings for the ANR26650m1B

To determine the nominal watt hours of a ANR26650m1B cell:

- *Nominal Watt hours (Wh) of the ANR26650m1B cell = Nominal Voltage of the cell (3.3V) x Nominal Capacity of the cell (2.5Ah)*

To determine the nominal watt hours of a battery using ANR26650m1B cells:

- *Nominal Watt hours of a battery (Wh) = Number of cells x Nominal Voltage of a cell (3.3V) x Nominal Capacity of a cell (2.5Ah)*

ANR26650 m1B batteries typically exceed this value when comprised of 12 or more cells.

Determining Watt Hour Ratings for the ANR18650m1A

To determine the nominal watt hours of a ANR18650m1A cell:

- *Nominal Watt hours (Wh) of the ANR18650m1A cell = Nominal Voltage of the cell (3.3V) x Nominal Capacity of the cell (1.1Ah)*

To determine the nominal watt hours of a battery using ANR18650m1A cells:

- *Nominal Watt hours of a battery (Wh) = Number of cells x Nominal Voltage of a cell (3.3V) x Nominal Capacity of a cell (1.1Ah)*

ANR18650m1A batteries typically exceed this value when comprised of 26 or more cells.

Determining Watt Hour Ratings for the AHR32113m1

To determine the nominal watt hours of a AHR32113m1 cell:

- *Nominal Watt hours (Wh) of the A AHR32113m1 cell = Nominal Voltage of the cell (3.3V) x Nominal Capacity of the cell (4.5Ah)*

To determine the nominal watt hours of a battery using AHR32113*m1* cells:

- *Nominal Watt hours of a battery (Wh) = Number of cells x Nominal Voltage of the cell (3.3V) x Nominal Capacity of the cell (4.5Ah)*

AHR32113*m1* batteries typically exceed this value when comprised of six or more cells.

Overview of the Regulatory Requirements

The following tables show a brief overview of the regulations required to ship a product that includes lithium ion both nationally and internationally.

Neither table is all inclusive of the required regulations to ship a product. These tables are meant to help you understand the complexity involved in shipping a lithium-ion product. The regulations cited here are intended to assist you to adhere to proper regulatory requirements; it is your responsibility to confirm all of the requirements that may be applicable to you, depending on your location, the specific contents of the goods you are shipping, the method of shipment and other factors that may be relevant in your jurisdiction. U.S. and international regulations require that anyone involved in the handling Dangerous Goods (Hazardous Material) must be trained to do so.

International Regulation Requirements Overview

The following table shows an overview of the international regulation requirements.

Lithium Ion Cell /Battery	Shipping Classification/Testing	Are there Special Packaging/Markings?
20 Wh cell / 100 Wh battery Maximum Watt hours	**Excepted / T1-T8**. Cells and batteries must pass UN T1-T8 Tests. Cells and batteries passing UN Tests are excepted from regulation. **NOTE**: The IMDG Code contains a grandfather clause for testing "small" cells and batteries until December 31, 2013.	Yes
Greater than 20 Wh cell / 100 Wh battery	**Class 9 I T1-T8**. All cells and batteries must pass UN Manual of Tests and Criteria Section 38.3 Tests T1-T8. They must also ship as a Class 9 dangerous goods.	**Yes**. Requires Class 9 markings, label, specification packaging, and shipping papers.

US Regulation Requirements Overview

The following table shows an overview of the U.S. regulation requirements.

Lithium Ion Cell /Battery*	**Shipping Classification /Testing**	**Are there Special Packaging/Markings?**	**Battery Size**
1.5 g / 8.0 g Max. ELC	**Excepted / T1-T8**. All cells and batteries must pass UN Manual of Tests and Criteria Section 38.3 Tests T1-T8.	**Yes**. Packages containing more than 12 batteries or 24 cells must meet certain packaging, marking, and shipping paper requirements.	Small
5.0 g / 25 g Max. ELC	**Class 9 / T1-T8**. All cells and batteries must pass UN Manual of Tests and Criteria Section 38.3 Tests T1-T8 and must be shipped as Class 9 hazardous materials **unless transported by motor vehicle or rail car**.	**Yes**. Requires Class 9 markings, label, specification packaging, and shipping papers **unless transported by motor vehicle or rail car**.	Medium
Anything greater than 5.0 g / >25 g ELC	**Class 9 / T1-T8**. All cells and batteries must pass UN Manual of Tests and Criteria Section 38.3 Tests T1-T8 and must be shipped as Class 9 hazardous materials.	**Yes**. Requires Class 9 markings, label, specification packaging, and shipping papers.	Large

*** NOTE**: Equivalent Lithium Content (ELC) of a cell is calculated as 0.3 times the rated capacity of a cell in Ah (0.3XAh of cell) with the result expressed in g. ELC of a battery is equal to the sum of the g of ELC contained in the component cells of the battery.

Using the IATA Rules to Test, Package, and Label

The International Air Transport Association (IATA) regulations provide requirements for testing, packaging, and labeling of lithium batteries. These regulations are found in Packing Instructions PI965-PI970.

IATA Packing Instruction PI-965, PI-966, and PI-967 apply specifically to *air shipment* of lithium ion batteries.

⚠ WARNING Products packaged with or containing lithium batteries must be packed to guard against accidental activation during transportation.

All Lithium ion cells and battery types (regardless of whether cells in batteries have undergone separate testing) require testing according to the UN Manual of Tests and Criteria, Part III, subsection 38.3. Cell and batteries that have met the criteria of UN38.3 are allowed to be shipped per the packing instruction described in section 3.9.1.

Where testing indicates that the lithium ion batteries are to be classified as Class 9 – Miscellaneous Dangerous Goods, the batteries must be packed for transport according to Packing Group II specifications, as well as labeled in accordance with Dangerous Goods Regulations requirements.

IATA PI965-PI967 provide specific requirements for the materials used and the “survivability” of packaging and over packs to potential damage, provision for safety venting, and prevention of short circuits when batteries, battery packs, products packaged with batteries and products containing batteries are packed for transportation by air.

The following table lists IATA PI965-PI967 requirements for packaging batteries for air transport.

Requirement	**PI-965 – Lithium Ion Cells and Batteries**			**PI-966 – Lithium Ion Cells and Batteries Packed <u>with</u> Equipment**			**PI-967 – Lithium Ion Cells and Batteries Packed <u>in</u> Equipment**		
	Cell ≤ 20 Wh	**Batt. ≤ 100 Wh**	**Class 9***	**Cell ≤ 20 Wh**	**Batt. ≤ 100 Wh**	**Class 9**	**Cell ≤ 20 Wh**	**Batt. ≤ 100 Wh**	**Class 9**
Capacity Labelling	-	Yes	Yes **	-	Yes	Yes **	-	Yes	Yes **
Max quantity (Gross) - Passenger Aircraft	10 kg (per package)		5 kg (per package)	Number of batteries required to power unit plus 2 spares (per package)		5 kg (weight of cells or batteries per package)			5 kg (net weight of cells and batteries per piece of equipment)
Max quantity (Gross) - Cargo Aircraft	10 kg (per package)		35 kg (per package)	Number of batteries required to power unit plus 2 spares (per package)		35 kg (weight of cells or batteries per package)			35 kg (net weight of cells and batteries per piece of equipment)
Outer Pack Standards	5.0.2.4, 5.0.2.6.1, 5.0.2.12.1		General Packing Requirements 5.0.2 AND Packing Group II performance Standards	5.0.2.4, 5.0.2.6.1, 5.0.2.12.1		General Packing Requirements 5.0.2 AND Packing Group II performance Standards	Equipment must be packed to: 5.0.2.4, 5.0.2.6.1, 5.0.2.12.1		Equipment must be packed to: 5.0.2.4, 5.0.2.6.1, 5.0.2.12.1
Inner pack required to enclose battery	Yes		Yes	Yes (inner pack completely encloses then packed with equipment)		Yes (inner pack completely encloses then packed with equipment)			
Prevent accidental activation				Yes (and prevent motion relative to outer pack)		Yes (and prevent motion relative to outer pack)	Yes: equipment secured against movement within outer packaging		Yes: equip. secured against movement within outer packaging

Requirement	**PI-965 – Lithium Ion Cells and Batteries**			**PI-966 – Lithium Ion Cells and Batteries Packed <u>with</u> Equipment**			**PI-967 – Lithium Ion Cells and Batteries Packed <u>in</u> Equipment**		
	Cell ≤ 20 Wh	**Batt. ≤ 100 Wh**	**Class 9***	**Cell ≤ 20 Wh**	**Batt. ≤ 100 Wh**	**Class 9**	**Cell ≤ 20 Wh**	**Batt. ≤ 100 Wh**	**Class 9**
Prevent short circuits internally	Yes		Yes	Yes		Yes	Yes		Yes
Prevent short circuits externally	No (A123 Yes)		Yes	No (A123 Yes)		Yes	No		Yes
Provide Safety Venting	No (A123 Yes)		Yes	No (A123 Yes)		Yes	No (A123 Yes)		Yes
1.2 m drop test (pack + content)	Yes		NA (see performance standard for Packing Group II)	Yes (for each package of cells or batteries, or completed package)		NA (see performance standard for Packing Group II)	No		-
Prevent Reverse flow	No, but A123 requires this		Yes	No, but A123 requires this		Yes	No, but A123 requires this		Yes
Lithium Battery Label	Yes; Repeat on overpack also.		Lithium battery label can be included with the Class 9 label	Yes; Repeat on over pack also.		Lithium battery label can be included with the Class 9 label	Yes†; Repeat on overpack		Lithium battery label can be included with the Class 9 label
Indicate "Contains Li ion batteries"	Yes		Complete Shipping declarations for Dangerous Goods Transport	Yes		Complete Shipping declarations for Dangerous Goods Transport	Yes†		Complete Shipping declarations for Dangerous Goods Transport
Handle with care, flammability risk if damaged	Yes		Complete Shipping declarations: Dangerous Goods Transport	Yes		Complete Shipping declarations: Dangerous Goods Transport	Yes†		Complete Shipping declarations for Dangerous Goods Transport

Requirement	**PI-965 – Lithium Ion Cells and Batteries**			**PI-966 – Lithium Ion Cells and Batteries Packed with Equipment**			**PI-967 – Lithium Ion Cells and Batteries Packed in Equipment**		
	Cell ≤ 20 Wh	**Batt. ≤ 100 Wh**	**Class 9***	**Cell ≤ 20 Wh**	**Batt. ≤ 100 Wh**	**Class 9**	**Cell ≤ 20 Wh**	**Batt. ≤ 100 Wh**	**Class 9**
Special procedures if pack damaged	Yes		Complete Shipping declarations for Dangerous Goods Transport	Yes		Complete Shipping declarations for Dangerous Goods Transport	Yes†		Complete Shipping declarations for Dangerous Goods Transport
Tel # for additional information	Yes		Complete Shipping declarations for Dangerous Goods Transport	Yes		Complete Shipping declarations for Dangerous Goods Transport	Yes†		Complete Shipping declarations for Dangerous Goods Transport
Indicate	PI-965; Lithium ion batteries; not restricted		Complete Shipping declarations for Dangerous Goods Transport	PI-966; Lithium ion batteries; not restricted		Complete Shipping declarations for Dangerous Goods Transport	PI-967; Lithium ion batteries; not restricted (if using an air waybill)		Complete Shipping declarations for Dangerous Goods Transport

* Lithium batteries with mass ≥ 12kg and having a strong, impact-resistant outer casing, or assemblies of such batteries, may be transported when packed in strong outer packaging in protective enclosures. These require approval of the authority having jurisdiction (copy of approval to accompany shipment.)

**Batteries manufactured after 31 December 2011 must be marked with Watt-hour rating on the outside case.

† Lithium battery label required if package contains more than four cells or two batteries installed in the equipment; except button cell batteries installed in equipment (including circuit boards.)

Note: Competent Authority Approval is required to ship by air for at least the following conditions. Otherwise, it is prohibited to ship by air:

- Any batteries over 35kg, even those that have passed UN testing
- Waste lithium batteries
- Prototype vehicles containing prototype batteries

Cells and batteries are prohibited from being transported by air for any reason if they have been identified by the manufacturer as:

- Defective for safety reasons
- Damaged
- Having the potential of producing a dangerous evolution of heat, fire, or short circuit

Storing Batteries

A123 Systems cells can be stored for up to 10 years in a cool environment. For long storage periods, a refresh charge is required every 4 years at 25°C. For temperatures above 40°C a refresh charge is required every year. Batteries should not be stored continuously above 60°C.

Battery Disposal

Do not incinerate or dispose of cells or batteries. Return end-of-life cells or batteries to your nearest recycling center as per the appropriate regulations.

Chapter 4

Nanophosphate® Technology and Cell Overview

This chapter includes the following sections:

Nanophosphate Technology

A123 Systems' low impedance Nanophosphate electrode technology provides significant competitive advantages over alternative battery technologies, including:

- **Power:** Our **high-power,** Nanophosphate products can pulse at high discharge rates to deliver unmatched power by weight or volume.
- **Safety:** A123 Systems' Nanophosphate technology is designed to be **highly abuse-tolerant**, while meeting the most demanding customer requirements of power, energy, operating temperature range, cycle life, and calendar life.
- **Life:** A123 Systems' Nanophosphate technology delivers **exceptional calendar and cycle life**. At low rates, our cells can deliver thousands of cycles at 100% Depth-of-Discharge, a feat unmatched by other commercial lithium ion cells.

Power

A123 Systems cells are designed to deliver high power in pulse and continuous applications. Figure 1 displays typical discharge curves showing that the voltage remains virtually flat during the discharges and the delivered AH capacity doesn't change significantly, no matter what the rate of discharge.

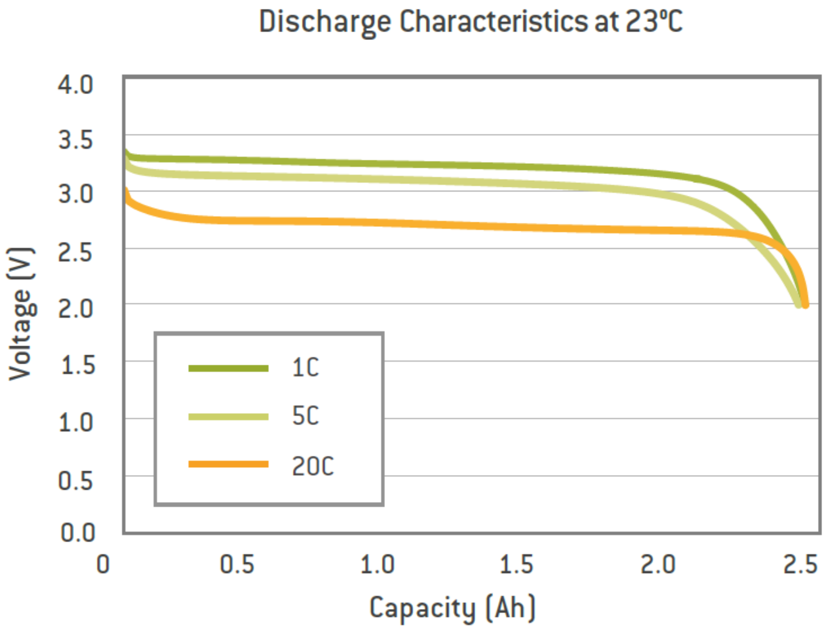


Figure 1 26650 Discharge Curve

Cell resistance changes with cell temperature. The warmer the ambient and/or cell temperature, the lower the resistance. Note that in Figure 5, the cells hold up voltages at cold temperatures less effectively than at ambient room temperatures. Voltages reach parity when the cells heat up to or beyond ambient room temperatures.

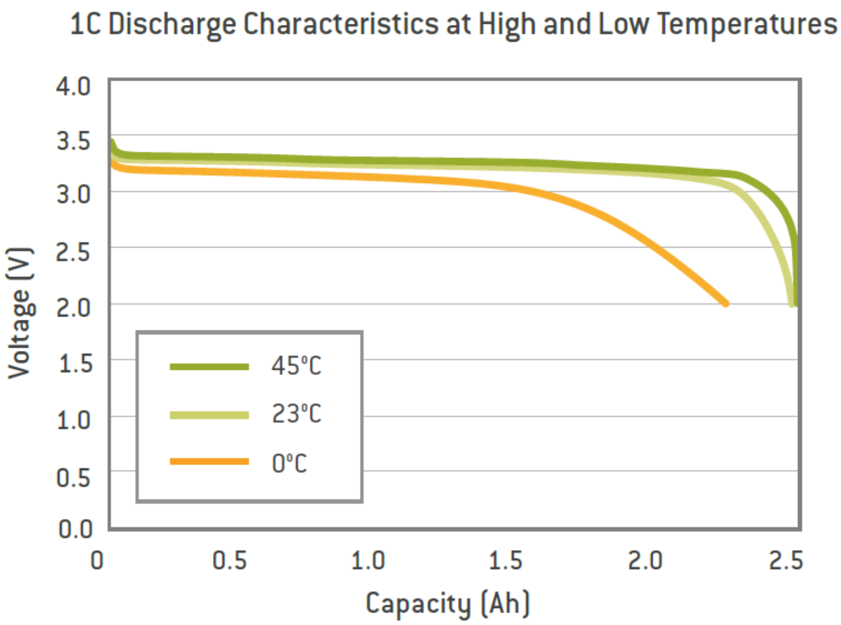


Figure 2 26650 Discharge Curves at Various Temperatures

Safety

Proper handling and battery pack design must be followed to make sure the A123 Systems Nanophosphate cells operate safely. These cells can store significant amounts of energy, and (unlike most other types of cells) deliver this energy very quickly. Appropriate pack design must provide sufficient mechanical and environmental protection to ensure the cells operate within the proper voltage, current, and temperature limits.

The following minimum safety precautions must be followed at all times. Failure to follow the following safety instructions may result in personal injuries or damage to the equipment!

⚠ DANGER

- Cells must not be subjected to ambient conditions or self-heating that result in a temperature in excess of 60°C during operation or while in continuous storage because they will either lose life or be rendered inoperable. Do not incinerate cells, or store or use them near open flames.
  Cells must not be punctured, ruptured, dented, or crushed. The pack design must likewise ensure this under normal operations or in a crash.
- Cell packaging must not be altered in any way.
- Cells must not be immersed or exposed to water or liquids.
- Never use pressure at the top and bottom of the cell to hold cells together in a way that leads to blocked cell vents. If the vents are blocked, the gas cannot exit the cell in case of cell failure. Cells shall be mounted in the application, in a way that will not interfere with the vent function on the cell.
- If the cell or battery emits smoke or flares, ventilate the area immediately and avoid breathing the fumes. See MSDS for additional precautions.
- Cells must not be subject to reverse polarity or short circuited. Individual cell fusing is required in pack designs with cells in parallel to be compliant with UN 38.3, US-DOT and other international shipping regulations. Cells must not be charged or discharged outside the operating temperature range in the datasheet, and reduced charging limits must be followed for lower operating temperatures.

Life

A123 Systems cells offer long cycle and calendar life, with minimal impedance growth over the life of the cells. The ambient temperature cycle life graphs in Figure 3 demonstrates that these cells also offer extended calendar life, even at elevated temperatures.

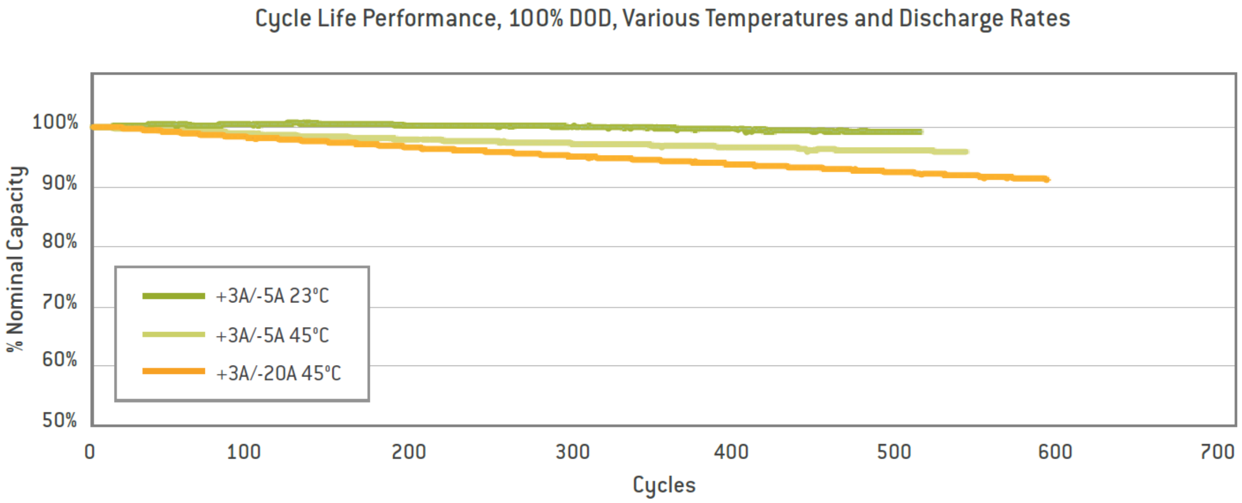


Figure 3 26650 Cycle Life

Chapter 5

Applications

A123 Systems’ cells can be used in many different applications, ranging from Hybrid Electric Vehicles (HEVs) to embedded systems to backup storage devices. This guide cannot cover all possible uses, pack designs and conditions for these cells; therefore, you must make sure the pack design is suitable for your application, and then design and test accordingly.

This chapter includes the following sections:

- Voltages and Capacity
- Discharging

Voltages and Capacity

Cells can be combined together either in series or in parallel to achieve higher operating voltages and capacities, respectively. When connecting cells, consider the principles of basic pack design discussed in Chapter 6 Basic Pack Design.

Series Strings

Cells combined in series strings can achieve higher operating voltages by connecting the positive terminal of one cell to the negative terminal of the next cell. Connect strings of series cells using their current collection tabs in a manner similar to that illustrated in Figure 4.

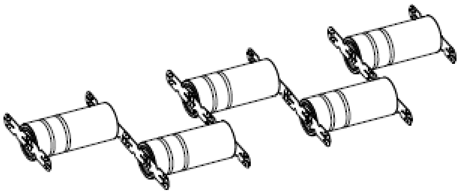


Figure 4 Cells Connected in Series

Two cells in series: 2 x 3.3V = 6.6V (nominal)

Three cells in series: 3 x 3.3V = 9.9V (nominal)

Parallel Strings

Cells combined in parallel strings can achieve higher operating capacities by connecting like-polarity terminals of adjacent cells to each other. Connect strings of parallel cells using their current collection tabs in a manner similar to that illustrated in Figure 5.

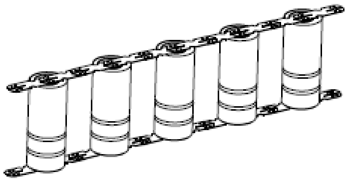


Figure 5 Cells Connected in Parallel

Two cells in parallel: 2 x 2.5Ah = 5Ah (nominal for 26650 cells)

Three cells in parallel: 3 x 2.5Ah = 7.5Ah (nominal for 26650 cells)

Charging Cells

Charging or Recharging Cells or Strings

⚠WARNING When charging or recharging Nanophosphate cells, the charger should apply a constant current (CC) charge followed by a constant voltage (CV) charge.

To achieve maximum life, reliability, and safety, A123 Systems recommends using cell balancing circuitry during cell charging to prevent an increasing spread between highest and lowest battery voltages. Refer to Cell Balancing on page 41 for more information.

Stop the charging process when either:

- The string voltage across the pack has exceeded the recommended maximum charging voltage for the string, or
- Any one cell in the series string, has exceeded its maximum recommended charge voltage, or
- The temperature measured in the pack has gone outside the recommended range for charing.

Determine the **charge current** for a string of cells by multiplying the number of parallel cells in the string by the recommended charge current for a single cell. Note that this calculation does not take into account limitations imposed by any protection electronics or any other features of the battery pack assembly.

Eq. 1 *(Number of cells in parallel) x (Recommended Charge Current, Cell) = Charge Current, String*

Determine the end of charge voltage for a string of cells by multiplying the number of series elements in the string by the recommended charge voltage of a single cell.

Eq. 1 *(Number of cells in series) x (Recommended Charge Voltage, Cell) = Charge Voltage, String*

Refer to Table 1 for recommended charge currents and voltage.

Table 1 Recommended Charge Current and Voltage

Example 1	If the cell string has 10 cells in parallel (10P), and the recommended charge current per cell is 3A, then the charge current for this string is 30A: (10 cells, parallel) x (3A) = 30A
Example 2	If the cell string has 10 cells in series (10S), and the recommended charge voltage per cell is 3.6V, then the end of charge voltage for the string is 36V: (10 cells, series) x (3.6V) = 36V
Example 3	If the cell string has 10 cells in series and 3 cell strings in parallel (10S-3P), the recommended charge voltage per cell is 3.6V, and the recommended charge current per cell is 3A, then the charge current and charge voltage for the string is 9A and 36V: (10 cells, series) x (3.6V) = 36V (3 cells, parallel) x (3A) = 9A

Once the end of charge voltage has been reached, apply a constant voltage hold at this voltage until the current decays to near-zero. This process charges the cells to 100% state of charge (SOC). Refer to Figure 6 for an illustration.

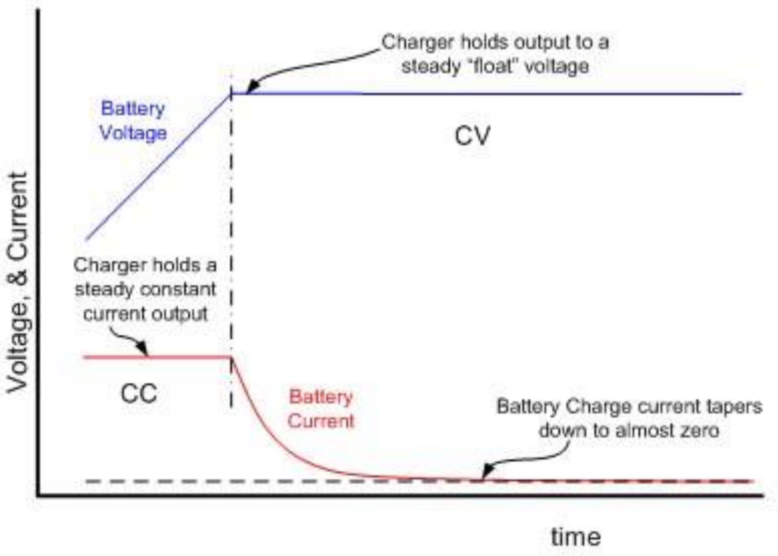


Figure 6: Battery Voltage and Current During Recharge

Recommended Fast Charge Method for Strings

The cells can be be charged at a fast rate if a short recharge time is desired by the application. Faster recharge rates will reduce the cycle life of the battery by:

1. Increasing the internal wear and tear on the cell electrodes and reduce its capacity faster than normal
2. Increase the internal temperatures in the cells which increase degradation rates of the cell’s capacity and impedance over time.

Determine the fast charge current for a string of cells by multiplying the number of parallel elements in the string by the maximum continuous charge current for a single cell. Determine the maximum recommended charge voltage by multiplying the number of series elements in the string by the recommended charge voltage of a single cell.

Charge the string at its maximum continuous charge current until the string or any one cell within the string has reached its maximum recommended charge voltage. Apply a constant voltage hold at the maximum recommended charge voltage, not exceeding the recommended charge voltage of any series cell, until the total charge time reaches the fast charge time. Do not attempt a fast charge outside the recommended temperature range, and stop if any individual cell voltage or temperature exceeds the maximum allowable limits.

Eq. 1 *(Number of cells in parallel) x (Max Continuous Charge Current, Cell) = Fast Charge Current, Strings*

Recommended Float Charge Method for Strings

The charge current shall be limited whenever any one cell in the string reaches its maximum recommended float voltage.

Eq. 1 *To hold the voltage of the cell string at the end of charge voltage (after reaching 100% SOC) for prolonged periods of time, lower the end of charge voltage to the recommended float-charge voltage. Determine the recommended float voltage by multiplying the number of series elements in the string by the recommended float-charge voltage of a single cell.(Number of cells in series) x (Recommended Float Charge Voltage, Cell) = Float Charge Voltage, String*

Refer to the appendix for recommended float charge voltages.

Discharging Cells

Recommended Discharge Method for Strings

Determine the maximum continuous discharge current for a string of cells by multiplying the number of parallel cells in the string by the maximum continuous discharge current for a single cell. Note that this calculation does not take into account limitations imposed by any protection electronics or any other features of the battery pack assembly.

Eq. 1 *(Number of cells in parallel) x (Max Discharge Current, Cell) = Max Discharge Current, String*

Additionally, correctly size the cell-to-cell current collection tabs to carry the maximum design current. Discharges at currents higher than the tab design limit risks damaging these tabs, as well as possibly overheating cells.

Discharge Cell Temperature Limits

For optimum life, do not continuously discharge the strings of cells faster than the maximum continuous discharge current. Do not allow the string of cells to self-heat beyond the maximum recommended cell temperature of 70°C for discharge or 60°C for recharge. Operation above the maximum recommended cell temperature will result in accelerated performance degradation during its service life. At low temperatures, the maximum available discharge current will decrease due to markedly increased internal impedance at these lower temperatures.

Discharge String/Cell Cut-Off Voltage Limits

Discharge should be cut off whenever any one cell in the string reaches its lowest recommended discharge cutoff voltage.

Stop discharges when any of the following occurances happen:

- The string of cells reaches the recommended discharge cut-off voltage
- Any one cell in the series connection reaches its minimum allowable cut-off voltage
- The maximum allowable cell temperature

Determine the recommended discharge cut-off voltage for a string of cells by multiplying the number of series elements in the string by the recommended discharge cut-off voltage for a single cell.

Eq. 1 *(Number of cells in series) x (Recommended discharge cutoff voltage, Cell) = Cutoff Voltage, string*

While the string can discharge at greater than the maximum continuous discharge current in short pulses, do not allow the individual cells to exceed the maximum allowable cell temperature. During pulse discharges, the string voltage can safely fall below the recommended discharge cut-off voltage. Although it is safe to temporarily discharge the string below the recommended discharge cut-off voltage, the cell will suffer a faster rate of permanent capacity loss over its service life when subjected to such repeated discharges.

⚠ DANGER

Under no conditions should the voltage of the cells be allowed to go under 0.5V. Under such conditions, it is unsafe to continue to operate the cell in its application.

Chapter 6

Basic Pack Design

This chapter includes the following sections:

- Overview
- Mechanical Connection and Protection
- Thermal Management

Overview

Battery Packs (also known as Energy Storage Systems (ESS) and battery modules) should be designed to protect and replicate the individual cell performance of multiple cells in the pack. This means providing mechanical protection and integrity, thermal stability, and electrical protection and performance.

Mechanical Connection and Protection

Design mechanical interconnects to prevent accidental short circuits. Size these mechanical interconnects to carry the expected maximum rated current for both the maximum time and ambient temperature in which the pack is expected to operate.

Cell Interconnects

Size cell interconnects for the expected maximum current carrying capability. Improperly sized tabs could heat up excessively, resulting in even higher resistivity. For reliable welded connections at the terminals, A123 Systems recommends either pure nickel tabs or nickel-clad copper tabs. In addition, other alloys afford both the weldability, strength and low resistance, which are all desirable features of a good interconnection. Cell interconnects (tabs) should be neither soldered on the end caps nor attached using extreme heat. A123 Systems recommends tabs be resistance or laser-welded to both ends of the cells. Resistance welding provides a constant current for a specified period of time through a salient feature in the weld tab. These parameters can be specified and regulated for a consistent high-quality weld every time.

Allowing the Cell to Vent in a Fault Condition

The cell vents, located on the end cap(s) of the cells (on the POSITIVE side of the cell), should not be blocked by any mechanical means. Blocking the cell vent and then sufficiently abusing the cell so as to build up pressure in the cell prevents the cell from properly venting. An ESS designed to install cells end-to-end needs at least 1 mm of space between the cells to allow the vent to open under fault conditions. Refer to Figure 7 as an example.

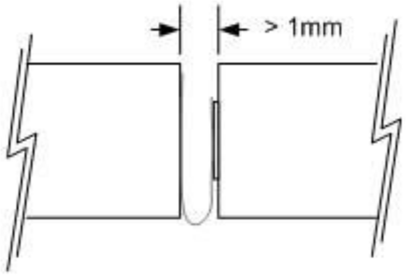


Figure 7 End-to-End Cell Spacing

Cell Insulation

The outside case of the 26650 and 32113 is electrically connected to the positive end (cathode) of the cell. Take care to keep this surface electrically-isolated from any electrical bus bar or mechanical support that may be of different voltage potential. Insulation, such as tapes, shrink wraps, or sleeves, must have at least a 150 °C melting point. This helps ensure that the cells do not short circuit to each other in a high temperature fault condition, which could cause even more widespread damage.

Cell Support

Secure the cells in place by supporting their outside cases, not their terminal ends. The vibration induced between the terminal ends and the rest of the case has been shown to be detrimental to the life of the cell, causing internal and external cell damage. The intercell terminations must be light enough not to cause vibration-induced damage to the cell.

Cell Protection

In addition to being supported, protect cells from exposure to corrosive substances and oxidizing catalysts, such as dust and moisture. The necessary level of protection for cells in a battery pack varies depending on the intended application. For example, a battery pack designed for use in an HEV must have an enclosure that isolates cells from shock and vibration, protects them from dirt and debris, as well as shielding them from other environmental dangers, such as salt spray. Unless it is hermetically sealed, even a sealed enclosure is subject to pressure differentials between its insides and the ambient, causing minute amounts of air exchange. Therefore, over time, some moisture may accumulate and condense on inside surfaces. An ESS designed to be sealed from the environment (from dust, moisture, and VOCs) must have a way to benignly drain off whatever condensate does manage to leak into it. In addition, enclosures protecting cells must work with the thermal management system to achieve optimum durability and safety of the battery pack. For example, a poor choice of materials for the enclosure, combined with insufficient cooling and controls, may cause the battery pack to overheat.

Thermal Management

A123 Systems’ cells operate throughout a wide temperature range; however, they are most effective between 10°C and 50°C. The temperature differential between the coolest cells and the hottest cells should be no more than 10°C. Careful attention to thermal management is necessary to keep the cells operating at peak efficiency and avoiding fault conditions. In most cases, this implies a cooling system. There are certain applications - such as HEV vehicles operating in cold climates - where a heater is beneficial to keeping the cells operating in their optimal range.

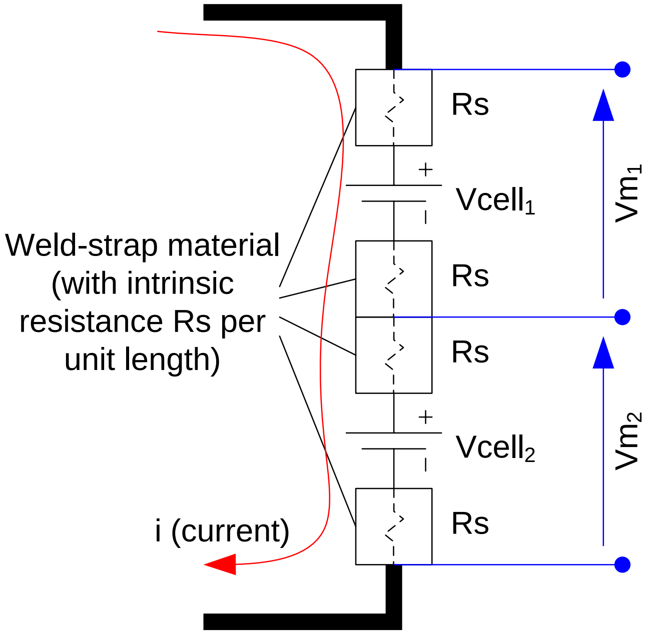
Electrical

When joining cells together, A123 recommends using a Battery Management System responsible for carefully monitoring cell voltage, current, and impedance. The BMS may be implemented as discrete circuitry or through a microcontroller.

Cell Monitoring

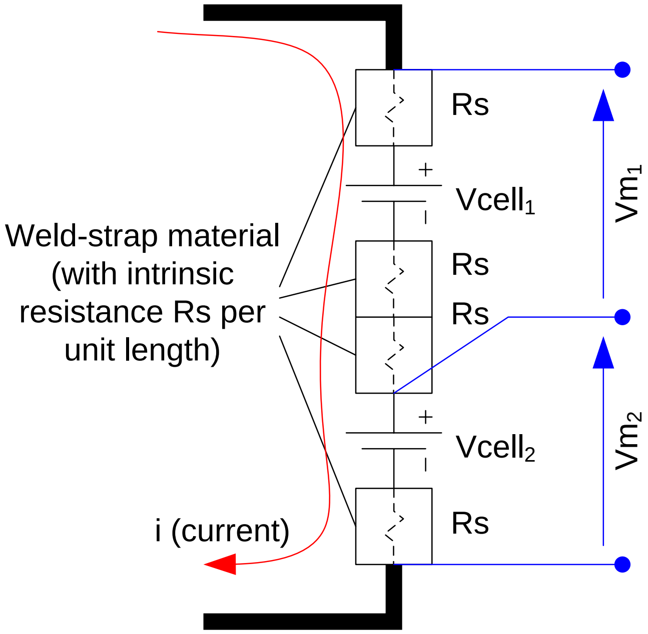
To ensure optimal performance, safety, and durability of the pack, the Battery Management System must monitor the voltage of each individual series cell in a battery string.Take care to place the voltage monitoring connections in such a place that they are not affected by high currents going through the interconnection elements.

The diagram below depicts an optimal positioning of the voltage monitoring contact points in an idealized setting:



In this case, Vm1 = Vcell1 – 2 x i x Rs and Vm2 = Vcell2 – 2 x i x Rs. The result of Vm1 – Vm2 would be exactly what is desired, and that being Vcell1 – Vcell2.

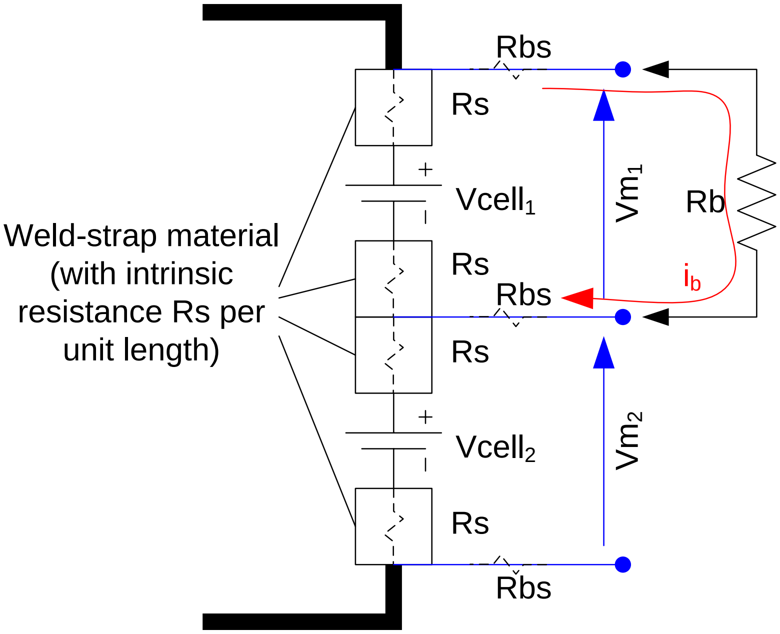
If the contact points are placed asymmetrically, such as shown below:



Vm1 = Vcell1 – **3** x i x Rs and Vm2 = Vcell2 – i x Rs. The result of Vm1 – Vm2 would contain an undesirable offset in it: Vcell1 – Vcell2 + i x Rs where Voffset = i x Rs.

This offset in the voltage readings would cause the BMS to read that there is more charge in one cell while the current is flowing in one direction, and have less charge in it while current is flowing in the opposite direction. So while the battery is discharging, the BMS would balance some of the cells, and while it is recharging, the BMS would balance the others. This results in a great deal of wasted heat and energy that contributes to a reduced performance and sevice lifetime of the battery. Ensure that balancing currents do not share the voltage sensing leads. Otherwise, the balancing currents will affect the voltage reading proportionally, increasing the time needed to achieve proper cell balancing, if not making it impossible.

The following circuit depicts a condition in which the measured voltages would be affect by balancing currents going through the sense leads:



In such a case, if Rb were connected to cell 1, Vm1 would read Vcell1 – ib x 2 x (Rbs + Rs). Having a separate wire for balancing current from the sensing wires eliminates a good portion of the error, as shown in the following diagram:

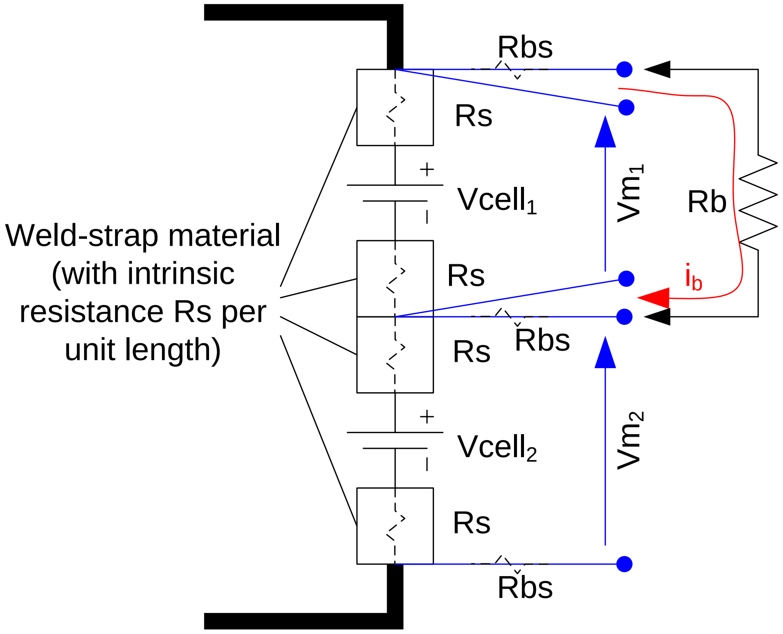


Figure 8 ESS Sample Block Diagram

In this case, Vm1 = Vcell1 – 2 x ib x Rs. If Rs is small, then Vm1 will substantially be the same as Vcell1.

Ideally, the temperature of every series element or cell would be monitored by the BMS; however, it is not as important as voltage, and is often impractical in cost-effective systems. A high-temperature condition is typically the result of monitored voltage and current conditions either being out of bounds or caused by an external thermal source. For such cases, monitoring a few representative places in a module or section of the ESS is adequate for proper ESS management and cell protection. Thermocouples can be placed on a representative worse-case cell's surface to monitor its temperature (that is, the hottest cell in the pack).

Supervising ESS Behavior

The circuitry that monitors the cells in an ESS should also be used to supervise the ESS environment and use, to preserve the safety and life of the ESS by protecting it from external fault conditions such as overcharge, overdischarge, overvoltage, undervoltage, overcurrent and undercurrent. Methods of supervising and controlling the battery pack include firmware based controls or special purpose integrated circuits. Regardless of how you choose to supervise the pack’s behavior, protection from fault conditions should be a top priority.

When monitoring cell behavior in the pack, histograms should be stored (e.g. saved in non-volatile EEPROM memory) that outline the condtions that the pack saw while in service. Suggested service histograms are as follows:

- Current and voltage Representative cell temperature
- State of Charge
- Energy Throughput

An example of the historgram data that might be stored is shown in the following table:

Temperature Range	**Duration (seconds)**
< -20 °C	0
-21 – 0 °C	10
1 – 10 °C	110
11 – 20 °C	450
21 – 30 °C	70457
31 – 40 °C	5042
41 – 50 °C	250
51 – 60 °C	60
61 – 70 °C	10
> 70 °C	0

Similar data sets would also be stored for state of charge, voltages, and currents.

Integrated Circuits

Integrated circuit cell monitors can work within the Battery Management System to offer complete, scalable design for use in packs of varying sizes. This solution requires an integrated circuit monitor connected to each series cell in a string reporting data measurements to a controller via an internal communication bus. Measurements taken on an individual cell level allows connection and measurement close to each individual cell, resulting in improved accuracy. Integrated circuit controllers offer active cell balancing technology, and are fully programmed from the factory – because the firmware is already embedded, no firmware development is required. In addition, the controllers are user-configurable to suit a variety of applications using a supplied graphical user interface.

For example, manufacturers such as TI offer Analog Front Ends (AFEs) that may be suitable for your application. AFEs integrate an I2C compatible interface to allow a BMS to monitor cell voltages and temperatures, enable cell balancing, enter different power modes, set current protection levels and blanking delay times. Certain TI AFEs provide safety protection for various fault conditions such as short circuits and cell overvoltage.

For more information on integrated circuit battery management systems and AFEs that may work in your application, contact Texas Instruments, Linear Technology, Analog Devices, Maxim, National Semiconductor, or O2-Micro. A123 Systems does not endorse or provide warranty for said companies.

Cell Balancing

Reasons for Cell Balancing

A123 Systems recommends cell balancing circuitry when more than one cell is put in series in a battery pack. This is important to achieve maximum life, reliability and safety. Charging or discharging an imbalanced series string of battery cells increases the spread between the highest and lowest cells' voltages. Spreads large enough result in the string delivering a noticeably smaller percentage of its energy content during full discharge cycles. This is because some of the cells are not being fully charged during recharge and the other cells are not being fully discharged during pack discharge. If the string is balanced, every cell can be charged to its maximum voltage during recharge, and every cell can be brought to its minimum allowable voltage during discharge. In this case every cell delivers its full energy to the load.

Each cell in every battery string will have different rates of self-discharge with respect to each other. Cell voltage divergence due to variations in cell construction, environment and aging requires some means of balancing. Three factors can cause series elements to diverge from each other over time:

- **Construction Variations** in the cell manufacturing process and operational conditions. Tolerances in the electrode material loading, active material make-up, and other factors can lead to how fast each cell will lose charge over time.
- **Environment Variations** in cell temperature across the series string can lead to different rates of self-discharge in each of the series elements.
- **Aging Variations** in cell performance can grow over time as each of the cells ages differently in response to its environment and physical construction.

⚠ CAUTION

If you do not include cell balancing in your pack design, you must monitor the voltages of each of the series cells to stop the charge when any one of them gets to the upper safe limit, as well as to stop discharging when any one of them gets to the lower voltage limit.

When to Balance Cells

To maximize deliverable energy from a series string, a balancer would ideally work full-time. This keeps the cells balanced no matter how fast they diverge or how fast the pack is cycling up or down. However, this is generally not practical because of the cost and complexity of the required power conversion. Also, the practical limitation of cell voltage sensing error on the flat part of the Open Circuit Voltage over State of Charge curve may serve to drive an imbalance. Depending on the application, some compromises can be made. For example, if the pack is intended for applications where the pack is fully recharged after each discharge, accurate cell balancing can be achieved when the pack is nearly-fully charged. When the pack is nearly full of charge, the State of Charge (SOC) of each cell can be accurately determined from their terminal voltages. On the other hand, if the pack is used in an HEV-type application, where it is rarely charged to its full SOC, the cell to cell voltage variation is more difficult to ascertain, because in the mid-SOC range, the voltage is very flat with respect to SOC. Balancing decisions must be made opportunistical under the following conditions:

- The pack current is under C/2
- The SOC is greater than 90% or less than 30% SOC (where the dV/dSOC is large)

Waiting for the current to be small eliminates errors due to resistive drops along the interconnecting bus bars and straps. Waiting for the SOC to be near the upper and lower limits reduces the error due to the very small dV/DOC that the A123 cells exhibit.

Short Circuit Protection

Because of the very low impedance of the A123 cells, a short circuit can cause excessive internal and external damage if not limited in either duration or current magnitude. Layered fusing in the pack interrupts excessive current at the cell or module level, helping to prevent the main fuse from blowing. Likewise, a fault at the module level will not cause the cell fuses to blow. This is considered best practice in the circuit protection field.

Individual Cell Fusing

You can achieve the circuit protection strategy described above by having the individual cell fuses operate at a higher fault current than that of the module. Likewise, design the module fuse to blow at a higher level than the main pack fuse. Refer to Figure 9 for an illustration of an individual cell fusing strategy.

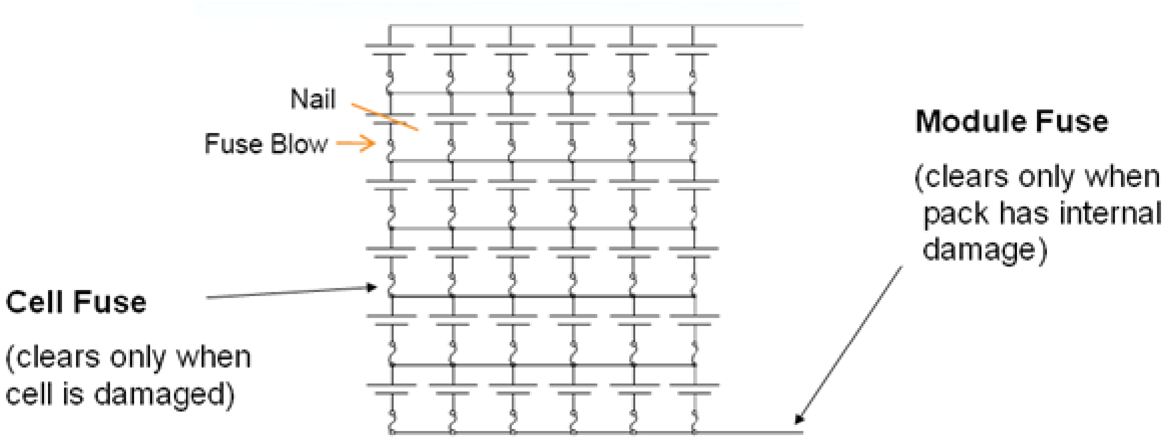


Figure 9 Individual Cell Fusing Strategy

Individual cell fusing can be accomplished by constricting the interconnecting metal material near the cell terminal.

⚠WARNING To prevent ignition of the hot vented gasses during a simulateous fusing and venting incident, place the fused tab on the opposite side of the outside casing where the vent is located. In the A123 26650 cells, the vent is located on the positive terminal.

In Figure 10, the 7 mil Nickel strap material is necked down to 3.6 mm, and clears at approximately 2100A in 0.1 sec. This and alternative designs should be verified using modeling software and bench testing prior to design release.

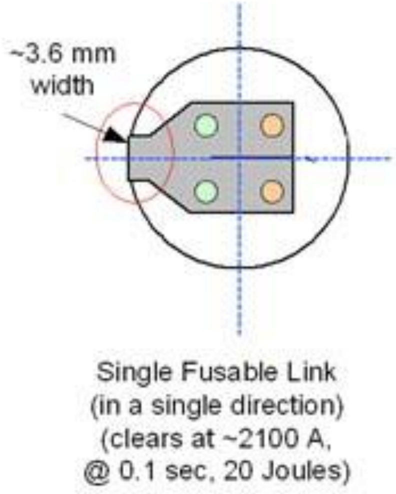


Figure 10 Individual Tab Fuse Example

Module Fuse Rating

Design the module fuse to blow at a lower current than that of the individual cell fuses. This ensures that the module blows before any of the cell fuses do in response to a fault on the module terminals. In addition, the module fuse must interrupt any short circuit path that may exist around multiple series modules situated between the main pack fuse and possible short circuit locations. Note in Figure 11, a short circuit involving four modules is possible with an internal fault.

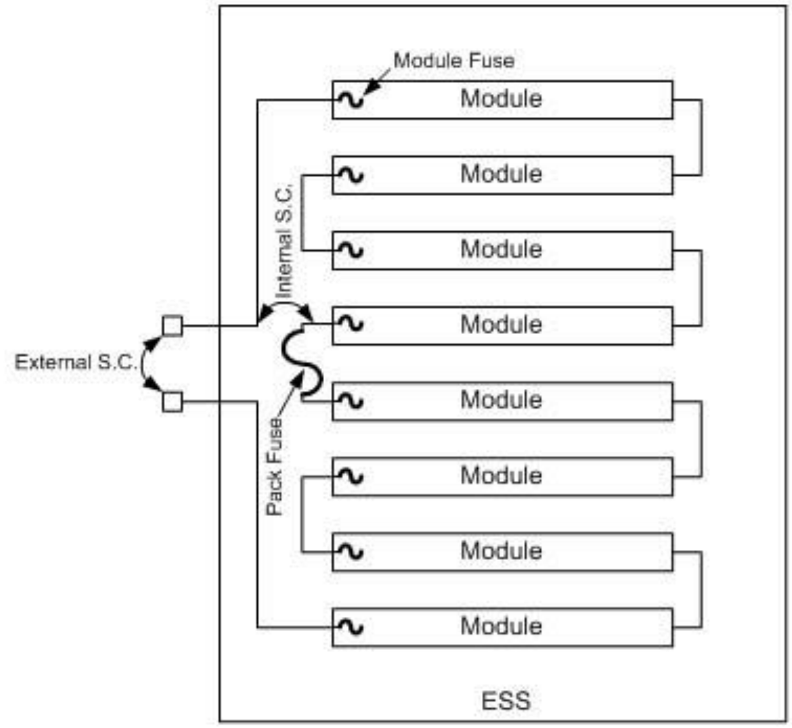


Figure 11 ESS with Representative Short Circuit Faults

Main Fuse Rating and Position

The main fuse needs to interrupt the full fault current of the ESS at its worst-case maximum terminal voltage. Size the main fuse so that it carries the system load current continuously at all rated temperatures. Specify the main fuse in the ESS to blow well before the module fuses. This ensures that if an external fault occurs, then only the main fuse is damaged., A main fuse is often more-easily replaced than the module fuses.

Fuse Coordination and Testing

Proper fuse coordination can ensure safe operation of the ESS, even in fault conditions. Once a prototype fusing strategy is in place, **perform the short circuit testing using a variety of cell temperatures and SOC's**, because these can affect the availability of current and the test results.

Overcharge Protection

Using individual series cell voltage monitoring, the BMS can employ a means to protect any cell from being overcharged. Some of these means include opening an input contactor, FET or other switch in series with the battery terminals, or by communicating to a smart external charger to adjust its output appropriately.

Because overvoltage is a sure way to ruin the cells, a best practice technique is to make sure there are redundant methods for monitoring and controlling the cell voltage. For example, if a microprocessor is involved in the decision-making process, employ an analog circuit to watchdog the processor or cell voltages. If an analog circuit is the only method to watch the circuit, use two for redundancy.

Fuel Gauging (Types, Methods)

Lithium ion batteries store a specific amount of charge at a characteristic voltage potential. The amount of storable charge is specified by its amp-hour (AH) rating. The chemistry of the electrode materials determines the amount of voltage potential that drives the charge out during discharge and must be overcome during recharge. A123 Systems' Nanophosphate chemistry produces about 3.3V on average during a discharge. This voltage is dependent on a number of factors, including current, history, age, temperature and SOC. Figure 12 shows the open circuit voltage (OCV) voltage compared to SOC at various temperatures of the 26650 cell.

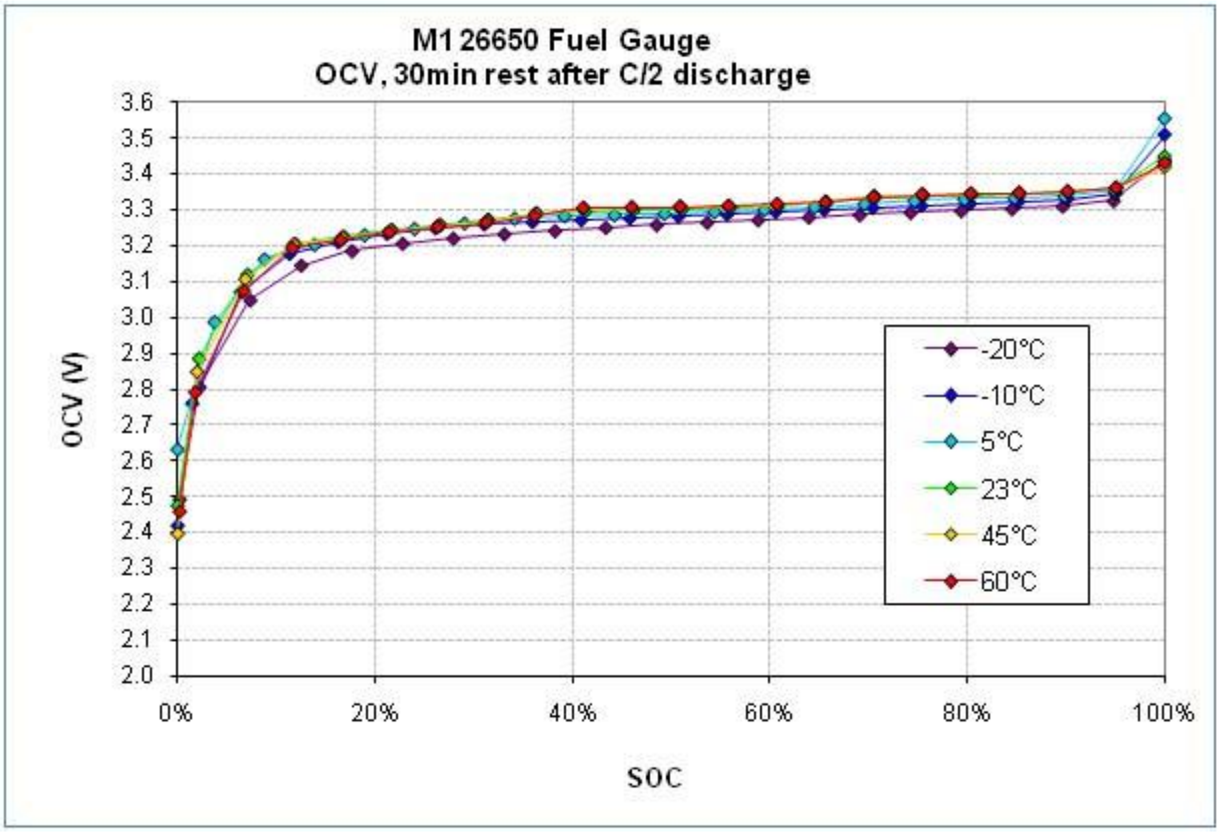


Figure 12 26650 Voltage vs. SOC at Various Temperatures

The middle portion of this plot is extremely flat, roughly equivalent to 1mV per 1% SOC. If a BMS were to rely on voltage alone for its SOC estimates, it would be required to have extremely accurate voltage sensing capability, on the order of 1mV resolution and accuracy per series cell.

There are a number of ways to estimate SOC. Due to an inherent amount of uncertainty in each method, you may need to combine the methods, and periodically reset SOC values, to maintain an accurate SOC measurement. In addition, different applications dictate the necessary level of accuracy, so there is no single ideal method that works for every application.

Voltage SOC (vSOC)

One method of determining SOC uses only voltage. The BMS takes a reading of the OCV and correlates it to the SOC using look-up tables based on the chart in Figure 12. The problem with this algorithm is that the voltage readings need to be extremely accurate for the A123 Systems battery technology. Also, the battery current affects the voltage reading proportional to the battery impedance, which depends on a number of factors such as temperature, age, and previous operational history. Figure 13 illustrates the possible range in SOC values resulting from uncertainty measuring OCV.

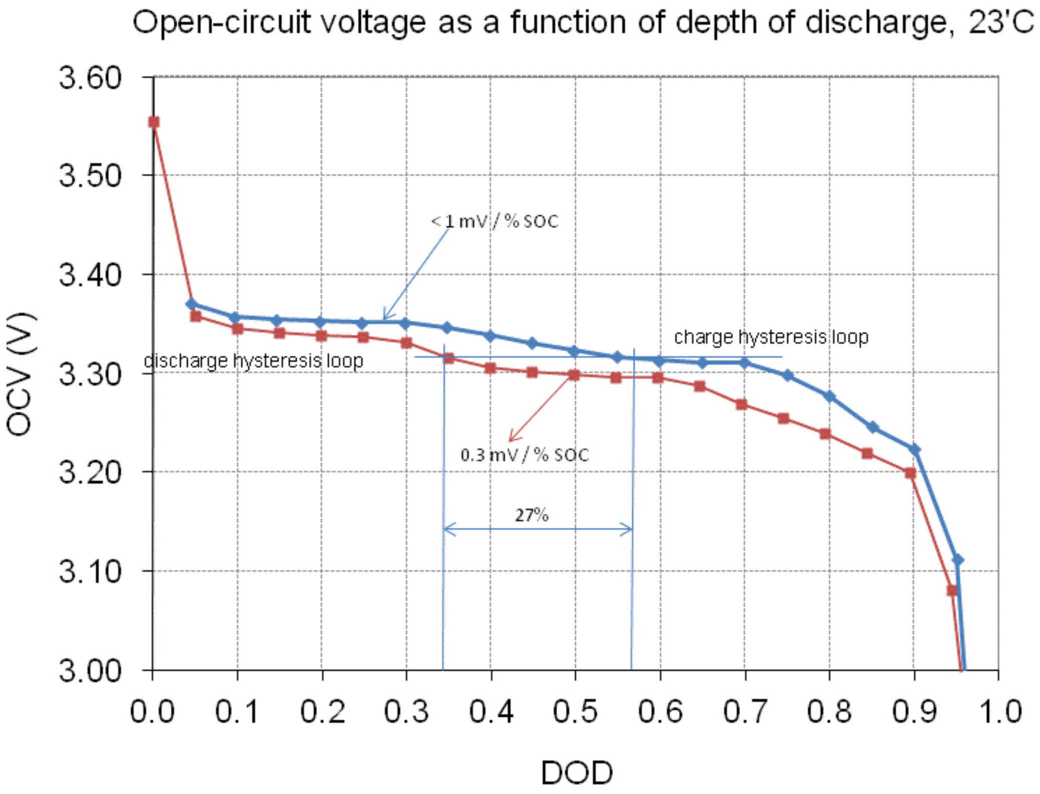


Figure 13 vSOC Sensitivity to OCV Error

For a single voltage of 3.32V, the OCV can represent either 66% SOC or 43% SOC depending on whether the cells were just discharged or charges (See the discussion about hysteresis below). Because some of the sections of the curve are very flat; < 1 mV per % SOC, even a small 1 mV error in the voltage reading can result in an error of several percent.

Coulomb Counting SOC (iSOC)

Another method uses only current and time. Based on a known starting SOC point, the BMS calculates the present SOC by integrating the measured current going into and out of the battery. This method is as accurate and resolved as the current and time measurements are. The problem with this algorithm is that the starting SOC is not always known. In addition, because the algorithm integrates the current signal, very small current levels, noise, inaccuracy and small offsets can gradually increase the error over time.

Combination of vSOC and iSOC

The problems with both vSOC and iSOC can be somewhat mitigated by using a combination of the two algorithms. For example, you can determine the starting SOC point in the iSOC algorithm by taking an OCV reading before discharge/recharge activity starts, and correlate it to an SOC. While the current is strong, the algorithm places a heavy emphasis on the iSOC algorithm. When the current tapers off or settles into a low current idle mode, the vSOC algorithm can take over and keep track of the SOC. Lastly, when the estimated OCV voltage nears the upper or lower range of the cell's voltage range, the vSOC can be used to estimate SOC. The estimated OCV is based on the actual termination voltage minus the current times the estimated battery impedance. The impedance is calculated based on the last known SOC the measured temperature.

Hysteresis

It is appropriate to mention Hysteresis at this point. There are two OCV vs SOC curves that the battery exhibits depending on whether it just delivered a discharge or received a charge. For any given battery SOC, an open circuit reading taken after the current goes INTO the battery will result in one voltage, while an open circuit reading taken after current is taken OUT of the battery will result in another. The difference between these two voltages varies over SOC and even temperature. Figure 14 shows this hysteresis at 23 °C.

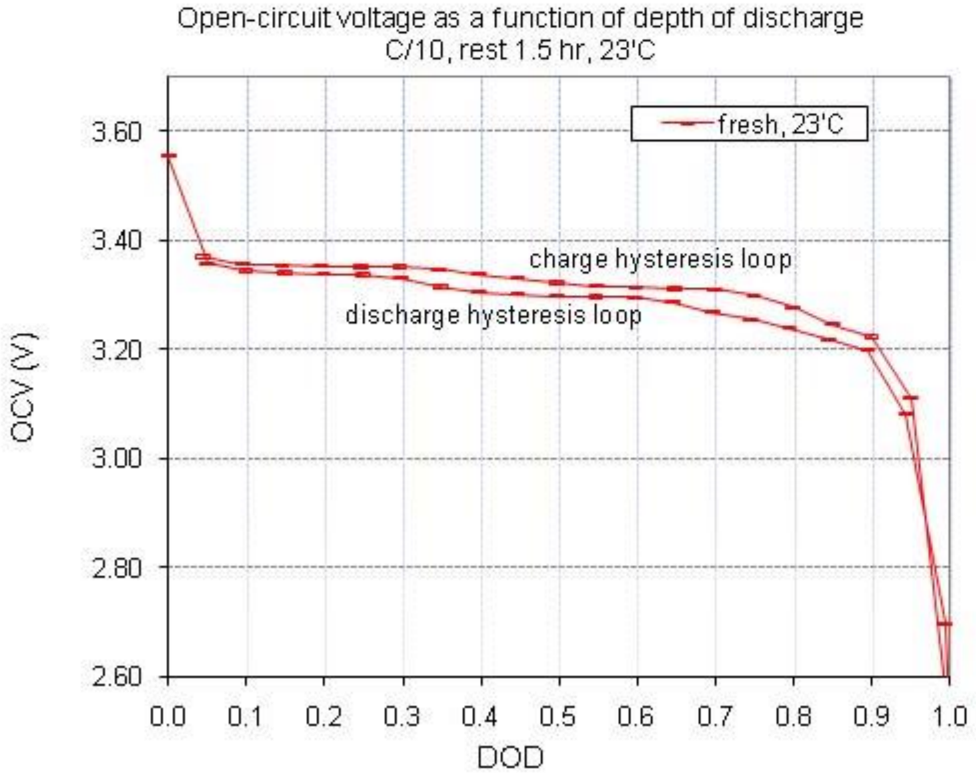


Figure 14 Charge and Discharge Hysteresis

Just as there is some uncertainty in measuring OCV when determining vSOC, there is a range of uncertainty in determining charge hysteresis when the ESS wakes or is reset. This uncertainty also impacts vSOC values, as illustrated in Figure 15.

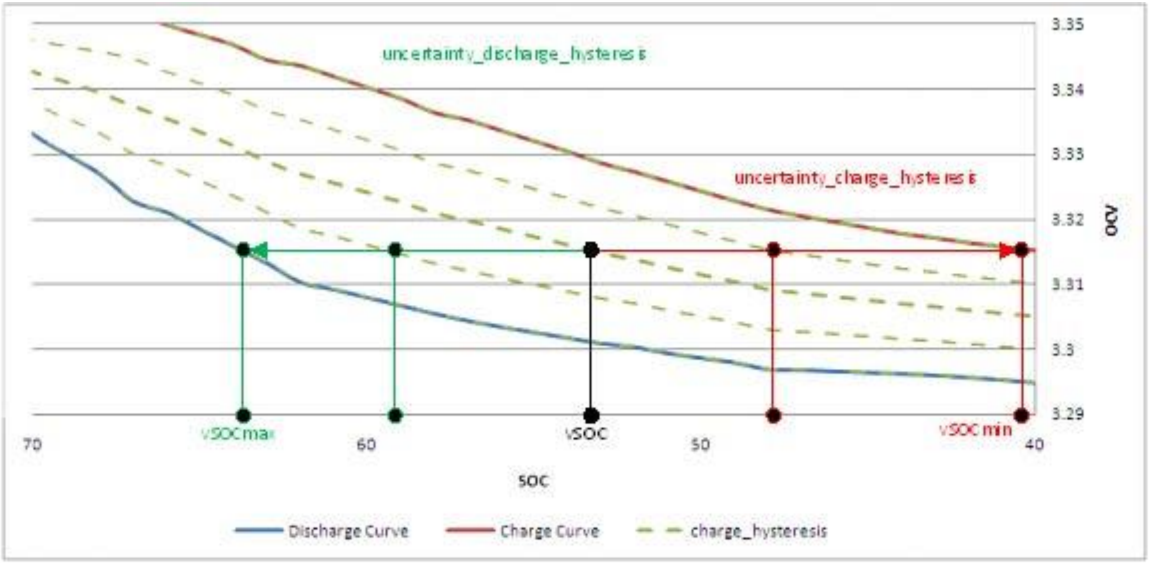


Figure 15 vSOC Sensitivity to Charge Hysteresis Error

Accuracy in determining charge hysteresis improves as the ESS is charged and discharged.

Chapter 7

Summary of ESS Testing

This chapter includes the following sections:

Overview

To ensure safe operating performance of an ESS using A123 Systems' cells, design the ESS to a minimum set of design standards that can pass a minimum set of design validation tests. This chapter summarizes the minimal testing recommended to be performed on an ESS, the performance criteria it must pass, and a set of design guidelines to follow while designing the product.

Performance Testing

ESS performance testing validates that the ESS performs basic application functionality in the application's intended environment. These tests include discharge, recharge, cycling, open circuit, thermal, and environmental testing. Applications for each ESS can vary significantly, so the key to these tests is to frame the test conditions around the expected application's conditions.

Table 2 Performance Tests

Name	Description
CC	Constant Current Discharge – Test Capacity of ESS using various constant current loads
PP	Peak Power Discharge – Test Power Capability of ESS using 2/3 OCV. I.e. determine at what power levels, the battery voltage falls to 2/3 of the starting OCV.
Application Specific Cycle Tests	Cycle the ESS using the application's expected cycle profiles. There are two application cycle testing goals. One is to measure short-term ESS performance and the other is to measure long-term performance over time. The latter takes into account the degradation of the battery over time with respect to the amount of usage the battery experiences.
Stand Test	Test Self-Discharge of ESS while off.
Thermal	Test temperature rise of cells over ambient temperature during worse-case load conditions. Test Temperature gradient from coolest to hottest cell during worse-case load conditions.
Vibration	Apply vibration in three axes to simulate a life-time of physical movement and test electro-mechanical integrity of the product throughout.

Abuse Testing

Abuse testing verifies reactions to harsh and out-of-specification conditions under which the product may be exposed. The results of these tests do not necessarily have to show that the product survives and functions after such tests. However, it is expected that a result of the abuse test show that the product will cause little or no damage to personnel and objects near them. Abuse testing is not intended to acknowledge or validate the design outside of proper operating conditions, even if the test units perform with a safe or acceptable reaction.

Table 3 Abuse Tests

Name	Description
Short Circuit	Test the ability of the ESS limit the output energy in the case of an accidental short circuit on its terminals. This testing also includes short circuiting individual elements within the ESS, such as modules, groups of modules, cells and cell groups.
Overcharge	Test the ability of the ESS to prevent any one of its cells from being overcharged as a result of excessive voltage being applied to the terminals of the ESS
Crush	Understand what happens when the ESS is crushed in a calibrated manner.
Drop	Observe the effects of the ESS being dropped from a specified height.
Shock	Observe the effects of the ESS being subjected to a large shock in three axes.
Immersion	Test the ability of the ESS to seal out liquid water when completely immersed.

Compliance Testing

Compliance or confomance testing verifies whether a product meets a set of defined standards dependent on the product application. The ESS needs to meet standards in areas such as safety, environmental, and electromagnetic compliance. This guide cannot cover all possible applications and uses for A123 Systems’ cells. Therefore, you must test your pack design based on the compliance standards appropriate for your intended application.

Chapter 8

Pack Manufacturing

This chapter includes the following sections:

Overview

This chapter discusses inspecting cells prior to assembling into packs and guidelines for creating weld schedules for A123 cells.

Cell Incoming Inspection

Cells are checked for excessive self-discharge at the factory before they are released for sale and shipment. A123 Systems still recommends inspecting cells before assembling them into packs. Cells are shipped at approximately 50% SOC, with a nominal voltage of 3.3V.

Material Handling and Storage

General

Minimize handling of cells to avoid damaging them. Reject any cell dropped from a height of more than 1200 mm. If a cell is dropped from a height of less than 1200 mm, carefully inspect the components for damage and then retest the OCV and alternating current resistance (ACR). Reject any cells where damage exceeds acceptable limits or either OCV or ACR are not within specified limits. Discard any cells that have been subjected to even a brief external short circuit. Do not damage the cells in any way that would make them unfit for your intended use. Any changes in handling, storage or inspection methods must be approved in writing by A123 Systems prior to implementation.

Ambient Conditions

Store and process cells in an environment of 15°C to 35°C and less than 75% relative humidity. Keep the cells under cover and protected from the elements at all times.

Cell Welding

Mechanical Cell Interconnects

⚠WARNING Cell interconnects (tabs) should NOT be soldered on the end caps or attached using extreme heat.

A123 Systems recommends resistance or laser welding tabs to both ends of the cell. Because it is impossible to cover every possible weld schedule, A123 Systems recommends meeting with welding consultants to discuss weld schedules optimized to your specific application. Welding consultants that may be able to assist include:

- http://www.welding-consultant.com
- http://www.ccl.fraunhofer.org/

Welders

You may find these welders useful for your needs:

- Unitek IPB5000A inverter welding control and an ITB-780A6 transformer, coupled with the 88A/EZ weld head.
- Miyachi MDB-4000B welder coupled with the 88A/EZ weld head
- Miyachi IS-120B inverter welding control and an IT-1040-3 transformer, coupled with the 88A/EZ weld head (transformer requires water cooling).

NOTICE The welding consultants and welders are referenced above for your convenience only. A123 Systems does not endorse or recommend any particular welder or consultant

Appendix A

Cell Specifications

This design guide covers A123 Systems’ **ANR26650*m1*B**, **APR18650*m1*A***,* and **AHR32113*m1*** cylindrical cells with the specifications outlined in this section.

Handling/Transportation: Do not open, dissemble, crush or burn cell. Do not expose cell to temperatures outside the range of -40°C to 60°C. Refer to Chapter 3 for more information.

Storage: Store cell in a dry location. To minimize any adverse affects on battery performance it is recommended that the cells be kept at room temperature (25°C +/- 5°C). Elevated temperatures can result in shortened cell life.

ANR26650M1B

Refer to the table below for specifications for the ANR26650**M1B** for a cell drawing. Note that actual performance of the cells may vary depending on use conditions and application.

Table 4 ANR26650M1B cell specifications

ANR26650M1B	
Nominal Voltage	3.3V
Nominal Capacity	2.5Ah
Maximum discharge current - continuous (A)	70A, with the caveat that the cells do NOT exceed their maximum operating temperature (+60°C)
Pulse discharge at 10 sec	120A
Peak power @ 10 s (watts)	210W
Recommended standard charge	1.5C to 3.6 V
Recommended fast charge	4C to 3.5V
Recommended float charge voltage	3.5V
Recommended end of discharge cutoff	2.0V
Operating Temp Range	-30°C to +60°C
Storage temperature range	-40°C to +60°C
Weight	75 grams
Nanophosphate® Chemistry	M1b
Current Interrupt Device (CID)	No

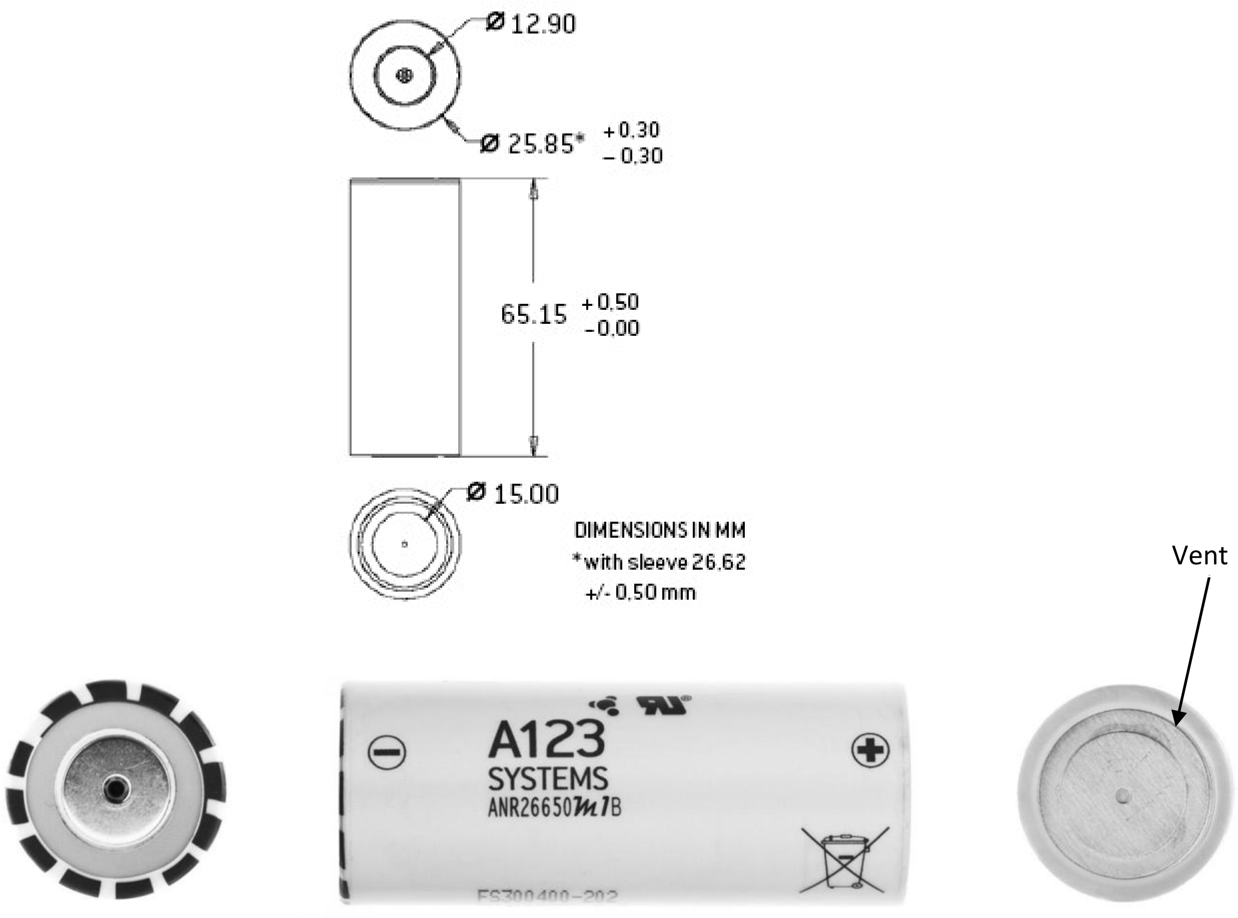


Figure 16 ANR26650m1B

APR18650m1A

Refer to the table below for specifications for the ANR18650m1A and for a cell drawing. Note that actual performance of the cells may vary depending on use conditions and application.

Table 5 APR18650m1A Cell Specifications

Cell Model Number	APR18650m1A
Nominal Voltage	3.3V
Nominal Capacity	1.1 Ah
Maximum discharge current - continuous (A)	30A
Pulse discharge at 10 sec	60A
Peak power (watts)	92W
Internal Impedance (1kHz AC)	18 mΩ typical
Internal Resistance (10A, 1s DC)	27 mΩ typical
Recommended standard charge	1.5C to 3.6V
Recommended fast charge	4C to 3.5V
Recommended float charge voltage	3.5V
Recommended end of discharge cutoff	1.6V
Operating Temp Range	-30°C to +60°C
Storage temperature range	-40°C to +60°C
Weight	39 grams
Nanophosphate® Chemistry	m1A
Current Interrupt Device (CID)	Yes

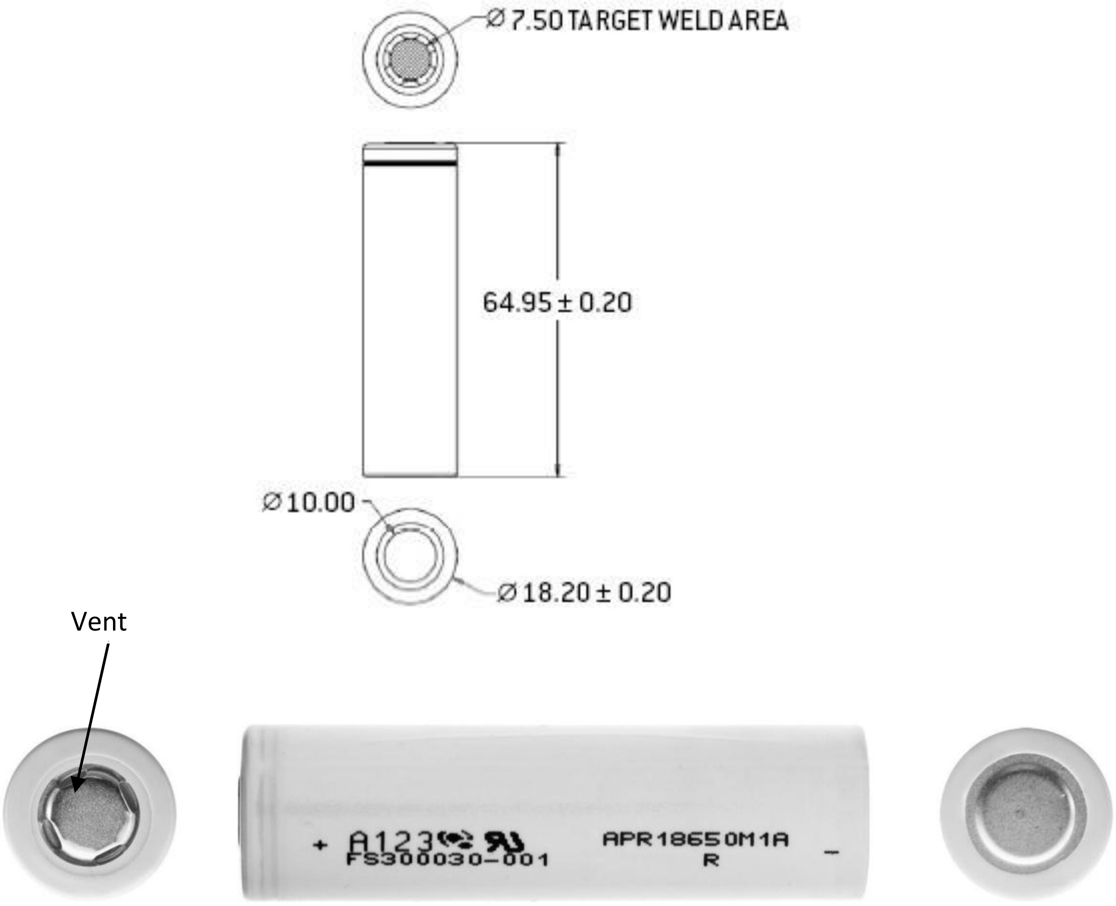


Figure 17 APR18650M1A

AHR32113m1

Refer to the table below for specifications for the AHR32113m1 and the following graphic for a cell drawing. Note that actual performance of the cells may vary depending on use conditions and application.

Table 6 AHR32113m1 Ultra-B Cell Specifications

Cell Model Number	**AHR32113m1**
Nominal Voltage	3.3V
Nominal Capacity	4.5 Ah
Maximum discharge current - continuous (A)	200
Pulse discharge at 10 sec @25’C (A)	300
Peak power @ 10 sec (watts)	550W
Recommended standard charge	1.5C to 3.6V
Recommended fast charge	4C to 3.5V
Recommended float charge voltage	3.5V
Recommended end of discharge cutoff	1.6V
Operating Temp Range	-30°C to +60°C
Storage temperature range	-40°C to +60°C
Weight	205 grams
Nanophosphate® Chemistry	**m1 Ultra -B**

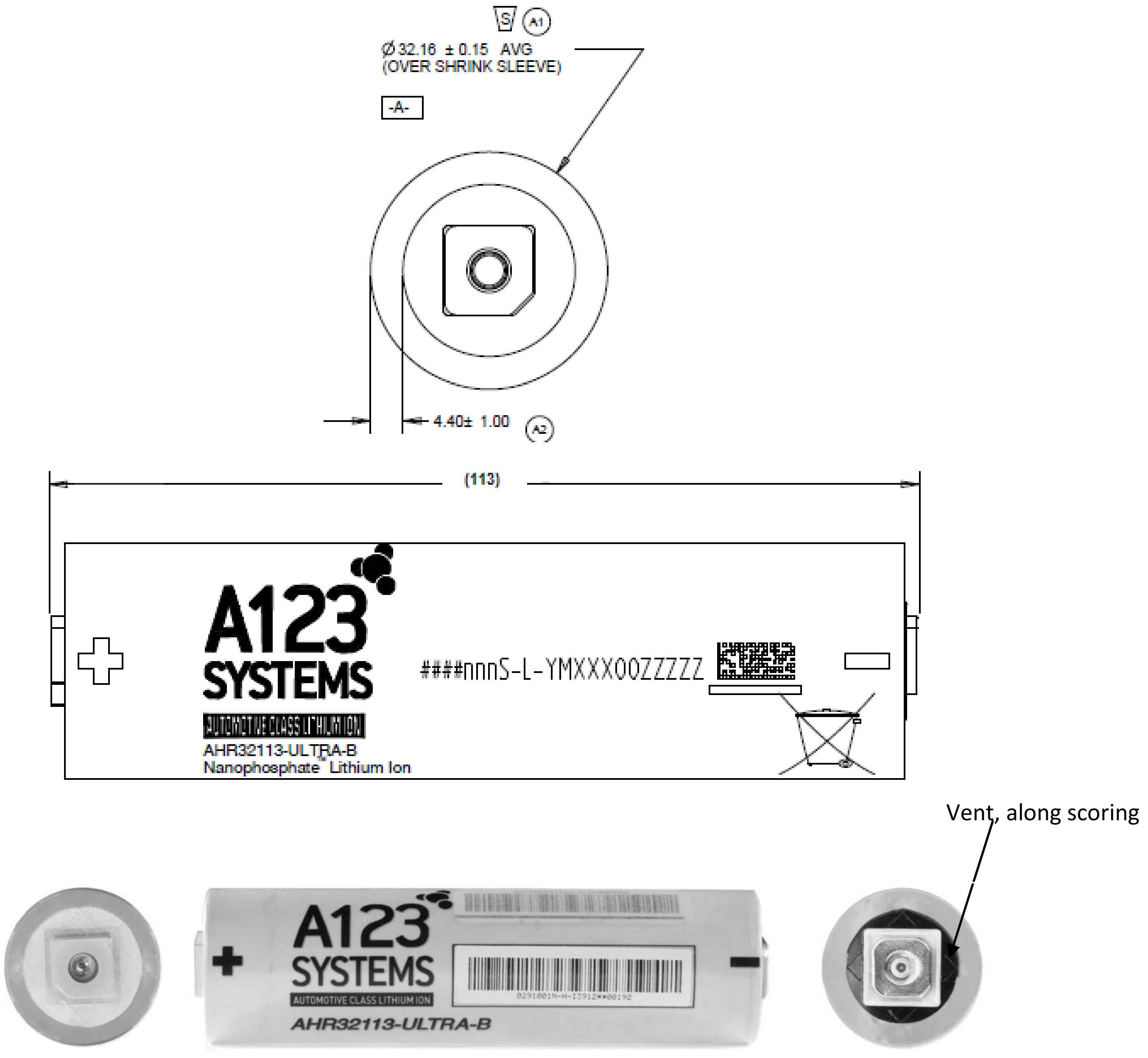


Figure 18 AHR32113m1

Appendix B

Glossary

This appendix describes the terminology used in this document.

Terminology Table

The following table describes the terminology used in this document.

Table 7 Terminology

Term/Acronym	Meaning
ACR	Alternating Current Resistance. Usually refers to the resistance of a cell for very short pulses of current (< 1 second)
AH	Amp-Hour is a unit of measure of charge that can be stored or delivered to/from a battery.
Battery	One or more cells which are electrically connected together by permanent means, including case, terminals and markings.
BMS	Battery Management System – The Battery Management System refers to the collection of electronics responsible for monitoring and controlling the ESS.
CC	Constant Current – A method to charge or discharge a battery in which the current is held constant independent of the battery's terminal voltage.

Term/Acronym	Meaning
Cell	A single encased electrochemical unit (one positive and one negative electrode) which exhibits a voltage differential across two terminals.
CID	Current Interrupt Device – A small device integrated into a cell designed to interrupt the flow of current through its terminal when too much pressure or current exists in the cell.
Competent Authority Approval	An approval by the competent authority that is required under an international standard.
CV	Constant Voltage – A method to charge a battery in which the terminal voltage is held constant and the current is determined by the power path impedance or some active current limiting.
ESS	Energy Storage System
iSOC	Current-based SOC algorithm
OCV	Open Circuit Voltage – voltage reading of a battery when there is no current going in or out of it.
vSOC	Voltage based SOC algorithm

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Battery Pack Design Safety Guidelines (DRAFT)

While we believe the A123Systems' Nanophosphate™ cells are the safest lithium ion cells on the market, there remain ways, including improper use or abuse, to make our cells fail, which can lead to potential safety hazards to the end user. Packs must therefore be designed in accordance with the customary parameters of battery pack design to avoid a safety incident:

Guidelines for safe cell protection and battery design:

- Pack must have dual, redundant over-voltage protection, with at least protection by hardware and one via software.
- The voltage of every single series element must be measured and monitored.
- In multi-cell batteries, use cell balancing and/or individual cell voltage controls to equalize the state of charge (voltage at full charge) of cells in series. Doing this will also maximize the life of the system.
- Cells discharged below 0.50V will be damaged and must be removed and properly disposed.
- Recommended and Absolute ANR 26650 Cell Limitations:

	Recommended	**Absolute**
Maximum cell voltage	3.85 volts	4.20 volts
Minimum cell voltage	1.60 volts	0.50 volts
Maximum continuous recharge current		10 amps
Maximum continuous discharge current		70 amps
Maximum 10 second pulse recharge (at Room Temperature)		10 C rate
Maximum 10 second pulse discharge		120 amps
Maximum temperature difference between cells in a pack	< 5°C	8°C

- Maximum charge and discharge current ratings are at STP (standard temperature and pressure); at different temperatures, especially lower temperatures, maximum current rates will be lower.

- Cells must not be subject to reverse polarity or short circuited. Fuses or some other protection must be incorporated in pack designs with batteries in parallel to avoid all the energy in one string being dumped to the neighboring batteries in the event of a hard short cell failure.

- Cells must not be charged or discharged outside the operating temperature range in the datasheet, and reduced charging limits must be followed for lower operating temperatures.

- Cells must not be exposed to heat in excess of 60°C during operation, 70°C in storage; or incinerated, stored or used near open flames.

- Cells must not be punctured, ruptured, dented or crushed; and the pack design must ensure this under normal operations or in a crash.

- Cell packaging must not be altered in any way, and cells must not be immersed or exposed to water or liquids

- Tabs should be resistance or laser welded to cells to avoid excessive heat. When leads are soldered to the cells, the cell casing must not exceed 150°C for more than 10 seconds.

- Never use a clamping force at the top and bottom of the cell or hold cells together, end to end, in a way that restricts the cell rupture vents at the ends of the cells. If the vents are blocked, the gas can't exit the cell in case of cell failure.

- **Overall: Cell specifications in the datasheets must be followed. Cells must be balanced during recharge for long life and safety, and individually monitored and protected from exceeding specified operating parameters. Battery packs must be designed and confirmed via testing to provide sufficient mechanical, thermal and electrical protection to keep each individual cell within proper operating limits. Do not ship product before thoroughly testing a pack design.**

In automotive or EV solutions we recommend that your pack abides by these general guidelines and makes use of the following components:

- All high voltage components, including wires, cables, connectors, and batteries with a potential greater than 54 volts must be colored orange.

- Crash sensor signal to disconnect the battery pack from the vehicle.

- Reliable and validated mechanical design that meets SAE J2464 & J2380 standards.

- National Highway Traffic Safety Administration, DOT, Part 571 – Federal Motor Vehicle Safety Standards, Standard No. 305; Electric-powered vehicles:

electrolyte spillage and electrical shock protection, and other FMVSS standard(s) that govern PHEV or crash testing

- Appropriate mechanical vibration tests to ensure the pack will meet the applicable environmental requirements.
- Mechanical mounting should prevent mechanical stressing of seals and joints on the cell. Mechanical design should also prevent deformation of the cell under all conditions.
- System components should be compatible with cell electrolyte solvent, in case a cell is vented and the electrolyte leaks.
- Battery cases and mounting hardware should be protected or made of appropriately rated dielectric material to prevent accidental shorting to chassis.
- All high voltage connections should be robustly isolated and protected from contacting adjacent components to prevent shorting during severe mechanical abuse (crash, crush, impacts, etc).
- Battery systems should be designed that it should be impossible to drop a tool into the pack and cause a short circuit. No high voltage should be accessible with an average finger.
- Batteries and battery packs should be fused. One fuse should be located in the center of the battery system to break the load at the center of the pack.
- Battery packs should use contactors capable of breaking full current loads on both the positive and negative poles of the battery pack. These contactors should be normally open contactors such that if supply power is stopped, they will open.
- Battery packs should include a HVIL (High Voltage Inter Lock) that supplies power to the main contactors. This loop should also run through switches that ensure that the housing is closed, the crash sensor (if included) is closed, and the high voltage power connector, low voltage communications connector, and other key interfaces are in place. In the event that any one of these opens, the contactors will open.
- Current conductors and connections should be of sufficiently low impedance to prevent localized heating of surfaces and components.
- A battery pack should be equipped with a battery management system to operate the pack properly and to shut down the pack in case of internal or external abusive conditions. The battery management system should provide the following:
  - Minimum and maximum voltage limits should be included in the algorithms to prevent abuse from overcharge and overdischarge.

  - Temperature sensors should monitor system and cell temperatures throughout the system for both safety and algorithm purposes.
  - The battery management system must be able to monitor each series element voltage.

- Temperature can act as a redundant check against overcharge, short circuit, and over discharge conditions that are not reported due to an error in voltage measurement. Both Tmax and dT/dt limits should be considered to prevent abuse of the cells.

- Monitoring the SOC of the cells is necessary to ensure a long life battery, but also should act as a secondary detection of overcharge and overdischarge conditions. Max SOC and min SOC limits should be set in the algorithm to prevent abuse.

- State of Health software algorithms should be implemented to detect weakening cells during operation. Examples of this are a cell being the highest voltage cell on charge and the lowest voltage cell on subsequent discharge. This is an indication that the cell is becoming resistive and should trigger a service condition.

- The customer further acknowledges that the following potential consequences may occur if the cells are subjected to misuse or abuse:
  - Cell may vent and will become inoperable
  - Cell life will be degraded
  - Cell performance to datasheet specifications will be degraded
  - Cell may cause burns due to excessive heating

A123 is providing this information based on its current knowledge of best practices in battery pack design in order to raise your awareness on appropriate cell use so that immediate corrective action can be taken if your firm is employing a pack design that can potentially cause safety problems.

A123 shall have no liability with respect to its products or any failure of its products to perform in accordance with their specifications or in accordance with any applicable warranty if such performance or failure results, either in whole or in part, from any use that is inconsistent with the above recommended Guidelines or any changes or modifications to the products that are not made by A123 or authorized in writing by A123. In such event, you will be solely responsible for the consequences of any noncompliance. In addition, A123 makes no warranties, either express or implied, regarding the contents of this letter or the completeness or accuracy of the guidelines and best practices described herein, which is provided for informational purposes only.

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April 24, 2012

A123 Systems ALM 12V7 User's Guide

End User Documentation

DOCUMENT NOTICE: The information contained in this manual is the property of A123 Systems, Inc ("A123 Systems") and is subject to change without notice. A123 Systems reserves the right to make changes in the design of its products or components as progress in engineering and manufacturing may warrant. It is the customer's responsibility to satisfy itself as to whether the information contained herein is adequate and sufficient for a user's particular use. It is the further responsibility of each user to ensure that all applications of A123 Systems' products are appropriate and safe based on conditions anticipated or encountered during use. This document does not create any additional obligation for A123 Systems and does not constitute additional warranties and representations.

Questions: Please call A123 Systems Customer Service at 855 A123 ESG (855 212 3374).

Revision Control

This section describes the changes made to each revision of this document.

Revision	Change
Rev 06	In Chapter 5, corrected mislabeled diagram and discharge current value.
Rev 05	Updated images depicting series and parallel configurations in chapter 5. Replaced all cell name references with the cell short name (ANR26650).
Rev 04	Updated ALM 12V7 photo to correct labeling information depicted
Rev 03	Updated float voltage 20 13.8 V and added 13.8 V minimum recharge voltage
Rev 02	Updated Design Release
Rev 01	Initial Design Release

Table of Contents

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A123 Nanophosphate® Technology inside the ALM 12V7

Applications

Configuration and Operation

Troubleshooting

Appendix A

Chapter 1

About this Document

This chapter includes the following sections:

- Overview on page 1-1
- Purpose of this document on page 1-1
- How this document is organized on page 1-2

Overview

A123’s ALM 12V7 Lithium Ion battery module (UL model number Series PSL000001) is designed as a drop-in replacement for the 12 volt 7 Ah lead-acid batteries that typically serve as a standby power source in many high-availability and service-critical applications. The Series PSL000001 is recognized as a standalone battery only. To ensure a seamless replacement process, the ALM 12V7 features identical dimensions to 12V7 lead-acid batteries, uses the same 0.250” faston terminal tabs and works with typical lead-acid chargers.

The ALM 12V7 battery pack consists of eight ANR26650 cells in a 4S2P configuration with integrated cell protection and balancing circuitry. The ALM 12V7 includes a user-replaceable 30 A fuse as well as a non-replaceable 120 A fuse. Furthermore, an integrated microprocessor protects the battery pack from over-voltage, under-voltage and over-temperature conditions.

Purpose of this document

This manual provides detailed specifications for the ALM 12V7 as well as guidance on the safe and effective operation and configuration of multiple ALM 12V7 modules for use as building blocks in various applications. This manual provides information to safely connect multiple modules up to a maximum configuration of four modules in series and 10 modules in parallel (4S10P), as well as how to charge and discharge the batteries.

How this document is organized

This document is divided into the following parts:

- Regulations

  Discusses the safety, EMC, environmental and transportation regulations applicable to the ALM 12V7 battery module.

- A123 Nanophosphate® Technology inside the ALM 12V7

  Discusses the Lithium Ion technology inside the ALM 12V7 and its advantages compared to traditional lead-acid batteries.

- Applications

  Discusses various applications for the ALM 12V7.

- Configuration and Operation

  Discusses how to safely connect multiple ALM 12V7s up to a maximum configuration of four modules in series and 10 in parallel. This chapter also provides details for charging and discharging multiple ALM 12V7s.

- Troubleshooting

  Discusses behavior unique to the ALM 12V7 compared to traditional lead-acid batteries, and how to operate the battery in those circumstances.

- Glossary

  Glossary of terms.

Chapter 2

Regulations

The chapter discusses the safety, EMC, environmental and transportation regulations applicable to the ALM 12V7 battery module.

The transportation material presented here is not all-inclusive of the regulations required to ship a product, but is meant to inform you of the complexity involved in doing so. Anyone involved in the integration of Lithium Ion battery packs into a host product must review the regulations cited here to meet compliance standards with industry regulations.

This chapter includes the following sections:

Safety Regulations

- UL subject 1973 - Batteries for use in Light Electric Rail (LER) Applications and Stationary Applications.
- CE — EU consumer safety, health and environmental regulations. Signifies conformity with EMC directive (2004/108/EC)
- FCC Part 15 Subpart B Class A — standards regulating unintentional emissions of radio frequencies from a digital device.
- UN 38.3 — requirements for safe transportation of Lithium Ion batteries.

Transporting Lithium Ion Batteries

This section discusses the regulations governing the transportation of Lithium Ion cells and batteries both within the United States and internationally. You should read and understand all relevant regulations discussed in this section before shipping ALM 12V7 modules. This section includes the following sections:

- Overview on page 2-2
- Regulations by Cell/Battery Size on page 2-3
- Following UN and DOT Regulations on page 2-4

NOTE

The regulations discussed in this manual apply to Lithium Ion cells and batteries. Once the ALM 12V7 is integrated into a host product, the host product may be subject to additional transportation regulations that require additional certification testing. Since A123 Systems can't anticipate every possible configuration and application of the ALM 12V7, you must verify that your ALM 12V7-powered host product is compliant with all applicable regulations. Refer to Table 2-3 on page 2-4 for a list of UN numbers to reference to find applicable regulations for your application.

Overview

Rechargeable lithium ion (including lithium ion polymer) cells and batteries are considered dangerous goods. The regulations that govern their transport are based on the UN Recommendations on the Transport of Dangerous Goods Model Regulations. Transport of dangerous goods is regulated internationally by

- International Civil Aviation Organization (ICAO) Technical Instructions, and
- International Air Transport Association (IATA) Dangerous Goods Regulations and
- International Maritime Dangerous Goods (IMDG) Code.

In the United States, transportation is regulated by Title (part) 49 of the Code of Federal Regulations or CFR's. Title 49 CFR Sections 100-185 of the U.S. Hazardous Materials Regulations (HMR) contains the requirements for transporting cells and batteries. Refer to the following sections within 49 CFR for specific information.

- Section 173.185 - Shipping requirements for Lithium cells and batteries
- Section 172.102 - Special Provisions
- Sections 172.101, 178 - Further information and specifications on packaging

The Office of Hazardous Materials Safety Administration (PHMSA), which is within the U.S. Department of Transportation (DOT), is responsible for drafting and writing the U.S. regulations that govern the transportation of hazardous materials (also known as dangerous goods) by air, rail, highway and water.

Regulations by Cell/Battery Size

Lithium ion batteries and cells are considered Class 9 which is one of nine classes of hazardous materials or dangerous goods defined in the UN, US and other regulations. As a class 9 material, cells and batteries must meet UN testing and packaging requirements as well as shipping regulations. The chart below provides a synopsis of the regulations now in effect for both the US and Internationally.

Table 2-1 Shipping and Packaging Regulations by Cell/Battery Size

Regulation	Lithium Ion Cell/Battery	Shipping Classification/Testing	Special Packaging/ Markings	Battery Size
US	1.5 grams / 8.0 grams Max. ELC(1)	Excepted / T1-T8(2)	Yes(5)	Small
	5.0 grams / 25 grams Max. ELC(1)	Class 9 / T1-T8(3)	Yes(6)	Medium
	>5.0 grams / >25 grams Max. ELC(1)	Class 9 / T1-T8(4)	Yes(6)	Large (more than)
International	20 Wh / 100 Wh Max. Watt_hours	Excepted / T1-T8 (7)	Yes	
	>20 Wh / 100 Wh	Class 9 / T1-T8 (4)	Yes (8)	

(1)Equivalent Lithium Content (ELC) in grams = rated capacity (Ah) X 0.3
(2)All cells and batteries must pass UN T1-T8 Tests.
(3)Cells and batteries must pass UN T1-T8 Tests and must be shipped as Class 9 hazardous materials *unless transported by motor vehicle or rail car*.
(4)Must pass UN T1-T8 Tests and be shipped as a Class 9 hazardous material.
(5)Packages containing more than 12 batteries or 24 cells must meet certain packaging, marking, and shipping paper requirements.
(6)Requires Class 9 markings, label, specification packaging, and shipping papers *unless transported by motor vehicle or rail car*.

(7)Cells and batteries must pass UN T1-T8 Tests. Cells and batteries that pass UN Tests are excepted from regulation. NOTE: The IMDG Code contains a grandfather clause for testing "small" cells and batteries until December 31, 2013.
(8)Requires Class 9 markings, label, specification packaging, and shipping papers.

Following UN and DOT Regulations

Failure to comply with UN and DOT regulations while transporting Class 9 Hazardous Materials (Dangerous Goods) may result in substantial civil and criminal penalties. Table 2-2 outlines a process that you can follow to help ensure that cells and batteries are shipped per the required regulations.

Table 2-2 Suggested Steps for Regulatory Compliance

Step Number	Process step	Comments
1	Insure use of UN certified packaging if applicable.	All dangerous goods must be shipped in UN certified packaging.
2	Packaging of cell or Battery	Pack per regulations
3	Package labeling[a]	Insure that packaging container has all required labeling
4	Fill out proper shipping documentation	Shipper's declaration for dangerous goods, airway bill, etc.
5	Ship package	Ensure that shipping company can ship DG

[a] Refer to Table 2-3 for proper shipping names and UN numbers for Lithium ion batteries

Table 2-3 Proper Shipping Names and UN numbers

Proper Shipping Name	UN Number
Lithium ion batteries	UN 3480
Lithium ion batteries packed with equipment	UN 3481
Lithium ion batteries contained in equipment	UN 3481

Environmental Regulations

The battery pack is compliant with the following environmental regulations.

- EU Directive 2002/95/EC for Restriction of Hazardous Substances (RoHS)
- EU Directive 2006/66/EC on batteries and accumulators and waste batteries and accumulators
- EU Directive 1907/2006 on the Registration Evaluation Authorization and Restriction of Chemicals (REACH)
- Management Methods for Controlling Pollution Caused by Electronic Information Products Regulation (China RoHS)

Chapter 3

A123 Nanophosphate® Technology inside the ALM 12V7

The ALM 12V7 consists of eight ANR26650 cells using patented Nanophosphate technology, and is intended as a replacement in the high-end market for the common lead-acid battery.

This chapter details the advantages of the technology behind the ALM 12V7 in the following sections.

Nanophosphate® Technology

Based on new, highly active nanoscale material initially developed at MIT, A123's low impedance Nanophosphate electrode technology provides significant competitive advantages over alternative high-power technologies. A123's cell and electrode designs are optimized for low cost/ watt and cost/watt-hour performance. They maintain a higher voltage than other long-life systems, enabling lower pack cost. This long life leads to reduced lifestyle and system costs, resulting in greater overall value.

- Nanophosphate is a positive electrode material of remarkable rate capability, which is critical to high-power systems. Our high-power products are able to pulse at discharge rates as high as 100C and deliver unmatched power by weight or volume. With their low impedance and thermally conductive design, you can continuously discharge A123's cells to 100% depth of discharge at 35C rate, a marked improvement over other rechargeable battery alternatives.
- A123's Nanophosphate technology is highly abuse-tolerant while meeting the most demanding customer requirements of power, energy, operating temperature range, cycle life and calendar life.
- A123's Nanophosphate technology delivers exceptional calendar and cycle life. At low rates these cells can deliver thousands and thousands of cycles at 100% Depth-of-Discharge, a feat unmatched by

commercial Lithium Ion cells. Even when cycled at 10C discharge rates, these cells deliver in excess of 1,000 full depth-of-discharge cycles.

Safety

A123's Nanophosphate cells are more abuse tolerant than competing cells of different Lithium Ion chemistries. For an illustration of the inherent safety of A123's Nanophosphate cells using thermal ramp testing by an independent lab, refer to Figure 3-1 and Figure 3-2.

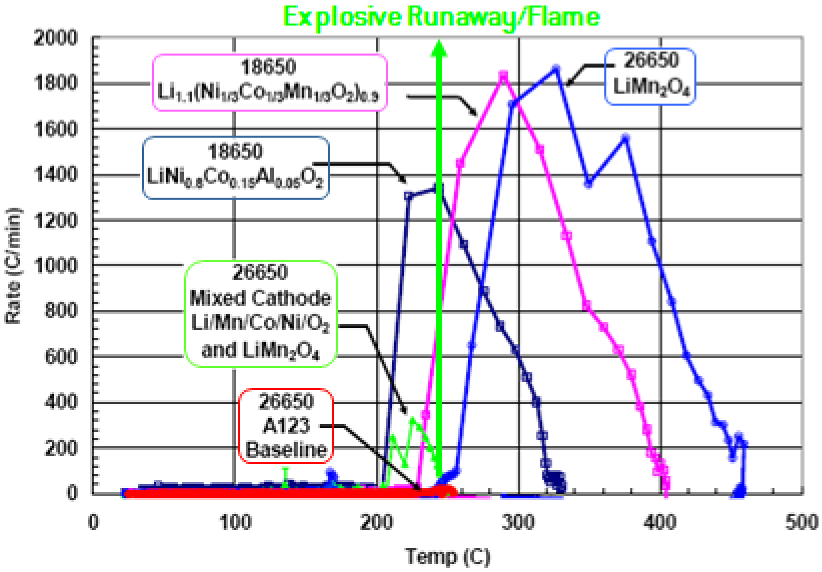

Figure 3-1 Heating Rate Profile Compared to Common Cathode Compositions in Competing Cells

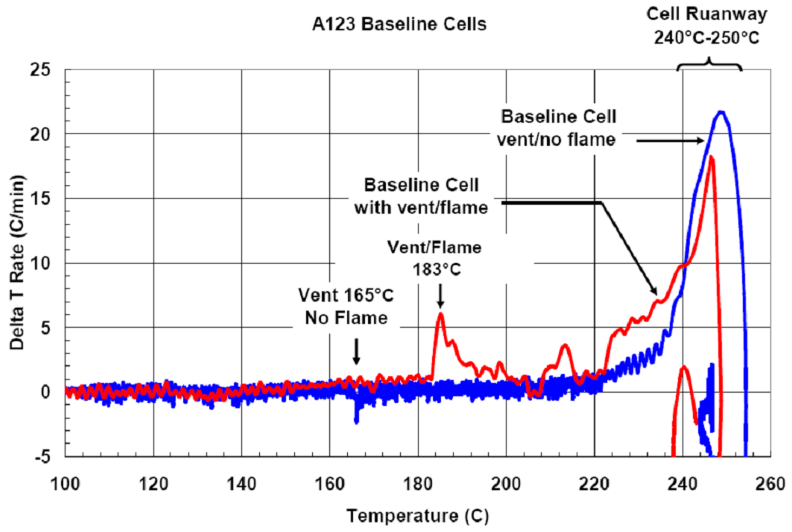

Figure 4. Heating rate profiles for two A123 baseline cells, one cell with burning vent gases.

Figure 3-2 Heating Rate Profiles for two A123 Baseline Cells

Figure 3-1 shows A123's cells have a higher onset temperature for thermal runaway than other Lithium Ion chemistries. Figure 3-2 shows a closer view of the data for A123's cells, illustrating how the maximum heat-rate for the Nanophosphate cells (20 °C/min) is only a fraction of the heat-rate for other Lithium Ion chemistries (almost 2000 °C/min).

Life

A123 Systems cells offer long cycle and calendar life, with minimal impedance growth over the life of the cells. Figure 3-3 illustrates the cells' ability to retain a high percentage of their first discharge capacity over thousands of low rate cycles. In addition, these cells also offer extended calendar life, even at elevated temperatures.

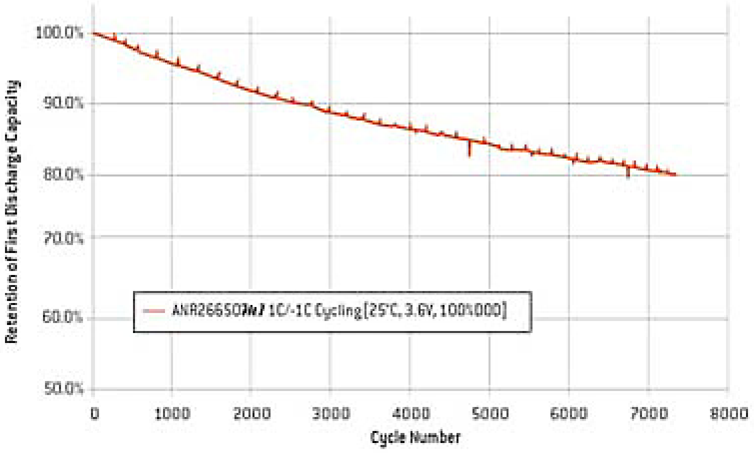

Figure 3-3 Thousands of Low Rate Cycles

The ALM 12V7

Figure 3-4 ALM 12V7 Module

The ALM 12V7 battery module consists of eight ANR26650 cells arranged in a four in series and two in parallel configuration (4S2P) with integrated cell protection and balancing circuitry. A123 Systems designed the ALM 12V7 as a drop-in replacement for the 12 volt 7 Ah lead-acid batteries that typically serve as a standby power source in many high-availability and service-critical applications. To ensure a seamless replacement process, the ALM 12V7 features identical dimensions to 12V7 lead-acid batteries, uses the same 0.250” faston terminal tabs and works with the same chargers. In addition, the ALM 12V7 leverages Nanophosphate technology for the following key advantages over lead-acid alternatives:

- Longer life in applications requiring repeated discharge and recharge cycles.
- Higher power capability, both during discharge and subsequent recharge.
- More energy during applications requiring four hours of runtime or less.
- Greater degree of safety due to the fact that the batteries are continually monitored by an integral microprocessor.
- Easier configuration of multiple modules - no external Battery Management System (BMS) required.

The advantages of Nanophosphate technology result in a powerful, safe battery pack that operates with a high rate of reliability throughout a longer useful life, reducing the overall cost of ownership over the battery pack’s life.

Functional Differences with Lead-Acid 12V7 Batteries

The integrated cell protection and balancing circuitry responsible for the durability and additional safety features of the ALM 12V7 module also cause functional behavior that differs from typical lead-acid batteries. The two biggest differences are:

- No voltage at the terminals does not necessarily indicate a bad battery.

  With a lead-acid battery, finding no voltage at the terminals often indicates the battery has reached the end of its life. With the ALM 12V7 module, no voltage at the terminals typically means the cell protection circuitry has interrupted current to protect the battery module. Simply connect the module to a charger to restore voltage to the terminals.

- State of Charge (SOC) with an ALM 12V7 appears constant, then drops suddenly.

  Voltage for an ALM 12V7 remains relatively constant throughout the depth-of-discharge, while voltage for a lead-acid battery decreases at a linear rate. Therefore, determining an ALM 12V7’s SOC using the same methods to determine a lead-acid battery’s SOC creates the impression that the ALM 12V7 has a full charge then loses power abruptly. A steady voltage across the depth-of-discharge is normal behavior for the ALM 12V7. Refer to Discharge Performance on page 3-7 for more details.

ALM 12V7 Specifications

Table 3-1 ALM 12V7 Specifications

Specification	
Maximum Discharge Current	30 A
Maximum Pulse Discharge Current	54 A for <200 ms (At 25 °C)
Ambient Operating Temperature Range	-20 °C to +58 °C
Maximum Operating Altitude	10,000 ft[a]
Operating Relative Humidity (non-condensing)	20% to 80%
Nominal Operational Voltage	13.2 V
Minimum Voltage	2 V @ any cell
Maximum Voltage	4.0 V @ any cell
Nominal Capacity	4.6 Ah
Standard Charge Voltage	14.4 V
Minimum Charge Voltage	13.8 V
Maximum Charge Voltage	14.4 V - 15.0 V
Float Charge Voltage	13.8 V
Standard Charge Current at 25 °C	3 A
Maximum Continuous Charge Current at 25 °C	10 A

[a] The maximum operating temperature decreases by a factor of 1.1 °C per 1,000 ft of elevation above 7,500 ft

Mechanical Dimensions

Figure 3-5 details the mechanical dimensions of the ALM 12V7 module.

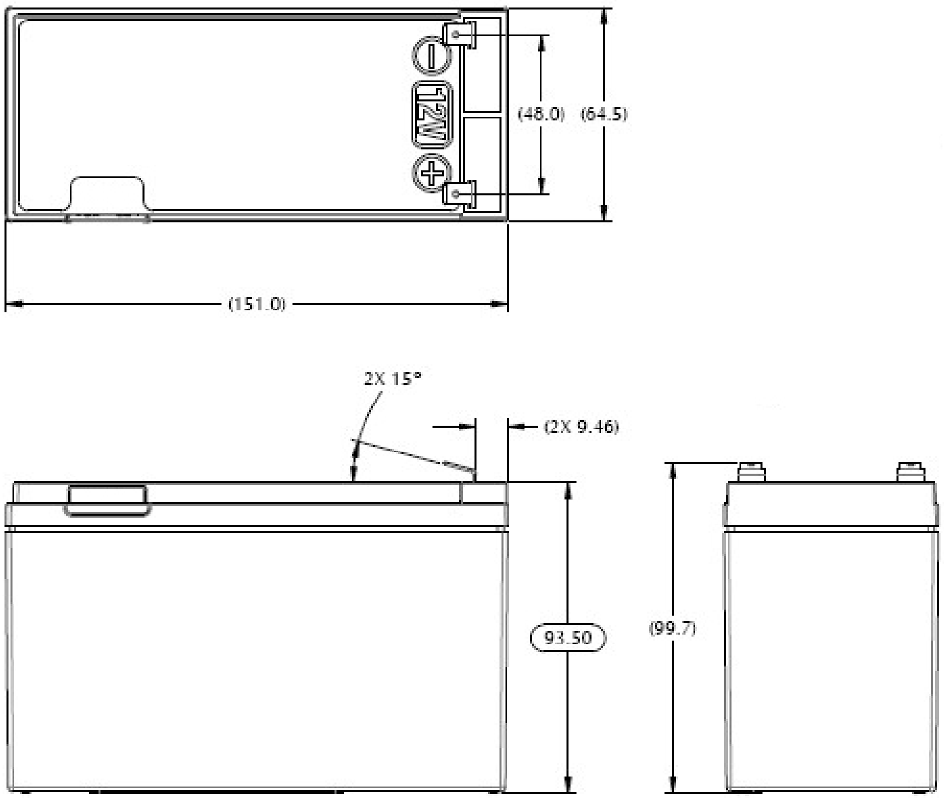

Figure 3-5 ALM 12V7 Mechanical Dimensions

The ALM 12V7 consists of the following components:

1. 12V7
2. Fuse plug
3. 30 A 58 V ATO®-style blade fuse

Discharge Performance

As shown in the typical room temperature discharge curve in Figure 3-6, the ALM 12V7's voltage remains virtually flat during the discharges and the capacity doesn't change significantly, no matter how fast the discharge is.

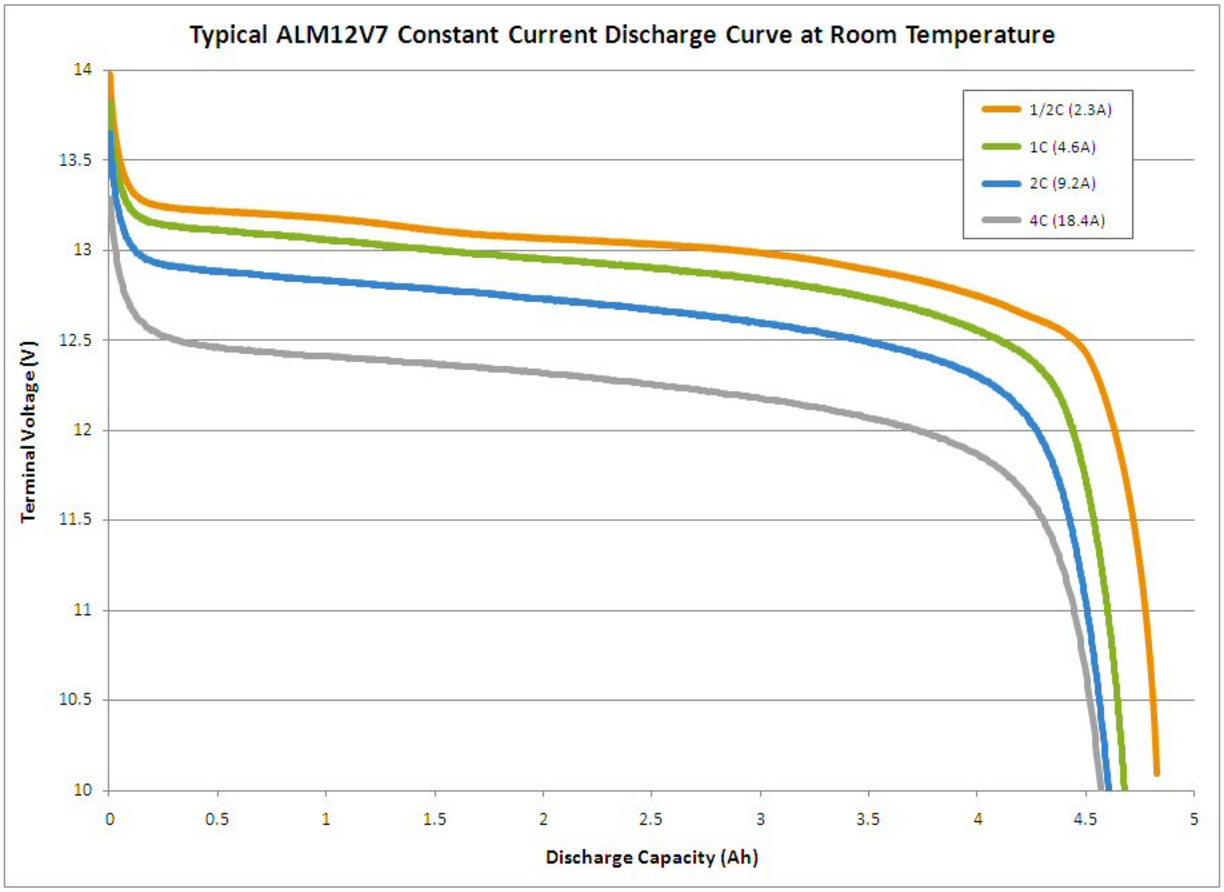

Figure 3-6 Room Temperature Discharge

Cell resistance changes with cell temperature. The warmer the ambient and/or cell temperature, the lower the resistance. Conversely, lower temperatures negatively impact the cell's ability to hold voltage under a load. Figure 3-7 and Figure 3-8 illustrate the impact ambient temperature has on the ALM 12V7's ability to hold voltage.

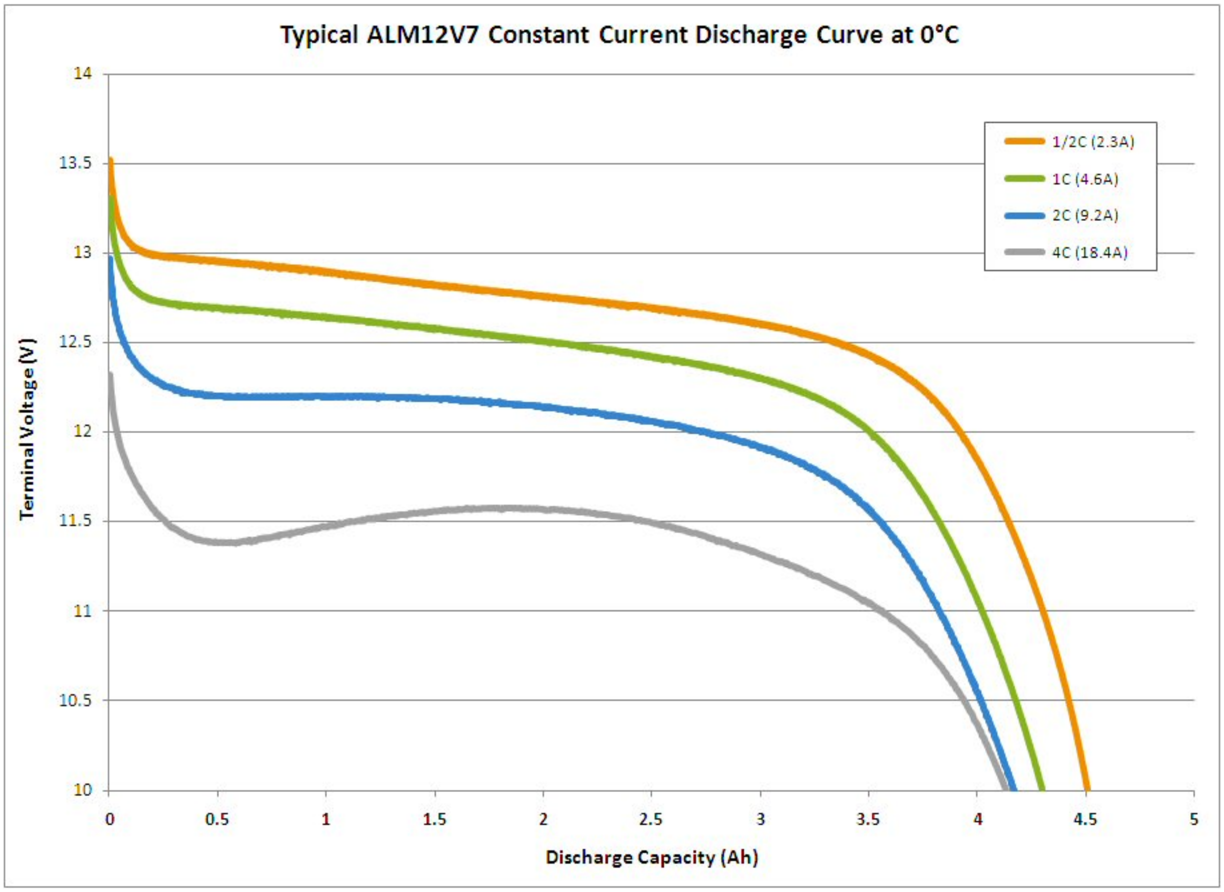

Figure 3-7 Discharge Curve at 0 °C

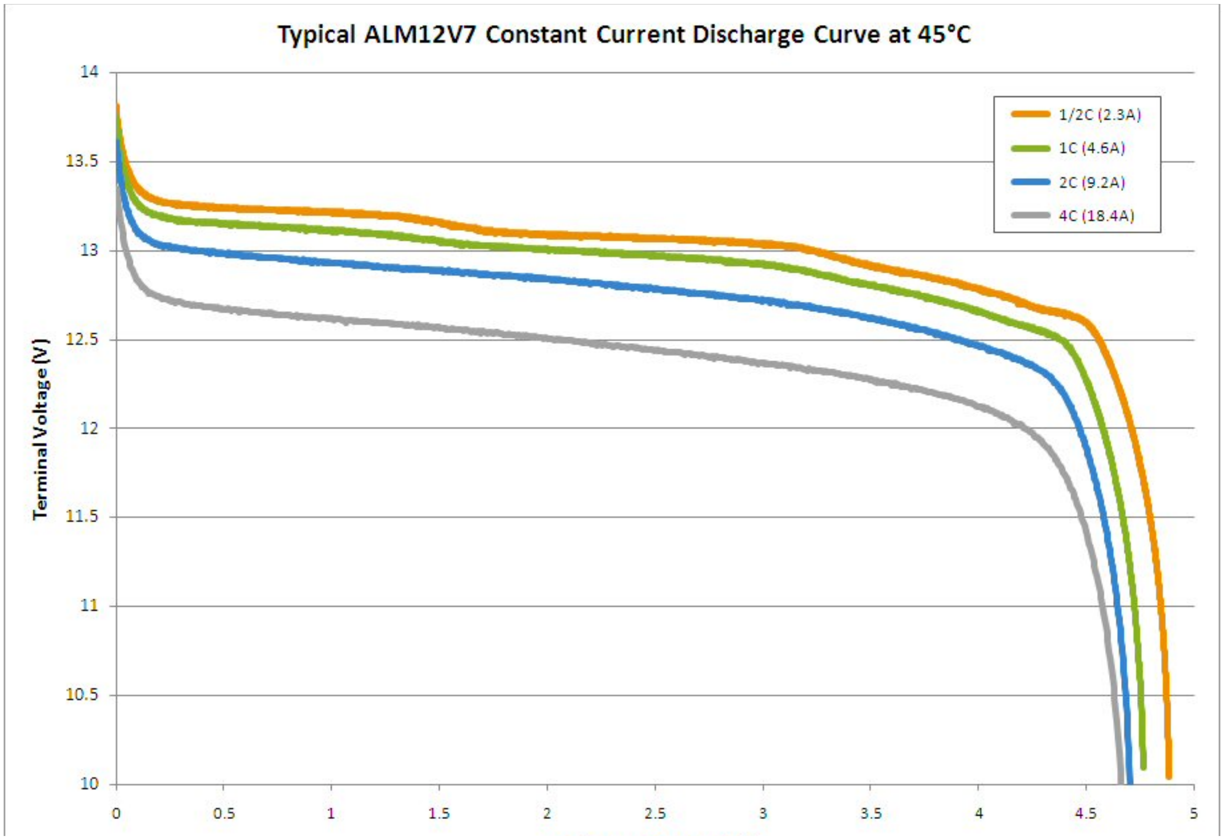

Figure 3-8 Discharge Curve at 45°C

Shelf Life

All ALM 12V7 battery packs ship from the factory at 50% SOC and can retain at least 10% SOC after 1 year of storage at temperatures not exceeding 25 °C. Note that higher storage temperatures reduce impedance and accelerate the rate of self-discharge.

Following this 1 year period the SOC falls below 10%, and the terminals become disconnected (open). The ALM 12V7 can remain in this state for a minimum of 2 more years. To reactivate the terminals, the battery must be recharged.

Cycle Life

The ALM 12V7's cycle life is determined by the 26650 cells inside it, as well as ambient temperature and charge/discharge rates. Under optimal conditions, the cells can deliver thousands of cycles at 100% Depth of Discharge (DOD). Even at 10C discharge rates, the cells can deliver in excess of 1,000 full DOD cycles. Refer to Cycle Life on page 3-10 for more details on cycle life.

Terminal Specifications

The ALM 12V7 module utilizes the same 0.250” by 0.032” Faston terminals found on 12V7 lead-acid batteries, and is compatible with any appropriately-sized receptacle.

Safety

A123’s Nanophosphate cells are more abuse tolerant than other Lithium Ion cells; however, correct handling of the ALM 12V7 module is still important to ensure safe operation.

CAUTION

Failure to follow the following safety instructions may result in personal injuries or damage to the equipment!

- Do not expose the ALM 12V7 to heat in excess of 58 °C during operation, 60 °C in storage; do not incinerate or expose to open flames.
- Do not short circuit the ALM 12V7. This blows the 30 A user-replaceable fuse.
- Do not charge or discharge the ALM 12V7 outside of its stated operating temperature range. Reduce charging limits for lower operating temperatures.
- Do not connect more than four modules in series. Connecting more than four modules in series exceeds the voltage limit of the integrated protection circuitry, leaving the module without critical safety features such as over-voltage and over-temperature protection.

Storage

A123 Systems ALM 12V7 can be stored in an environment with temperatures between -40 °C and +60 °C and between 10% and 90% relative humidity, non-condensing. In addition, you can store the ALM 12V7 at altitudes up to 25,000ft. For long storage periods at 25 °C, charge the battery every three years. For temperatures above 40 °C, charge the battery annually. Do not store the ALM 12V7 at temperatures above 60 °C.

Disposal

Do not incinerate or dispose of the battery. Return end-of-life or defective batteries to your nearest recycling center as per the appropriate local regulations.

Chapter 4

Applications

This chapter discusses competitive advantages and potential applications of the ALM 12V7 battery module in the following sections:

Competitive Advantages on page 4-1

Applications on page 4-2

Competitive Advantages

A123's ALM 12V7 is a battery module offering tremendous value in many applications. The battery is designed to be a drop in replacement for standard lead-acid 12V7 batteries, and provide the following advantages.

Power

- Higher power capability during discharge and subsequent recharge.
- Greater efficiency due to less energy lost during high rate applications and less power required to keep the module fully charged.
- Smaller and lighter systems due to higher power and energy density.

Safety

- High degree of safety due to inherently stable cell chemistry and integrated protection circuitry.
- Limited environmental impact – lead free and no hazardous material content.

Life

- Longer useful life due to higher usable energy.
- Longer lifetime in float applications.
- Longer cycle life.
- Longer shelf, storage life due to lower self discharge.

Applications

Applications that could benefit from these competitive advantages range from sophisticated computer backup equipment and security systems to children’s toys. The ALM 12V7 is particularly well suited for applications in the following categories:

- Backup Power
- Light-weight/Long-Life Solutions

While the ALM 12V7 features a sturdy case it is not designed for outdoor use or other environmentally challenging applications.

Backup Power

The occurrence of power outages, brownouts and surges are well known in business and residential environments. These power events can potentially cause havoc in any environment. Computer data loss and equipment damage are commonly avoided by installing Uninterruptible Power Supplies (UPS) that rely on lead-acid batteries for power. Replacing the standard lead-acid batteries with A123’s ALM 12V7s helps users immediately benefit from A123’s technology:

- Longer useful life helps avoid costly battery replacements where lead-acid batteries fail due to high temperatures or frequent UPS cycling
- Lighter weight solution helps with physical installation of UPS
- Lead free design supports environmentally friendly needs

A123 has helped many customers realize the simplicity of installing the ALM 12V7 into backup power systems to replace lead-acid solutions. Installation possibilities include:

- Home cable backup system
- Home security systems
- Single computer backup UPS
- High availability IT backup UPS
- Telecom cell tower backup UPS
- Power supplies for Computers on Wheels

Light-weight/Long-Life Solutions

Many applications today are using batteries for supplemental power. These applications typically require high-energy density and cycle the batteries frequently. Examples of these applications are:

- Electric bicycles
- Marine applications such as sonar fish finders
- Recreational camping applications such as large flashlights

- Various portable devices such as lighting

The applications listed above all look for characteristics which are consistent with the A123 value propositions. Lightweight, long cycle life and good energy density enable the A123 ALM products to provide superior performance in these applications. Comparison to lead-acid batteries quickly demonstrates the superior performance of A123 technology:

- A123 ALM batteries are less than half the weight of their lead-acid equivalents
- A123 batteries deliver more energy than lead-acid equivalent at high-rate discharges (short run time)
- A123 batteries deliver up to ten times more cycles than their lead-acid equivalents

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Chapter 5

Configuration and Operation

This chapter discusses configuring, charging and discharging the ALM 12V7 in the following sections.

- Terminology on page 5-1
- Configuration Options on page 5-2
- Charging Multiple Modules on page 5-7
- Discharging Battery Systems on page 5-10
- Integrated Module Protection on page 5-11

NOTE

The series PSL000001 is UL Recognized as a standalone battery only and has not been evaluated for series and/or parallel configuration.

Terminology

This chapter discusses configuring and operating ALM 12V7 modules using the following terminology:

Table 5-1 Configuration Terminology

Terminology	Definition
Cell	Refers to an individual ANR26650 cell that is the basis for the ALM 12V7 battery module. Each ALM 12V7 contains eight ANR26650 cells combined in a 4S2P configuration.
Module or Battery Module	The ALM 12V7 battery module.
Series String	A string of cells arranged in series to achieve higher voltage.
Parallel String	A string of cells arranged in parallel to achieve higher capacity.

Terminology	Definition
Battery System	Battery modules connected in series and/or in parallel to achieve higher voltage and/or capacity.

Configuration Options

You can arrange A123's ALM 12V7 battery modules in series and/or in parallel to achieve higher operating voltages and capacities for your intended application, with a maximum configuration of 4S10P. An external BMS or other electronics are not required to configure multiple ALM 12V7s.

CAUTION

Do not connect more than four ALM 12V7 modules in series, as the total voltage exceeds the limits of the integrated protection circuitry. Compromising the integrated protection circuitry increases the risk of an over-voltage or over-temperature event that may damage the ALM 12V7 and the host equipment.

CAUTION

Do not short circuit the ALM 12V7. This blows the 30 A user-replaceable fuse.

Connect the ALM 12V7 modules using 8 AWG wire and any receptacle that fits a 0.250" by 0.032" Faston terminal tab. The 8 AWG wire is necessary to carry the maximum current allowed by the user-replaceable 30 A fuse in each module. Refer to Figure 5-1 for an illustration of the components used to connect multiple ALM 12V7s.

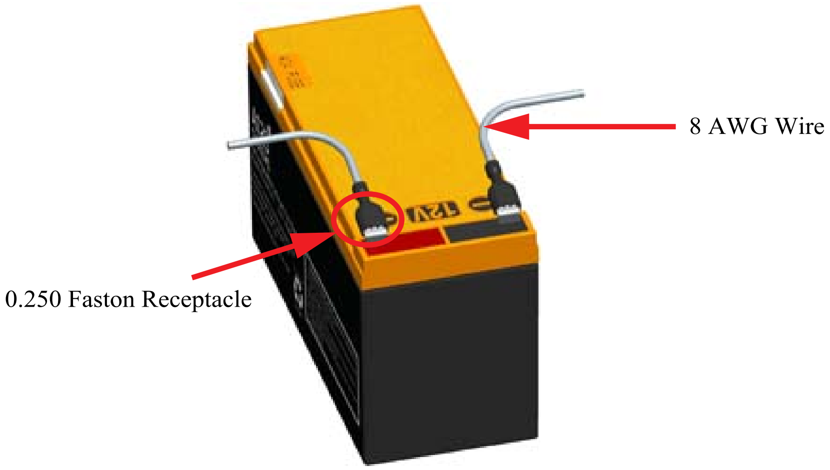


Figure 5-1 Components Used to Connect Multiple ALM 12V7s

NOTE

Do not connect ALM 12V7 modules to battery modules of other chemistries or ALM modules of different capacities. For example, do not connect an ALM 12V7 to a lead-acid 12V7 or an ALM12V35.

Series Strings

The modules can be combined together in series strings to achieve higher operating voltages by connecting the positive terminal of one module to the negative terminal of the next module. The maximum number of ALM 12V7s you can connect in a series is four. Figure 5-2 illustrates two ALM 12V7s connected in series, for a 2S1P configuration.

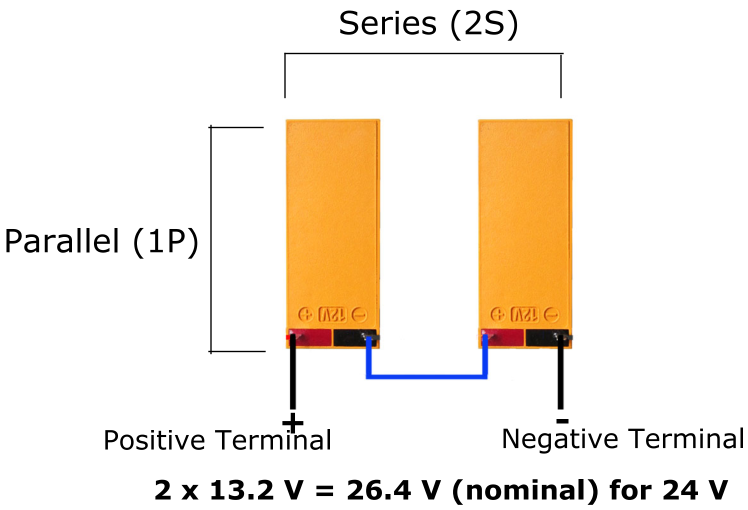


Figure 5-2 Connecting Modules in Series (2S1P Configuration)

- Two modules in series: 2 x 13.2 V = 26.4 V (nominal) for 24 V applications
- Three modules in series: 3 x 13.2 V = 39.6 V (nominal) for 36 V applications
- Four modules in series: 4 x 13.2 V = 52.8 V (nominal) for 48 V applications

Parallel Strings

You can combine modules together in parallel strings to achieve higher operating power and/or energy by connecting like-polarity terminals of adjacent modules. To combine modules in parallel strings, connect all like-polarity wires on adjacent modules to an appropriately sized terminal block for your application. Reference local electrical codes for terminal block specifications. Refer to Figure 5-3 for an example of eight ALM 12V7 modules connected together in a 4S2P configuration.

With certain restrictions, the ALM12V7 can support paralleling for added discharge current. These restrictions are described below, and depend upon accurate balancing which typically requires fairly lengthy charge periods to ensure.

If impedance, capacity, or self-discharge rates between cells vary significantly then FET failure may occur regardless of how well you adhere to these instructions. This is because the overvoltage and undervoltage protection mechanisms operate based upon individual cell voltages and unfortunately you can only monitor and respond to terminal voltages. Therefore these provisions for paralleling for added current assume that all cells the same way. Otherwise, the FETs may open unexpectedly which could lead to the failure modes previously described.

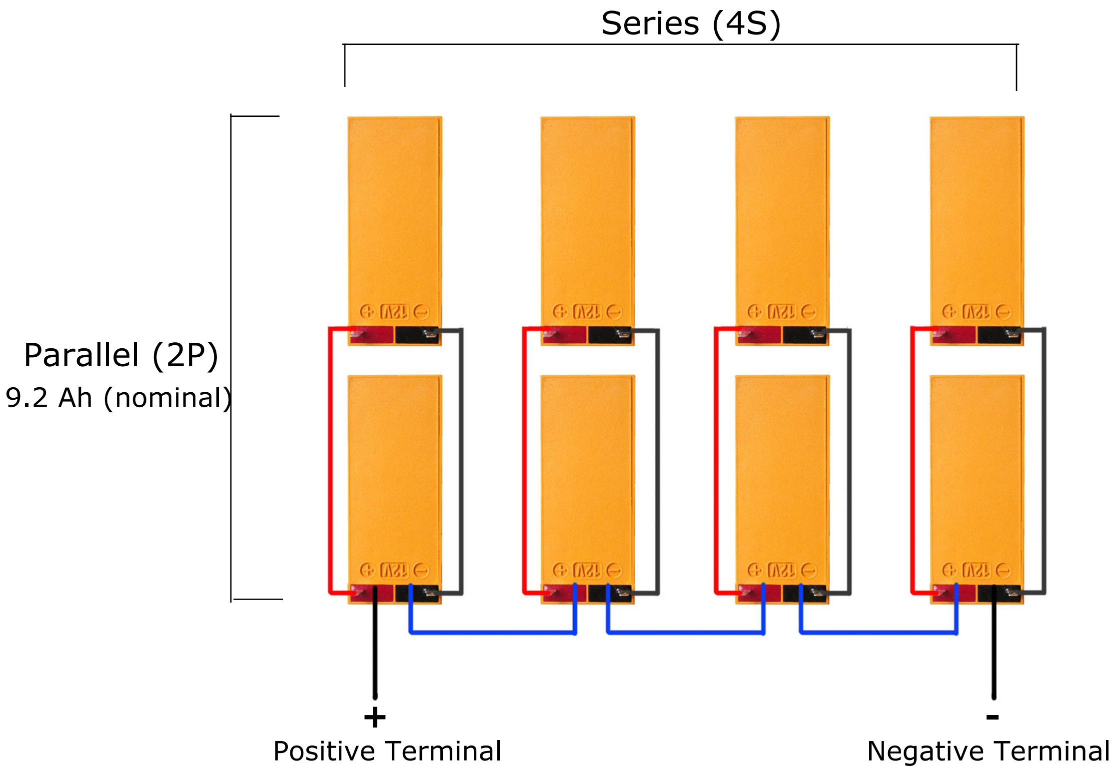
Paralleling for higher discharge currents:

1. Before wiring multiple ALM batteries together, all batteries must be individually charged to 100% SOC using a 10 A current limit. To ensure that 100% SOC is reached, a 14.4 V charge voltage should be maintained for at least 4 hours.
2. Connect batteries together in a configuration not to exceed 4s10p (4 in series, 10 in parallel).
3. The entire group of batteries should then be float charged at a 10 A current according to the number of series elements (14.4 V for 1 s, 28.8 V for 2 s, 43.2 V for 3 s, or 57.6 V for 4 s). This float should be held for at least 24 hours to allow the batteries in the system to fully balance.
4. To recharge the group, repeat the process starting at step 3. This will ensure that all cells are once again properly balanced in preparation for the next discharge.

* If operation below 23 °C is required, you should adhere to a current ramp rate of no more than 10 A per second to prevent sudden dips in pack voltage that could lead to inadvertent activation of the UVP mechanism.

Paralleling for higher charge currents:

Paralleling for higher charge currents is not supported at this time.



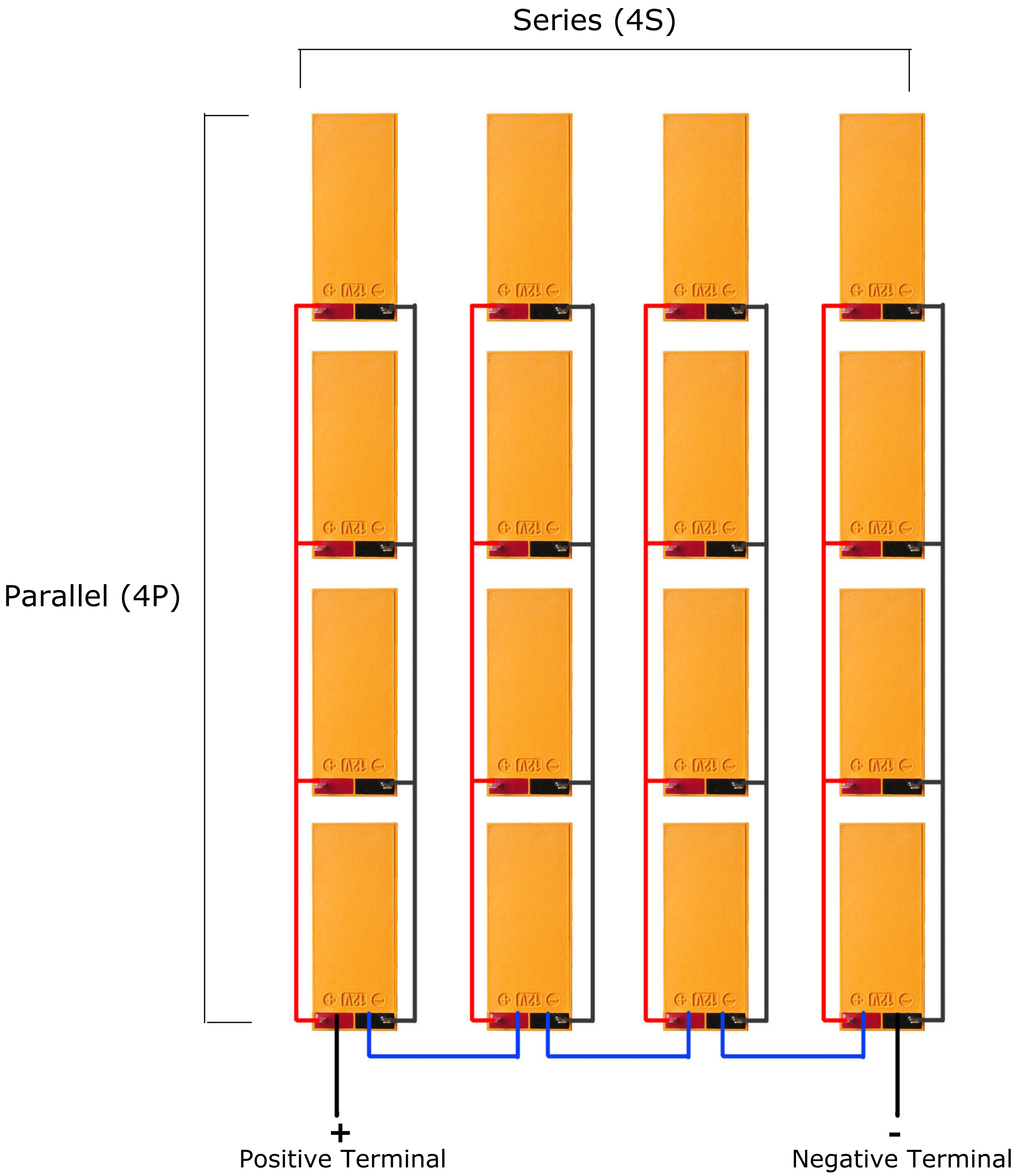
2 x 13.2 V = 26.4 V (nominal) for 24 V

Figure 5-3 Example of a 4S2P Configuration

- Two series strings in parallel: 2 x 4.6 Ah = 9.2 Ah (nominal)
- Three series strings in parallel: 3 x 4.6 Ah = 13.8 Ah (nominal)
- Four series strings in parallel: 4 x 4.6 Ah = 18.4 Ah (nominal)

Large Configuration Example

Figure 5-4 illustrates a larger configuration of ALM 12V7 modules arranged in series and parallel. This configuration features four series strings and four parallel strings (4S4P).



4 x 13.2 V = 52.8 V (nominal) for 48 V

Figure 5-4 Example of a 4S4P Configuration

Charging Multiple Modules

This section describes how to charge and discharge ALM 12V7 modules configured in series or parallel up to a maximum configuration of 4S10P.

CAUTION

Failure to follow the following safety instructions may result in personal injuries or damage to the equipment!

- Do not connect more than four modules in series. Connecting more than four modules in series exceeds the voltage limit of the integrated protection circuitry, leaving the module without critical safety features such as over-voltage and over-temperature protection.
- Do not short circuit the ALM 12V7. This blows the 30 A user-replaceable fuse.

Charging Modules or Battery Systems

The ALM 12V7 is compatible with any 12V7 lead-acid battery charger of 10 A or less. Chargers that automatically detect voltage at the terminals and charge accordingly may fail to wake the ALM 12V7 from a state of under-voltage protection. Constant Voltage (CV) chargers may result in an inrush of current due to the low impedance of the cells, interrupting the charge. Reset the charger and continue charging normally if the charger trips.The Total charge current for the group should be 10A.

Determine the end-of-charge voltage for the battery system by multiplying the number of modules connected in series by the maximum recommended charge voltage of a single module (14.4 V), as shown in Equation 1.

Eq. 1 (Number of modules in series) x (Recommended Maximum Charge Voltage, module) = Charge Voltage, String

To prevent damage to ALM12V7 modules connected in series from a current inrush during charging, ensure that the difference between battery system voltage and charger voltage is never greater than 10.0 V and limit the peak inrush current to 10 A. Limit the peak inrush current by minimizing charger capacitance and/or providing current limiting circuitry between the charger and battery system. To charge a single ALM12V7 module, the maximum charge voltage is 14.4 V and the maximum charge and inrush current is 10 A.

Refer to the following table for recommended charge currents and voltage.

Table 5-2 Examples for Charging

Example	Description
Example 1	If the module string has 10 modules in parallel (10P), and the recommended charge current per module is 10 A, then the charge current for this parallel string is 10 A.
Example 2	If the module string has four modules in series (4S), and the recommended charge voltage per module is 14.4 V, then the end of charge voltage for this series string is 57.6 V: (4 modules, series) x (14.4 V) = 57.6 V
Example 3	If the module string has four modules in series and 10 module strings in parallel (4S-10P), the recommended charge voltage per module is 14.4 V, and the recommended charge current per module is 10 A, then the charge current and charge voltage for the string is 100 A and 57.6 V: (4 modules, series) x (14.4 V) = 57.6 V (10 modules, parallel) 10 A

Once you reach end-of-charge voltage, apply a constant voltage hold at this voltage until the current decays to almost zero. This charges the cells to 100% state of charge (SOC). Refer to Figure 5-5 for an illustration.

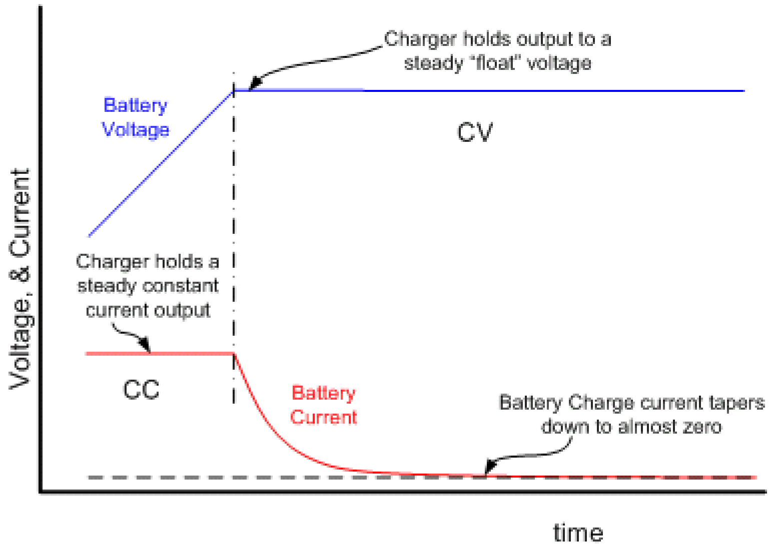


Figure 5-5 Battery Voltage and Current During Recharge

Relationship Between Charge Limits and Temperature

Due to the chemistry of Lithium Ion cells, the cells cannot accept as much charge current at lower temperatures without risking permanent loss of capacity. As the cells' temperature rises during the charging process, they can gradually accept higher currents.

To maintain optimum performance and durability of the ALM 12V7, A123 Systems recommends the following charge limits based on ambient temperature:

Table 5-3 Charge Rate by Temperature

Temperature (°C)	Charge rate
-20	C/5 (0.9 A)
-10	C/2 (2.3 A)
0	1C (4.6 A)
10	2C (9.2 A)
20	4C (10 A)[1]

[1] Maximum recommended continuous charge rate is 10A

Recommended float charge method for an ALM 12V7 battery system

If you hold the voltage of the battery system at the end-of-charge voltage (after reaching 100% SOC) for prolonged periods of time, lower the end-of-charge voltage to the recommended float-charge voltage. Determine the recommended float voltage by multiplying the number of modules connected in series by the recommended float-charge voltage of a single module (13.8 V), as shown in Equation 2.

Eq. 2 (Number of modules in series) x (13.8 V) = Float Charge Voltage, battery system

Recommended fast charge method for parallel strings

Determine the fast charge current for a battery system by multiplying the number of modules connected in parallel by the maximum continuous charge current for a single module (10 A), as shown in Equation 3. You can determine the maximum recommended charge voltage by multiplying the number of modules connected in series by the recommended charge voltage of a single module (14.4 V). Charge the battery system at its maximum continuous charge current until you reach its maximum recommended charge voltage. Apply a constant voltage hold at the maximum recommended charge voltage until the total charge time reaches the fast charge time. Do not attempt a fast charge outside the recommended temperature range and stop if the battery exhibits signs of overheating, such as the battery current disappearing during a charge.

Eq. 3 (Number of modules in parallel) x (10 A) = Fast Charge Current, battery system

Discharging Battery Systems

Recommended discharge method for strings

Determine the maximum continuous discharge current for a battery system by multiplying the number of modules connected in parallel by the maximum continuous discharge current for a single module (30 A), as shown in Equation 4.

Eq. 4 (Number of modules in parallel) x (30 A) = Max Discharge Current, String

Discharge temperature limits

For optimum life, do not discharge a battery system faster than the maximum continuous discharge current or allow the batteries to self-heat beyond 110 °C. Operation above 110 °C results in accelerated performance degradation during the battery’s service life. At low temperatures, the maximum available discharge current decreases due to increased internal impedance at lower temperatures. Refer to Discharge Performance on page 3-7 for more details.

Discharge Cut-Off Voltage Limits

When configuring your application stop discharges when the battery system reaches the recommended discharge cut-off voltage or any module reaches 110 °C. To determine the recommended discharge cut-off voltage for a battery system, multiply the number of modules connected in series by the recommended discharge cut-off voltage for a single module (8 V), as shown in Equation 5.

Eq. 5 (Number of modules in series) x (8 V) = Cutoff Voltage, battery system

You can discharge the battery system at greater than the maximum continuous discharge current in short pulses as long as individual modules do not exceed 110 °C. The maximum pulse discharge current for each parallel string is 54 A for less than 200 ms. During pulse discharges, the battery system voltage can safely fall below the recommended discharge cut-off voltage. Although you can safely discharge the battery system below the recommended discharge cut-off voltage, do not leave the modules below this level. Recharge the battery system to prevent permanent capacity loss and damage to the modules.

Integrated Module Protection

The ALM 12V7 includes integrated protection circuitry to prevent the battery module from exceeding its voltage limits. The module’s circuitry interrupts either charging or discharging current if the battery is in danger of exceeding upper or lower voltage or temperature limits.

Over Voltage and Under Voltage

The ALM 12V7’s circuitry continuously monitors cell voltage and can interrupt either charge or discharge current in the event that a cell’s voltage exceeds safe operating limits.

The protection circuitry interrupts current if the voltage on any single cell rises above 4.0 V or falls below 2 V.

- If the voltage on a single cell falls below 2 V, the protection circuitry enables under-voltage protection, preventing continued discharge until you charge the battery. To avoid degradation you must recharge the battery module within 7 days. The protection circuitry disables under-voltage protection once you charge the module to the point where all cells are above 3.0 V.
- If the voltage on a single cell rises above 4.0 V, the protection circuitry enables over-voltage protection, preventing continued charging until the voltage falls. The protection circuitry disables over-voltage protection once the voltage falls below 3.6 V.

NOTE

Under-voltage protection creates an open circuit, removing voltage from the terminals. With a lead-acid battery, finding no voltage at the terminals often indicates the battery has reached the end of its life. With the ALM 12V7 module, no voltage at the terminals typically means the cell protection circuitry has interrupted current to protect the battery module. Simply connect the module to a charger to restore voltage to the terminals.

Over Temperature

The ALM 12V7's circuitry continuously monitors the battery pack's temperature and can interrupt current if the module exceeds 110 °C. Module temperature must fall below 70 °C before the protection circuitry restores current.

Balancing

Over time, the cells inside a batter pack diverge in both capacity and SOC. An advantage of the ALM 12V7 is the circuitry continuously monitors the capacity and SOC of each individual cell and balances the battery module to ensure maximum capacity. Completely balancing the battery module can take up to 48 hours.

Fusing

User-Replaceable Fuse

A 30 A 58 V, user-replaceable, ATO®-style blade fuse manufactured by LittleFuse (PN 142.6185.5302) protects the ALM 12V7 from short circuits. If required, you must replace the fuse with a LittleFuse (PN 142.6185.5302). The use of other fuses voids your warranty.

The fuse can commonly be found in automotive parts retailers as well as electronics retailers. Ensure the replacement fuse's voltage rating is appropriate for your application.

To replace the 30 A 58 V fuse:

1. Hold the fuse plug at the lower lip (indicated in Figure 5-6), then remove it and place it in a safe location. Do not lose it.

Figure 5-6 Removing the Fuse Plug

2. Remove the 30 A fuse using an ATO fuse puller, commonly available in hardware or automotive supply stores.
3. Replace the fuse with a 30 A 58 V, ATO®-style blade fuse manufactured by LittleFuse (PN 142.6185.5302).
    a. Place the top of the replacement fuse in the fuse plug. Covering the fuse with the fuse plug prior to inserting the fuse into the battery pack is the easiest way to ensure proper fitment of the fuse plug.

Figure 5-7 Fuse Fitment in the Fuse Plug

b. Insert the replacement fuse and fuse plug into the battery pack.

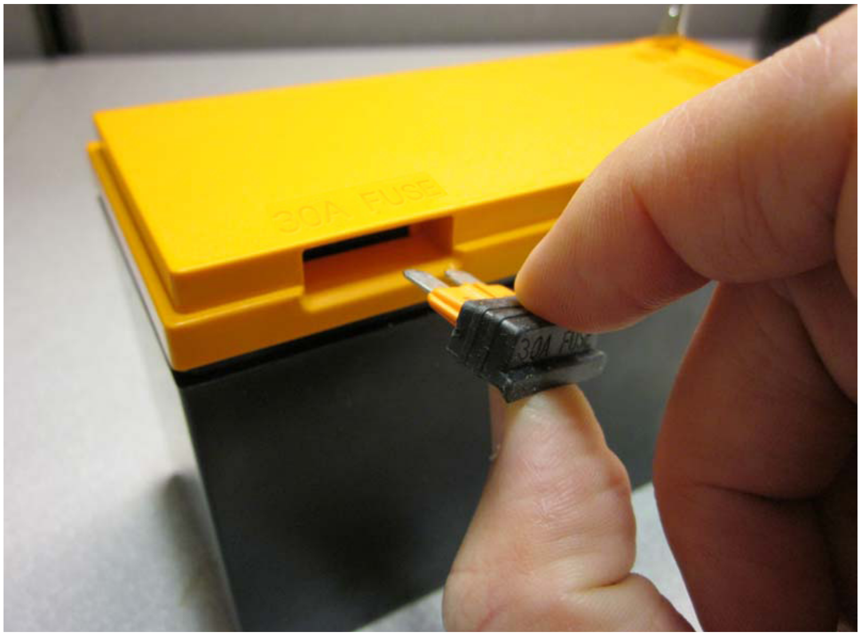


Figure 5-8 Inserting the Fuse and Fuse Plug into the ALM 12V7

c. Ensure that the fuse plug is flush with the module, as shown in Figure 5-9.

Figure 5-9 Fuse Plug Flush with the ALM 12V7 Module

4. Connect the module to a charger to wake the battery.

Secondary fuse

In addition to the user-replaceable 30 A fuse, A123 Systems integrated a secondary 120 A fuse into the battery pack’s cell connections as a safety feature in the event the user-replaceable fuse does not meet the above specifications and fails to protect the battery pack. Blowing the secondary fuse permanently disables the ALM 12V7, as it is not user-replaceable.

Chapter 6

Troubleshooting

The ALM 12V7 is an extremely reliable battery module that provides greater useful life than comparable 12V7 lead-acid batteries. Despite the high reliability of the ALM 12V7, you may encounter situations where the battery module does not operate as expected. These situations are typically the result of misuse, abuse or a non-optimal operating or storage environment. This chapter details potential issues you may encounter with the ALM 12V7 and the appropriate troubleshooting procedures.

Charger Trips using Constant Voltage

Problem

CV charger trips when charging the ALM 12V7. This is due to the low impedance of the module creating a current inrush.

Solution

Reset the charger and try again.

Terminal Voltage Absent or Low

Problem

Using a multimeter to check terminal voltage shows the terminal voltage is low.

Possible causes for this problem are:

- Blown fuse
- The voltage of a cell within the module dropped below 2 V, causing the microprocessor to enable under-voltage protection.

- The module’s SOC dropped below 5% from either an extended idle period or heavy use, enabling under-voltage protection.
- The module overheated, causing the microprocessor to enable over-temperature protection.

Solution

To resolve situations where terminal voltage is absent or low:

1. Allow the battery to cool and then recheck terminal voltage.
2. Inspect the fuse and replace it if necessary. Use only fuses that meet the specifications described in Fusing on page 5-12. Ensure the replacement fuse’s voltage rating is appropriate for your application.
3. Connect the battery to a charger to wake the battery and recover terminal voltage. Depending on the module’s voltage and state of balance it may take up to 48 hours to completely charge and balance the module.

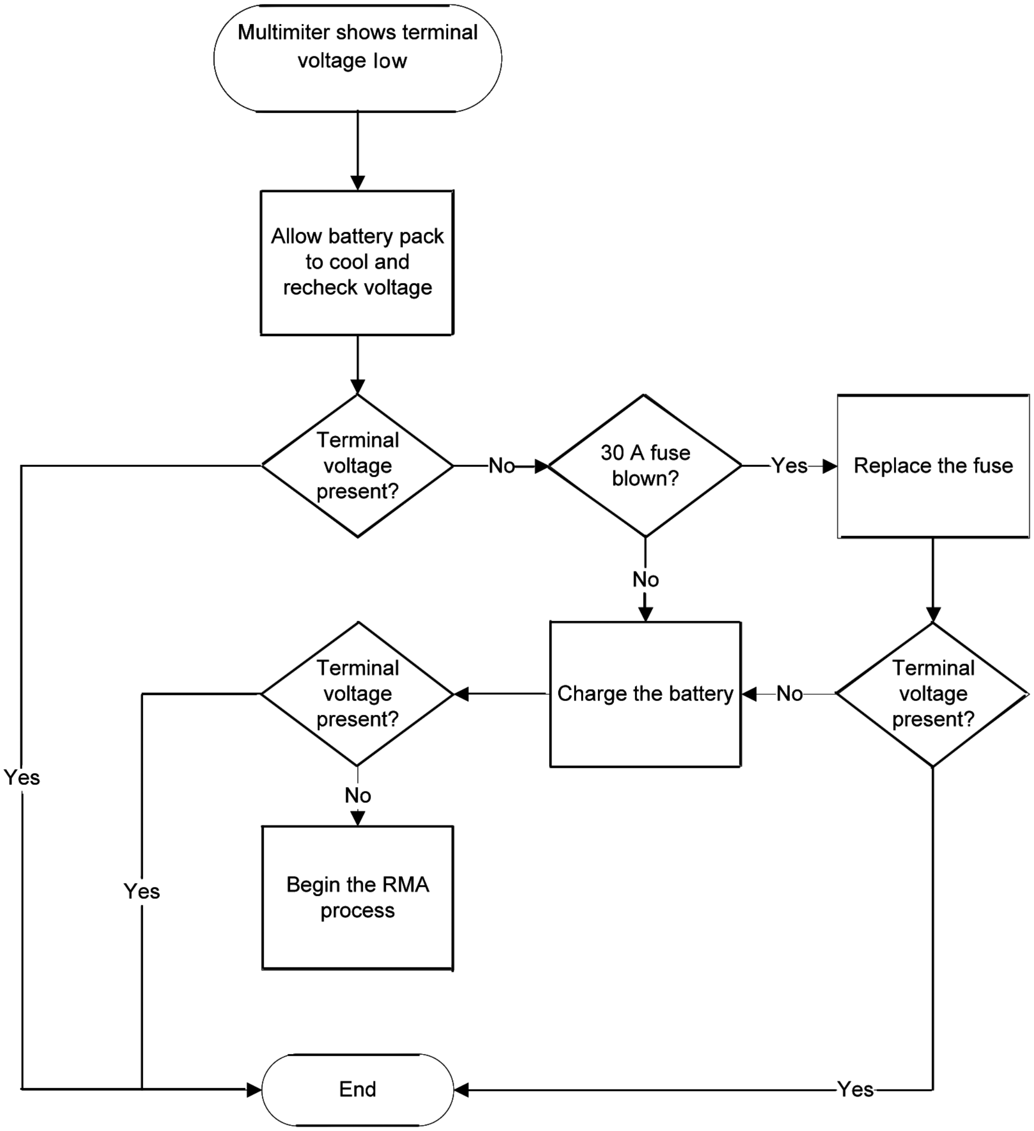


Figure 6-1 Terminal Voltage Low or Absent Troubleshooting Flow Chart

Battery Rapidly Depletes Energy between Charges

Problem

The ALM 12V7 rapidly depletes its energy between charging. Possible causes for this problem are:

- The battery pack is out-of-balance.
- The battery pack has reached the end of its useful service life.

Solution

To resolve situations where the battery rapidly depletes its energy between charges:

1. Apply a float charge (13.8 V, 10 A) for 48 hours to balance the battery pack's cells.
2. Replace the battery pack.

Battery Current Disappears when Charging

Problem

Battery current disappears when charging. Possible causes for this problem are:

- The battery overheated, enabling over-temperature protection.
- The battery pack is out-of-balance.
- Charger voltage is too high.

Solution

To resolve situations where current disappears when charging:

1. Allow the battery to cool.
2. Apply a float charge (13.8 V, 10 A) for 48 hours to balance the battery pack's cells. For more details on charging battery modules or strings, refer to Charging Modules or Battery Systems on page 5-7.
3. Reduce charger voltage to 14.4 V or less.

30 A Fuse Blows Frequently

Problem

The user-replaceable 30 A fuse blows frequently. Possible causes for this problem are:

- The fuse was replaced with a fuse that does not meet the specifications detailed in User-Replaceable Fuse on page 5-12.
- Failure to ensure correct polarity when connecting the battery pack to other battery packs or a host product's output terminals.

- The battery exceeded maximum current specifications while charging or discharging the battery.

Solution

To resolve situations where the battery’s 30 A fuse blows frequently:

1. Ensure you are using a fuse that meets the fuse specifications detailed in User-Replaceable Fuse on page 5-12.
2. Verify correct polarity on all connections.
3. Do not exceed maximum current specifications while charging or discharging the battery.

Voltage Drops Abruptly

Problem

Battery voltage appears constant, then drops abruptly.

Solution

This is normal for A123’s cells. Constant voltage throughout the battery’s SOC ensures maximum usable life. Once the voltage of a cell within the module drops below 2 V, the ALM 12V7’s circuitry enables under-voltage protection, which creates an open circuit at the terminals.

Refer to Nanophosphate® Technology on page 3-1 for more details on the cell technology within the ALM 12V7.

Appendix A

Glossary

This appendix contains the following sections:

- Terminology Table on page A-1

Terminology Table

The following table describes the terminology used in this document.

Table A-1 Definitions and Acronyms

Term/Acronym	Meaning
ACR	Alternating Current Resistance.
AH	Amp-Hour is a unit of measure of charge that can be stored or delivered to/from a battery.
Battery	One or more cells which are electrically connected together by permanent means, including case, terminals and markings.
BCM	Battery Control Module – The Battery Control Module is necessary to aggregate information from modules and communicate with the system the ESS resides in.
BMS	Battery Management System – The Battery Management System refers to the collection of electronics responsible for monitoring and controlling the ESS.
C-Rate	An electrical current corresponding to that which will fill or empty a cell in one hour.

Term/Acronym	Meaning
CC	Constant Current – A method to charge or discharge a battery in which the current is held constant independent of the battery’s terminal voltage.
CE	Consultants Europe - Tests and Certifies safe and compliant product operation in Europe
Cell	A single encased electrochemical unit (one positive and one negative electrode) which exhibits a voltage differential across two terminals.
CID	Current Interrupt Device – A small device integrated into a cell designed to interrupt the flow of current through its terminal when too much pressure or current exists in the cell.
CV	Constant Voltage – A method to charge a battery in which the terminal voltage is held constant, and the current is determined by the power path impedance or some active current limiting.
DVT	Design Verification Testing
ESS	Energy Storage System
iSOC	Current based SOC algorithm
OCV	Open Circuit Voltage – voltage reading of a battery when there is no current going in or out of it.
OEM	Original Equipment Manufacturer – in reference to this document, the maker of the equipment into which an ESS is installed and used.
FCC	RF Emissions governing body in the United States
UL	Underwriter Laboratories - Tests and Certifies safe and compliant product operation in North America
vSOC	Voltage based SOC algorithm