APPLICATION NOTE

Selecting BMS Transformers for Isolated Communications in High Voltage Energy Storage

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INTRODUCTION

Battery Management Systems (BMS) connect to high-energy battery packs and manage the charging and discharging of the pack. They also monitor essential safety factors including temperature, state of charge and the pack's state of health. Providing additional application protection, the BMS is able to connect the battery and disconnect it from the load or charging source, as required.

This application note provides an overview of the key features of battery monitoring Integrated Circuits (ICs) typically specified in BMS. It includes background information on battery cell chemistries as they relate to the requirements for communications in high voltage BMS. An application example will be used to explain the technology benefits that Bourns® transformers deliver to meet these specifications.

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Overview of Lithium-Ion Battery Chemistries

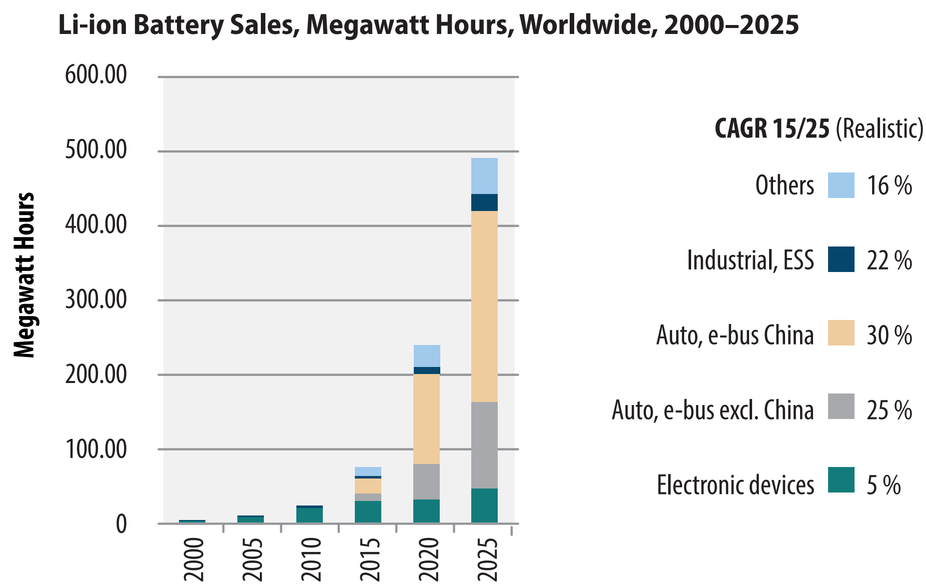

Figure 1. | *Forecasted Growth in Lithium-Ion Sales*[1]

Consulting and market research firm Avicennes[1] has predicted that the usage of lithium-ion (Li-ion) battery cells for energy storage and automotive applications will continue to grow significantly through 2025 with compound annual growth rates up to 30 percent forecasted in China's transport sector. As Li-ion usage grows and expands into new applications, it is important to understand the nature and use of various battery chemistries.

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Overview of Lithium-Ion Battery Chemistries *(Continued)*

Table 1 shows a summary of the most popular chemistries by energy density, cell voltage and charge rate for 48 V and higher voltage battery packs. These next-generation packs match the power density required to drive new electronics and motor designs. The latest battery cell developments in different chemistries deliver the increased power energy over longer periods of time necessary for full electric battery power.

Table 1: Summary of Most Common Li-ion Chemistries for Battery Applications

Cathode	Anode	Energy Density	Cell Voltage	Charge Rate
NMC	Graphite	150 – 220 Wh/Kg	3.6 – 3.7	1 C Max.
LFP	Graphite	100 –120 Wh/Kg	3.2 – 3.3	1 C Max.
NMC	LTO	50 – 80 Wh/Kg	1.8 – 2.5	5 C Max.
LMO	LTO	100 – 150 Wh/Kg	2.4 – 2.6	3 C Max.

There are several factors to consider when choosing the chemistry for a battery powered application. As can be seen in Table 1, Lithium Nickel Manganese Cobalt (NMC) with Graphite has the highest energy density among the commonly-used chemistries. This is advantageous for heavy loads such as consumer energy storage or plug-in electric vehicles. The disadvantage, however, of this chemistry is that it creates a higher risk of lithium plating on the anodes, which can reduce battery life and lead to thermal runaway (fire or explosion). The potential for these harmful conditions can be exacerbated with today's faster charging connectors.

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Overview of Lithium-Ion Battery Chemistries *(Continued)*

Lithium Titanate (LTO) has a lower energy density than NMC and does not suffer from the problem of cracking graphite, which together improve the estimated battery life. The lower internal resistance of LTO facilitates faster charging rates making this battery chemistry beneficial for plug-in electric vehicles. The downside is the higher cost for heavier battery packs as more cells are needed to provide the necessary energy in kilowatt hours (kWh).

Lithium chemistries have very narrow operating temperature ranges, typically from 20 °C to 40 °C. Operating outside these temperatures leads to a loss of capacity and a shorter lifespan. Elevated temperatures can also cause further degradation and a thermal runaway condition. A paper by NASA[2], which studied the protection within 18650 cells found that the interrupt devices in all the cells connected in series and parallel were not as effective as single cells in preventing thermal runaway during fault conditions. This study illustrates the strong need for a Battery Management System when multiple cells are interconnected.

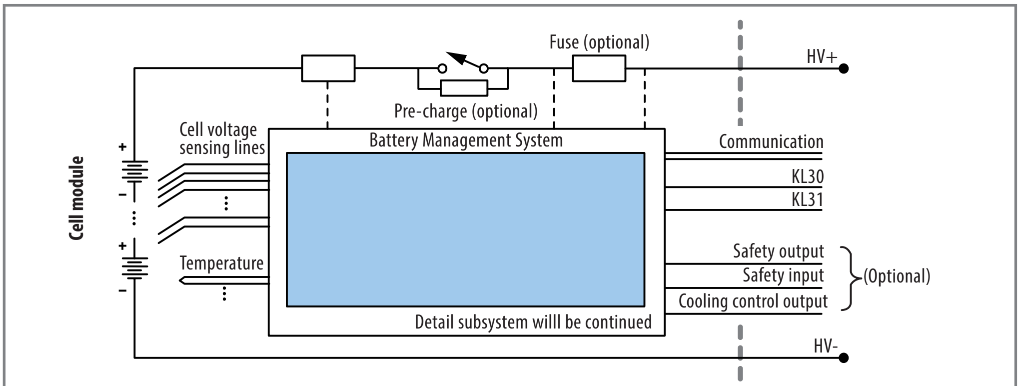

Figure 2. Block Diagram Showing the Battery Management System in Relation to the Battery Pack

Overview of Battery Management ICs and Transformers

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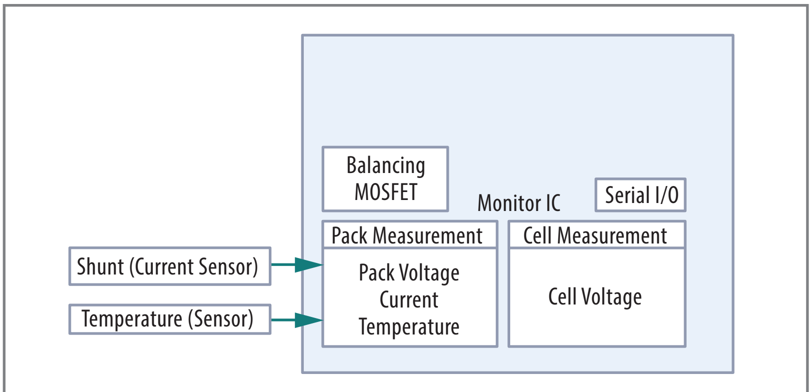

Figure 3. Block Diagram of BMS IC

A typical battery monitor IC (shown in Figure 3) measures cell voltage and pack temperature and performs cell balancing. In some models, there is also a current sense input port for shunt-based current measurement. Including this feature makes sense in 48 V systems that use a limited number of battery cells and do not experience hazardous voltage levels, and, hence, monitoring ICs.

Conversely, it does not add a lot of value to integrate a current sense function into an IC for high voltage battery packs. These packs require only one current sensing chip and several monitoring ICs to monitor the individual cells in the pack. For instance, the 2011 Nissan® Leaf® has a working voltage of 360 V and energy of 24 kWh (NMC technology)[3]. The structure of the pack is 96S2P (192 cells). Or, a simpler way to put it: if each monitoring IC can check 10 cells, then at least 20 monitoring ICs will be needed. Another consideration in high voltage battery packs is that the BMS IC module or board must be located on top of the shunt resistor, which may pose a mechanical design challenge.

APPLICATION NOTE

Selecting BMS Transformers for Isolated Communications in High Voltage Energy Storage

SM91501AL

SM91502AL

BMS High Voltage Communications

The BMS typically has two ports for isolated communications, allowing battery monitoring modules to be daisy-chained throughout the battery pack. The source and sink currents of the serial port drivers are balanced, enabling the IC to drive a transformer without saturating it. The transformer, with a rated working voltage of several hundred volts, provides the necessary protection of the communications line from any hazardous voltage coming from the battery pack. Furthermore, the drivers on the IC encode a four-line serial peripheral protocol into the differential signal needed for isolated communication from board to board.

Serial Peripheral Interface (SPI) is an interface bus commonly used to send data where one device or "master" transmits a clock pulse and control bit to a series of slaves. On each clock pulse, the slave either reads a command from the master or if the control bit is inverse, transmits its data on the data line. In this way, a central battery controller IC (master) can interrogate each monitoring IC (slave) in turn and retrieve necessary voltage and temperature information from the whole pack. In addition, the transformer and integrated common mode choke filter out common mode noise from the daisy-chained network.

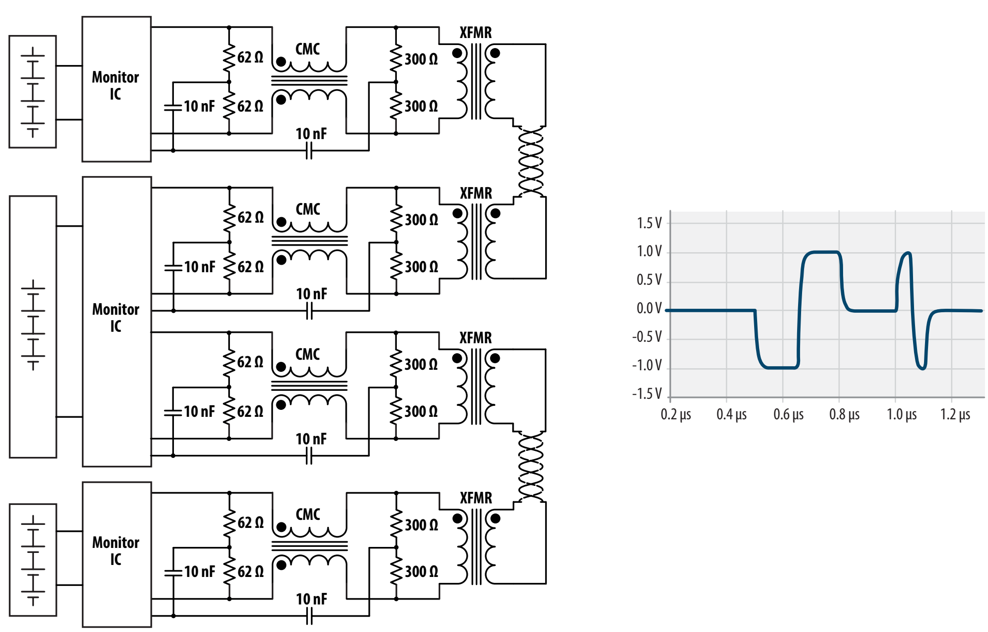

Figure 4. | *BMS Transformer with Center Tap Capacitor and Resistor. Right: Image of SPI Signal.*

Although BMS ICs have balanced currents on their I/O pins, most manufacturers recommend a center-tapped transformer. These have been found to improve Common Mode Noise Rejection (CMNR) if a filter capacitor and termination resistor are used, as shown in Figure 4.

APPLICATION NOTE

Selecting BMS Transformers for Isolated Communications in High Voltage Energy Storage

SM91501AL

SM91502AL

Bourns® BMS Transformer Safety Features

The windings inside the Bourns® Model SM91501AL transformer use enamelled fully-insulated wire (FIW) that passes the dielectric strength (Hi-POT) test of 4.3 kV (1 mA, 60 seconds). Per Table 2N of IEC 60950[4], the minimum creepage distance for material group I, pollution degree 2 of functional insulation for a working voltage of 1600 V is 8 mm. The Bourns® Model SM91501AL transformer data sheet shows a minimum 10 mm creepage distance. This is because the actual tracking distance over the surface of the transformer and chokes has been calculated at 10.4 mm in the samples measured.

The replacement test for IEC 60950 (IEC 62368-1)[5], which becomes mandatory in June, 2019 for audio/video, information technology and communication equipment will recognize FIW in the future. The use of FIW may qualify the device as having reinforced insulation with a lower working voltage (depending on the standard) of approximately 800 V. This may allow the device to meet UL Listing requirements and may enable its use in additional applications such as consumer energy storage, which mandate reinforced insulation.

Recommended Electrical Characteristics

The recommended primary inductance values by some IC manufacturers will depend on the voltage of the communication signals, the pulse widths and the frequency. Bourns designed its Model SM91501AL transformer with a primary inductance span between 150 µH and 450 µH over an operating temperature range of -40 °C to +125 °C. The inductance is directly proportional to the permeability of the core. The permeability of the ferrite core of a transformer is temperature-dependent and tends to increase with temperature. Therefore, the primary inductance in the Bourns® model will drift up towards 450 µH at the upper end of the temperature range. This is the reason for the large variation in the inductance value as specified on the data sheet.

Figure 5. Bourns® Model SM91501AL Transformer on Bourns' BMS Demonstration Board

The noise immunity of the BMS IC and transformer can be evaluated using a bulk current injection (BCI) test. The BCI test injects current into the twisted-pair lines at set levels over a frequency range of 1 MHz to 400 MHz with the bit error rate being measured. A 40 mA BCI test level is sufficient for most industrial applications. The 200 mA test level is typically used for automotive testing. The Bourns® Model SM91501AL and SM91502AL have been evaluated by certain BMS IC manufacturers for select automotive applications and have successfully passed requirements for BCI.

APPLICATION NOTE

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SM91501AL

SM91502AL

Summary and Conclusions

The demand for Li-ion battery power is predicted to grow at a CAGR of 20 - 30 percent over the next eight years[1]. Battery Management Systems that integrate isolated communications are expected to be an important part of the safety and security of the battery system. An effective and reliable BMS will help increase the lifespan of Li-ion cells while also enhancing safe operation for end users.

Offering an optimal protection solution for isolated communications in industrial and consumer BMS applications, Bourns engineered its latest Model SM91501AL and SM91502AL BMS transformers with the higher working voltages of 1600 V and 1000 V, respectively. They feature an inductance value of 150 µH and 450 µH over an operating temperature range of -40 ˚C to + 125 ˚C which meets higher voltage BMS requirements. Additionally, the transformer windings use fully insulated wire passing the dielectric strength (Hi-POT) test, further increasing electrical insulation protection for overvoltage transients.

Bourns Part Number	Description	BMS IC
SM91501AL	2 Channel BMS Transformer 1600 VDC	LTC6811 MC33771

Bourns® Model SM91501AL and SM91502AL have been tested by several BMS IC companies in their test laboratories who found them to function well with their chipsets, passing the necessary BCI tests.

References
[1] Avicennes, Christophe, Pillot, Rechargeable Battery Market 2017-2025 The Battery Show, Hannover, May 15, 2018
[2] NASA, Jeevarajan, Judith A., Safety Limitations Associated with Commercial 18650 Lithium-ion Cells presented at Lithium Mobile Power and Battery Safety 2010, Boston, MA
[3] Hayes, J. G., & Goodarzi, G. A. (2018). Electric powertrain: Energy systems, power electronics and drives for hybrid, electric and fuel cell vehicles. Hoboken, NJ: John Wiley & Sons.
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[5] International Electrotechnical Commission, Audio/Video, Information and Communication Technology Equipment- Part 1: Safety Requirements IEC 62368-1 Edition 2.0 2014-02

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