Improve Lithium-Ion Battery-Stack Safety in Electric Vehicles by Leveraging Optocouplers to Isolate High Voltages

White Paper

Andy Poh, Product Marketing Engineer, Avago Technologies Inc.

Introduction

There are many challenges associated with high-voltage Li-ion battery-stack management in all-electric or hybrid automotive applications. Charge and discharge cycles must be monitored and controlled, and the battery stack, which often delivers voltages of several hundred volts, has to be isolated for safety concerns. In particular, this paper will examine the requirements for Li-ion cell monitoring, and review the architecture and components used in the cell-monitoring subsystem, digital-communications subsystem, and isolation interface.

Within the management system, the battery-monitoring boards employ two key subsystems to reliably monitor cell health and deliver digital results to a host processor that orchestrates system operation. Separating those subsystems, a signal interface employing optical isolation between high-voltage battery-sensing circuitry and communications devices on the boards ensures that the high voltages will not compromise the digital subsystem.

Li-ion cell characteristics

The sophisticated electronics system required to meet EV performance, safety, and reliability requirements is basically derived directly from the characteristics of Li-ion cells. In a discharging Li-ion cell, lithium is ionized in a (typically) graphite anode, and the Li ions move through an electrolyte to pass through a separator to a cathode, resulting in charge flow. The charging process reverses the flow, bringing Li-ions from the cathode through the separator to the anode.

The performance and reliability of this chemical process are dependent on cell temperature and cell voltage. At low temperatures, the chemical reaction slows, lowering cell voltage. As temperature increases, the reaction rate increases until the Li-ion cell components begin to break down. At temperatures above 100°C, the electrolyte begins to break down, releasing gases that can cause pressure to build within cells designed without pressure-relief mechanisms. At high enough temperatures, Li-ion cells can experience thermal runaway as oxides break down, releasing oxygen, which further accelerates the temperature increase.

Consequently, maintaining optimum operating conditions for Li-ion cells is a critical requirement for the battery-management system. The challenge in designing the control/management system is ensuring reliable data collection and analysis to monitor and control the state of the Li-ion cells in the vehicle—a problem exacerbated by the nature of Li-ion cells themselves.

In an EV such as the Chevy Volt, the battery pack contains 288 prismatic Li-ion cells, which are, in turn, divided into 96 battery-cell groups that are connected to deliver a system voltage of 386.6V dc. Those battery-cell groups, in turn, are combined with temperature sensors and cooling elements into four main battery modules. Voltage-sense lines attached to each cell group terminate in a connector on top of each battery module, and a voltage-sense harness joins the connector to a battery-interface module that sits on top of each battery module. Here, four color-coded battery interface modules operate at different positions in the battery stack, corresponding to low-, medium-, and high-voltage ranges of dc voltage offset for the set of four modules.

Data from the battery-interface modules moves upstream to the battery-energy-control module (Figure 1). That module in turn passes fault conditions, status, and diagnostic information to the hybrid-powertrain-control module, which serves as the host controller for vehicle level diagnostics. At any time, the overall system runs more than 500 diagnostics every tenth of a second; 85% of those diagnostics focus on battery-pack safety, and the remainder target battery performance and life.

Multilayer board

The downstream analysis of battery performance starts with the battery-interface control module such as the one used in the Chevy Volt (Figure 2). Designed for high signal integrity, the four-layer PCB uses a combination of trace-layout techniques, isolation techniques, and ground planes to help ensure signal integrity in this challenging environment. The uppermost layer includes a majority of the components, including the optical isolators, a ground plane and signal traces with multiple vias providing connections to lower layers. In the second layer, power and ground planes spread under the high-voltage areas of the PCB; the third layer contains signal traces passing under those areas. The other side of the PCB, the fourth layer, is used for the ground plane and signal traces, and contains some additional components.

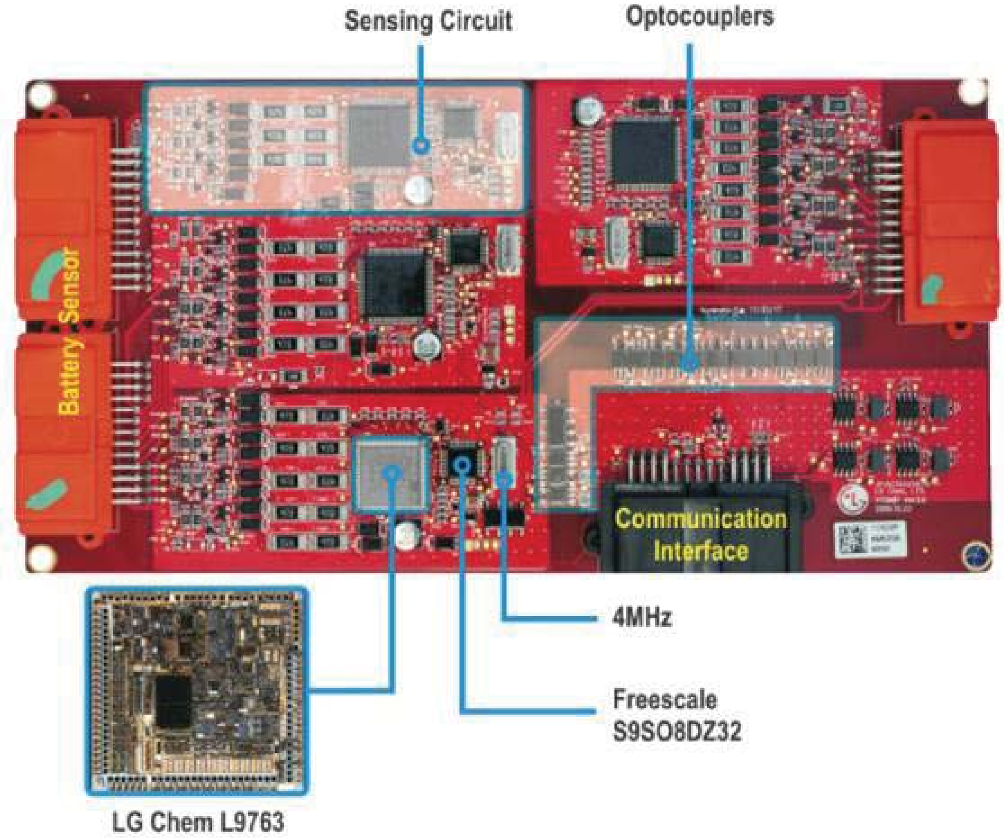

Figure 2. Each of the four battery-interface control-module PCBs in the Chevy Volt combines multiple sensing circuits with CAN communications circuitry isolated by optocouplers sitting at the edge of the communications subsystem. (Courtesy of UBM TechInsights)

Signal isolation

In EVs, communications and control are the cornerstone of vehicle operations, and in a car such as the Volt, multiple networks isolate and protect individual subsystems. Complex algorithms manage individual Li-ion cell groups and monitor battery packs within each sensing subsystem on a particular battery-interface control module. Ultimately, however, the critical data needed for overall battery management is contained in the CAN (control-area network) bus signal interface and a high-voltage fault signal. At the same time, system safety and reliability depend on safe isolation of the CAN bus network from the high-voltage sensing circuits. Although isolation can be engineered using a variety of methods and components, the harsh environment and multiple safety regulations make optocouplers a preferred solution in this kind of application.

Optocouplers offer high common-mode noise immunity and are essentially immune to the EMC and EMI associated with electrically noisy environments such as automobiles. In addition, these types of devices offer high levels of isolation, which is vital in the face of long-term dc voltage stress from the battery pack as well as the fast high-voltage transients that can occur during testing, charger connection/disconnection, and dc/dc conversion.

In selecting this critical component, key requirements for automotive applications include suitable package and working-voltage specifications. Although performance specifications such as speed, data rate, and power consumption remain important, concerns over EMI from fast switching times and high current transients tend to limit the need for very high-speed devices and instead increase the requirement for greater flexibility in adjusting slew rate and performance to limit EMI further.

To meet the stringent specifications required for the automotive environment, Avago offers multiple families of optocouplers that can handle the voltage sensing in the battery packs, provide isolation in the data communications interfaces, and still other applications . See Table 1 for an overview of available optocouplers qualified for automotive environments.

Automotive-grade optocoupler

For example, Avago Technologies' ACPL-M43T optocoupler provides isolation in the battery-interface control-module PCBs. A member of the Avago R2Coupler family, the ACPL-M43T is an automotive-grade, single-channel digital optocoupler in a compact five-lead SO-5 Jedec package designed for surface mounting. Along with reinforced insulation, Avago R2Coupler devices such as the ACPL-M43T use double wire bonds to reinforce critical functional pads (Figure 3). In addition, hermetic optocouplers have demonstrated extended reliability and a wide temperature range, well beyond those available with optocouplers based on consumer-grade LEDs. Intended for automotive applications, the Avago part uses automotive grade LEDs and is manufactured in conformance with the ISO/TS16949 quality system and is qualified to AEC-Q100 specifications.

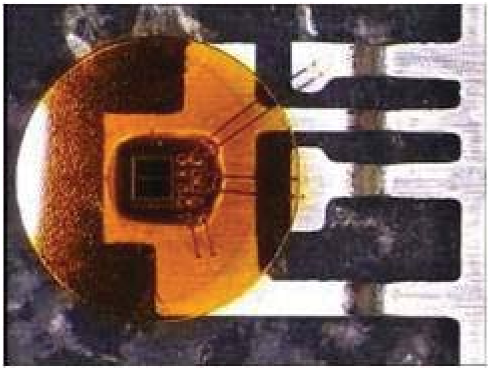

Figure 3. For automotive-grade R^{2}Coupler devices such as the ACPL-M43T optocoupler, Avago reinforces critical functional pads with double wire bonds (shown in the highlighted area).

Table 1. Suitable automotive applications

	Gate Drive	IsoAmp	IPM Driver	10MBd Digital	≤1MBd Digital	Analog
	ACPL-312T	ACPL-782T	ACPL-M46T	ACPL-M71T/K71T/K74T	ACPL-M43T/K43T/K44T	ACPL-M43T/K43T/K44T
	ACPL-38JT	ACPL-C87AT	ACPL-M43T	ACPL-M72T/K72T/K75T	ACPL-M49T/K49T	ACPL-M49T/K49T
	ACPL-34JT	ACPL-C87BT	ACPL-K43T/K44T	ACPL-M61T	ACPL-M46T	
	ACPL-K34T*	ACPL-C797T*				
Charger	•	•	•	•	•	•
Inverter	•	•	•	•	•	•
HVAC	•	•	•	•	•	•
DC/DC	•	•	•	•	•	•
Oil Pump			•	•	•	•
BMS		•		•	•	•

The device is well suited for EV battery-pack requirements, with specifications that include 567V continuous working voltage, 6000V maximum transient overvoltage, 5-mm creepage, and 5-mm clearance. The device features common-mode transient immunity of 30 kV/µs for either logic high or logic low output at 10-mA forward input current, reducing the likelihood that transients from other automotive subsystems might enter the CAN transmissions network.

The device's 1M baud speed is more than sufficient for this kind of design. Furthermore, the device features an open collector output, letting engineers tune the output slew rate to reduce electromagnetic emissions that could be fallout from fast switching times in downstream components—including CAN transceivers—despite the relatively low EMI inherent in the CAN physical-transmission protocol.

In the battery-interface module PCB, the ACPL-M43T devices sit on the edge of the communications section, isolating it from the high-voltage-sensing subsystems that are further shielded by ground planes in deeper PCB layers. The isolation interface provides three individual ACPL-M43T optocouplers for each of the three lines brought out from each sensing circuit—specifically, the CAN Tx output pin, the MCU CAN Rx input pin, and the high-voltage fault signal from the MCU. Output from the MCU CAN Tx pin, for example, passes through a shielded signal layer in the PCB to reach the pin 1 anode of an ACPL-M43T device to energize the embedded LED, resulting in a change of state at pin 5 Vo (Figure 4). The isolated signal is then passed to the communications output stage of the battery-interface module.

Optocouplers thus play an important role in the electronic subsystems of all-electric and hybrid gas/electric vehicles, providing signal isolation, high noise immunity and system protection (safety) by preventing the high voltages from breaching any path that could cause damage or shocks to the driver or passengers. The Chevy Volt is just one example of how optocouplers are applied to help manage the battery stack.

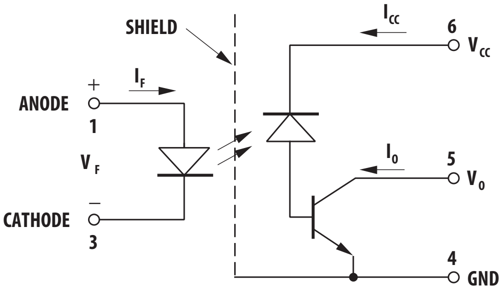

Figure 4. Avago ACPL-M43T optocouplers isolate signals between the MCU and the CAN transceiver.

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