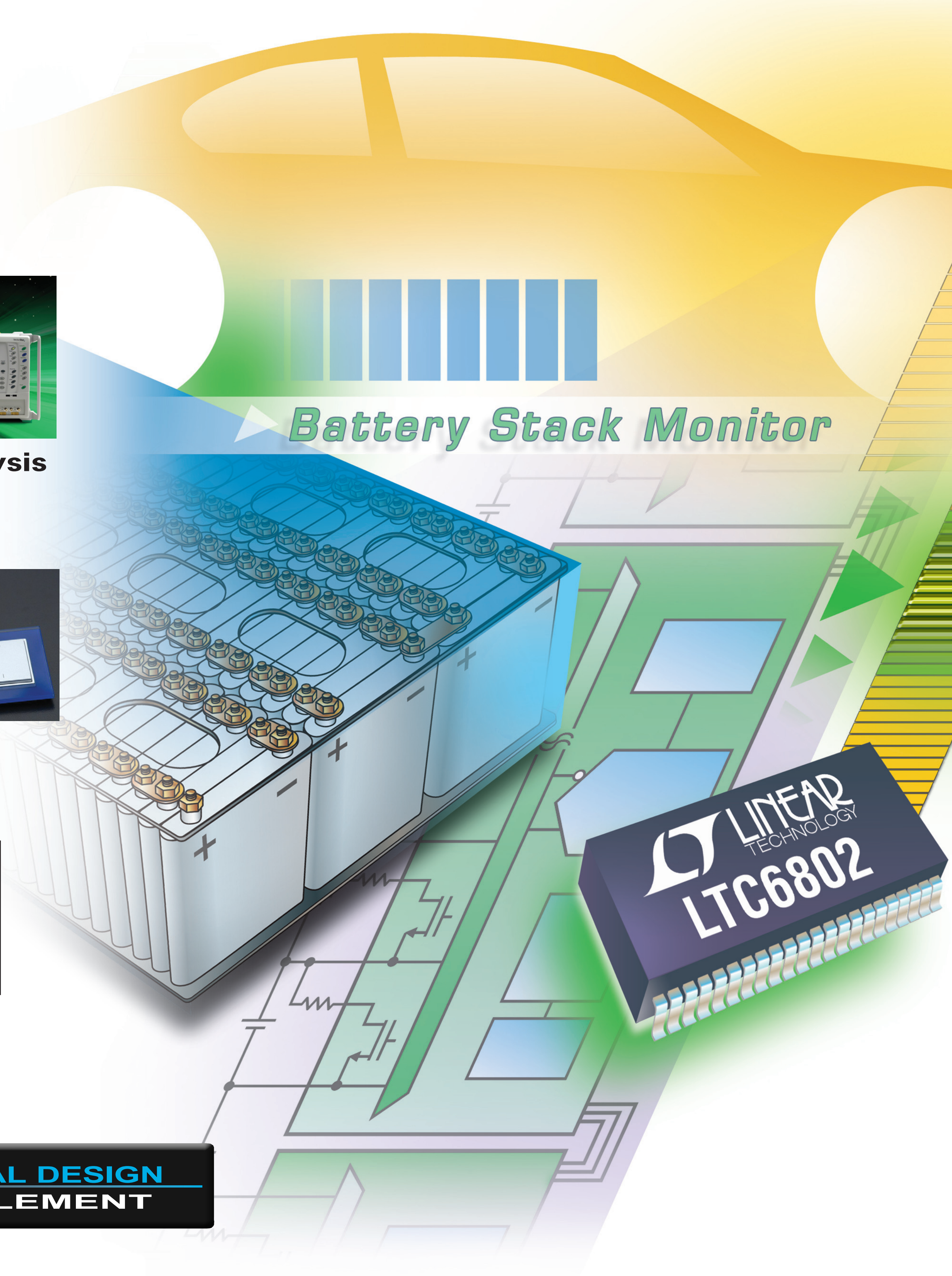
ELECTRONIC PRODUCT DESIGN

The magazine designers read

march 2009



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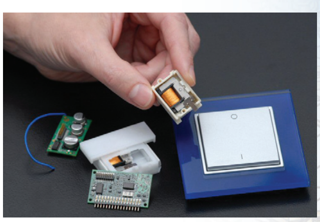

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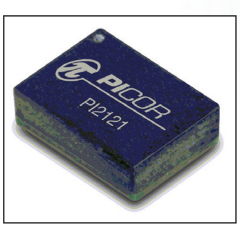

Power
Safe supply

MEDICAL DESIGN SUPPLEMENT

BATTERY MANAGEMENT ARCHITECTURES FOR HYBRID/ELECTRIC VEHICLES

Next generation Electric (EV) and Hybrid Electric Vehicles (HEV) are pushing the development of new battery technologies. To minimise cost and maximise efficiency, vehicle system designers need to exploit the full usable battery storage capacity.

Remarkable progress has been achieved on battery technologies for EVs and HEVs. Battery energy densities have steadily increased, and batteries today can be reliably charged and discharged thousands of times. If designers can effectively exploit these advancements in energy capacity, EVs and HEVs have the potential to be competitive with traditional vehicles in terms of cost, reliability, and longevity.

A battery's specified capacity refers to the amount of charge the battery can supply from 100% State of Charge (SOC) to 0% SOC. Charging to 100% SOC or discharging to 0% SOC will quickly degrade a battery's life. Instead, batteries are carefully managed to avoid complete charge or discharge conditions. Operating between 10% SOC and 90% SOC (80% of capacity) can reduce the total number of charging cycles by a factor of 3 or more, when compared to operating between 30% and 70% SOC (40% of capacity).

The tradeoff between effective battery capacity and battery lifetime creates challenges for battery system designers. Consider the above case of 40% cycling versus 80% cycling. If a system limits batteries to only 40% cycling in order to increase battery longevity by a factor of 3, the battery size must be doubled to achieve the same usable capacity as the 80% cycling case. This would double the weight and volume of the battery system, increasing costs and reducing efficiency.

	Parallel Independent CAN Modules	Parallel Modules with CAN Gateway	Single Monitoring Module with CAN Gateway	Series Modules with CAN Gateway
Accuracy	+ LTC6802s local to battery module	+ LTC6802s local to battery module	– Sensitive analog wires routed to single board	+ LTC6802s local to battery module
Reliability	+ CAN provides robust communications over cables, but extra circuitry gives increased failure modes	+ SPI interface not as robust as CAN over cables, but parallel communications minimizes negative impact	+ + Communications local to a single board, minimizing cable connections and sensitivity to communications interference	– SPI interface not as robust as CAN over cables
Manufacturability	– Significant parallel communications wiring required	– Significant parallel communications wiring required	– Single precision board, but analog sensitivity can create wiring challenges	+ Communications wiring in series between modules
Cost	– – Microcontrollers, CAN interfaces, and isolation in every module, plus a main controller board	– Single microcontroller and CAN transceiver, but separate precision PC boards with digital isolators	+ + Single microcontroller, CAN transceiver, and isolator, on one precision PC board	+ Single microcontroller, CAN transceiver, and isolator, but separate precision PC boards
Power	– – Multiple microcontrollers and CAN interfaces require excessive power consumption	– High-speed digital isolators have significant current draw	+ + Minimal circuitry with low-power SPI interface	+ Minimal circuitry, but SPI interface requires more power to communicate between boards

Table 1

Electric vehicle battery pack systems

An electric vehicle battery pack consists of dozens of batteries stacked in series. A typical pack might have a stack of 96 or so batteries, developing a total voltage in excess of 400 V for Li-Ion batteries charged to 4.2 V. While the vehicle power system sees the battery pack as a single, high-voltage battery—charging and discharging the entire battery pack at once—the battery control system must consider each battery's condition independently. If one battery in a stack has slightly less capacity than the other batteries, then its SOC will gradually deviate from the rest of the batteries over multiple charge/discharge cycles. If that cells' SOC is not periodically

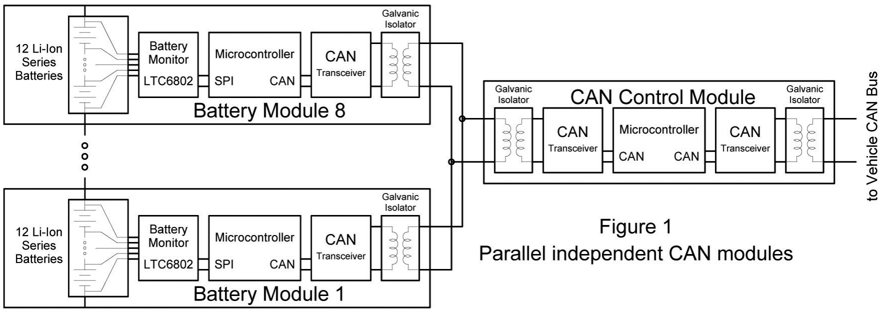

Figure 1
Parallel independent CAN modules

balanced with the rest of the batteries, then it will eventually be driven into deep discharge, leading to damage, and eventually complete battery stack failure. To prevent that from happening, each cell's voltage must be monitored to determine SOC. In addition, there must be a provision for cells to be individually charged or discharged to balance their SOCs.

An important consideration for the battery pack monitoring system is the communications interface. For communication within a PC board, common options include the Serial Peripheral Interface (SPI) bus and Inter-Integrated Circuit (I^2C) bus. Each has low communications overhead, suitable for low-interference environments. Another option is the Controller Area Network (CAN) bus, which has widespread use in vehicle applications. The CAN bus is very robust, with error detection and fault tolerance, but it carries significant communications overhead and high materials cost. While an interface from the battery system to the main vehicle CAN bus may be desirable, SPI or I^2C communications can be advantageous within the battery pack.

Battery monitoring requirements

There are at least five major requirements that need to be balanced when deciding between battery monitoring system architectures. Their relative importance depends on the needs and expectations of the end customer.

Accuracy

To take advantage of the maximum possible battery capacity, the battery monitor needs to be accurate. A vehicle, however, is a noisy system, with electromagnetic interference over a wide range of frequencies. Any loss of accuracy will adversely affect battery pack longevity and performance.

Reliability

Automobile manufacturers must meet extremely high reliability standards, irrespective of the power source. Furthermore, the high-energy capacity and potentially volatile nature of some battery technologies is a major safety concern. A failsafe system that shuts down under conservative conditions is preferable to catastrophic battery failure, although it has the unfortunate potential of stranding passengers. To minimise both false and real failures, a well-designed battery pack system must have robust communications, minimised failure modes, and fault detection.

Manufacturability

Adding sophisticated electronics and wiring to support an EV/HEV battery system is an additional complication for automobile manufacturing. The total number of components and connections must be minimised to meet stringent size and weight constraints and ensure that high volume production is practical.

Cost

Minimising the number of relatively costly components, like microcontrollers, interface controllers, galvanic isolators, and crystals can significantly reduce total system cost.

Power

The battery monitor itself is a load on the batteries. Lower active current improves system efficiency and lower standby current prevents excessive battery discharge when the vehicle is off.

Linear Technology has introduced a device that enables battery system designers to meet these difficult requirements. The

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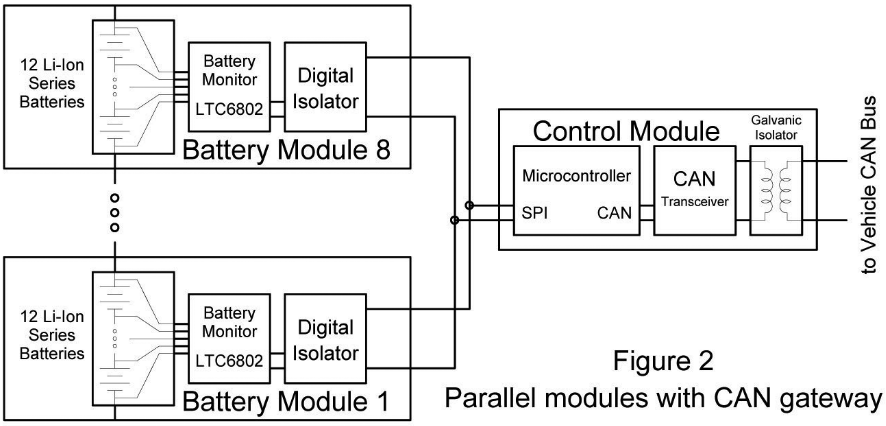

Figure 2
Parallel modules with CAN gateway

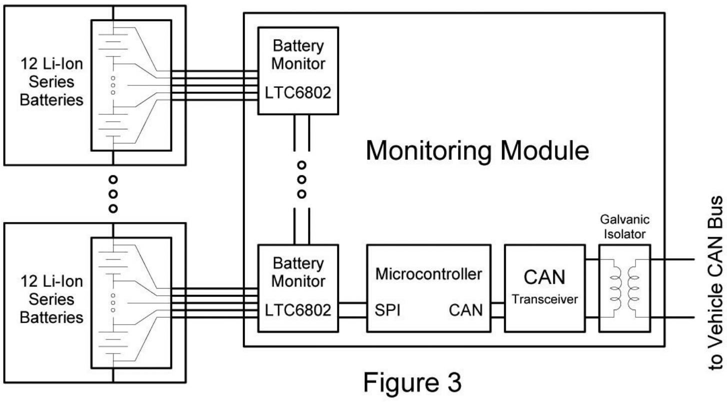

Figure 3
Single monitoring module with CAN gateway

LTC6802 is a battery stack monitor integrated circuit that can measure the cell voltages of up to 12 stacked cells. The LTC6802 also has internal switches that provide for the discharge of individual cells to bring them into balance with the rest of the stack.

Battery monitoring architectures

Four architectures for battery monitoring systems are depicted in Figures 1-4 and described below. Table 1 summarises the pros and cons of each architecture, assuming a 96-battery system organised into 8 groups of 12 batteries. In every case, one LTC6802 monitors each group of 12 batteries. For example, using 4.2 V Li-Ion batteries, the bottom monitoring device would straddle 12 batteries with potentials scaling from 0 V to 50.4 V. The next group of batteries would have voltages ranging from 50.4 V to 100.8 V, and so forth, up the stack. Each architecture is designed to be an autonomous battery monitoring system. Each provides a CAN bus interface to the vehicle's main CAN bus and is galvanically isolated from the rest of the vehicle.

Parallel independent CAN modules (Figure 1)

Each 12-battery module contains a PC board with an LTC6802, a microcontroller, a CAN interface, and a galvanic isolation transformer. The large amount of battery monitoring data required for the system would overwhelm the vehicle's main CAN bus, so the CAN modules need to be on local CAN sub-nets. The CAN sub-nets are coordinated by a master controller that also provides the gateway to the vehicle's main CAN bus.

Parallel modules with CAN gateway (Figure 2)

Each 12-battery module contains a PC board with an LTC6802 and a digital isolator. The modules have independent interface connections to a controller board containing a microcontroller, a CAN interface, and a galvanic isolation transformer. The microcontroller coordinates the modules and provides the gateway to the vehicle's main CAN bus.

Single monitoring module with CAN gateway (Figure 3)

In this configuration, there is no monitoring and control circuitry within the 12-battery modules. Instead, a single PC board has 8 LTC6802 monitor ICs, each of which is connected to its battery module. The LTC6802 devices communicate through non-isolated SPI-compatible serial interfaces. A single microcontroller controls the entire stack of battery monitors via the SPI-compatible serial interface, and it also is the gateway to the vehicle's main CAN bus. A CAN transceiver and a galvanic isolation transformer complete the battery monitoring system.

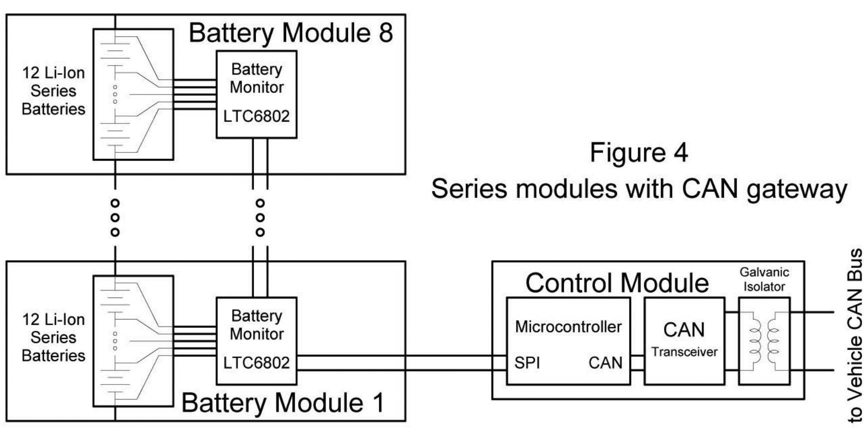

Figure 4
Series modules with CAN gateway

Series modules with CAN gateway (Figure 4)

Each LTC6802 is on a PC board within its 12-battery module. The 8 modules communicate through the LTC6802 non-isolated SPI-compatible serial interface, which requires a 3- or 4-conductor cable to be connected between pairs of battery modules. A single microcontroller controls the entire stack of battery monitors via the bottom monitor IC, and also acts as the gateway to the vehicle's main CAN bus. Once again, a CAN transceiver and a galvanic isolation transformer complete the battery monitoring system.

Battery monitoring architecture selection

The first and second architectures are generally problematic due to the significant number of connections and the external isolation required for the parallel interface. For this added complexity, the designer has independent communication to each monitor device. The third (single monitoring module with CAN gateway) and fourth (series modules with CAN gateway) architectures are simplified approaches with minimal limitations. The LTC6802 can address all four configurations, leaving the choice to the system designer.

Two variants of the LTC6802 have been created, one for series configurations and one for parallel configurations. The LTC6802-1 is designed for use in a stacked SPI interface configuration. Multiple LTC6802-1 devices can be connected in series through an interface that sends data up and down the battery stack without external level shifters or isolators. The LTC6802-2 allows for individual device addressing in parallel architectures. Both variants have the same battery monitoring specifications and capabilities.

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