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Battery Management Architectures for Electric Vehicles Using CAN Controller

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Abstract: Electric Vehicles [EV] of next generation are pushing the development of new battery technologies. To minimize cost and maximize efficiency, vehicle system should have full usable battery storage capacity. Remarkable progress has been achieved on battery technologies for EVs and HEVs [Hybrid Electric Vehicles]. 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. 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^2 C) 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.

Keywords: Electric Vehicle [EV], Hybrid Electric Vehicle [HEV], Microcontroller, Controller Area Controller [CAN], CAN Gate way, CAN Bus, LTC6802 [Battery Monitor], Galvanic isolation transformer.

1. INTRODUCTION

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. 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 reach 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 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

Moreover, 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 trade-off 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.

2. BATTERY MONITORING REQUIREMENTS

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

A. 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.

B. Reliability

Automobile manufacturers must meet extremely high reliability standards, irrespective of the power source. Furthermore, the high-energy capacity and potentially

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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.

C. 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.

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

E. 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 [Ref: Fig 2] when the vehicle is off.

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

3. 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	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

A. Parallel independent CAN modules
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. Fig 1: shows the block diagram of parallel independent CAN modules.

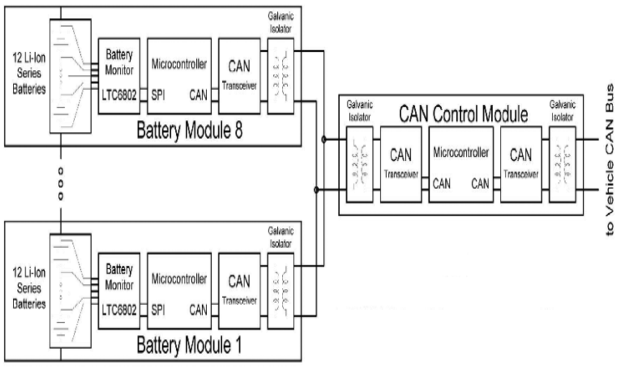

Fig 1: Parallel Independent CAN modules

B. Parallel modules with CAN gateway
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. Fig 2: shows the parallel modules with CAN gateway.

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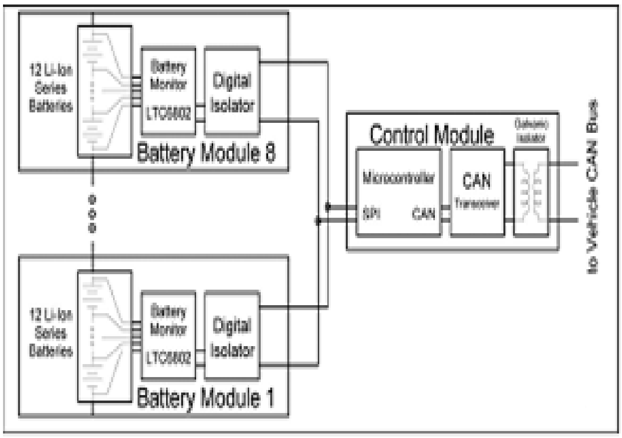

Fig 2: Parallel modules with CAN gateway

C. Single monitoring module with CAN gateway
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. Fig 3: shows the single monitoring module with CAN gateway.

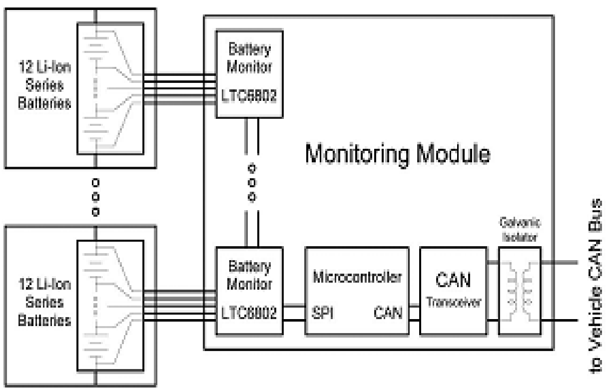

Fig 3: Single monitoring module with CAN gateway

D. Serial modules with CAN gateway
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. Fig 4: shows the serial modules with CAN gateway.

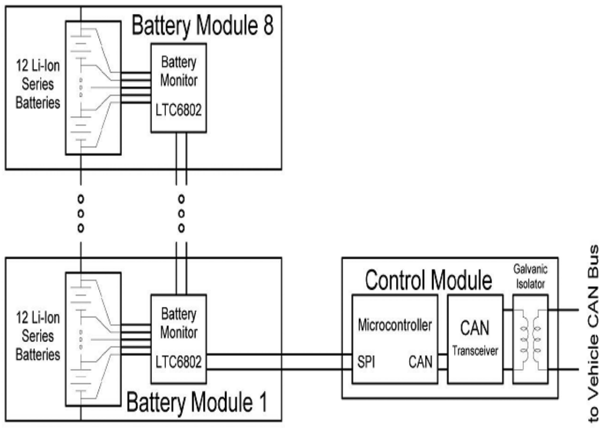

Fig 4: Serial modules with CAN gateway

4. 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.

5. CAN BASED NETWORK SYSTEM

The main difference for messages in CAN is that they are non-pre-emptive i.e., a lower priority frame may block a higher priority frame. Let the worst case response time of a given message m be Rm, [Equation 1]. Where T is the period of a given task, wm is the worst case queuing delay, Cm is the longest time taken to transmit message, B is the worst case blocking factor for possible interface from tasks with lower priority than m. The queuing jitter Jm may be used instead of Rsend (m) JI is the release jitter, Tbit is the time to transfer one bit on the CAN bus, and hp (m) is the set of tasks with higher priority than m.

$$R_m = R_{send(m)} + w_m + C_m$$

$$w_m^{n+1} = B_m + \sum_{\forall j \in hp(m)} \left\lceil \frac{w_m^n + J_j + \tau_{bit}}{T_j} \right\rceil C_j \qquad (1)$$

Consider a CAN-based experimental set-up for the networked power train subsystem of a HEV. The worst case response time for one period operation in this network-based system is found as the sum of the worst case response time required for the execution of tasks in every node and the worst case response time for communication tasks between nodes. One of challenging problems in control of a network-based system is network delay effects. The time for reading a sensor measurement and for sending a control signal to an actuator through the network depends on network characteristics such as their topologies, routing schemes, etc. Thus, the total performance of a network-based control system can be seriously affected by network delays. The severity of the delay problem is aggravated if data loss occurs during a transmission period. Moreover, the transmission delays do not only degrade the performance of a network-based control system, but may also destabilize the system.

6. CAN INTERFACE UNIT

The interface unit can capture signals on the bus without disturbing the flow of signals and monitor the status of network communication. Basically, it shows the target identifier and the data in the message frame on the bus; moreover, elapsed time for communication between nodes and the task computation time in each node are also analysed.

PCI-CAN hardware supports the Real-Time System Integration (RTSI) bus as a way to synchronize multiple interface cards in a system by sharing common timing and triggering signals. The programming model using the frame APIs for C function in the PCI-CAN system is represented in Fig 5.

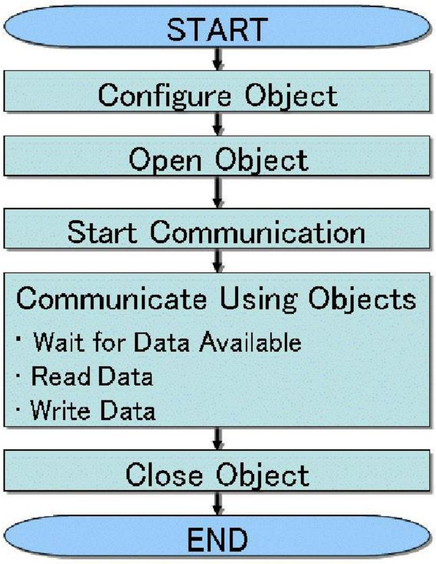

Fig.5. Programming model using APIs for PCI-CAN

The communication between the Windows platform-based monitoring program and the PCI-CAN board is performed using the supplied frame APIs. The monitoring program stores the captured messages in a frame unit and displays the identifier with the corresponding data in user-configurable format. The monitoring program is coded using the Win32 5546 APIs and MFC under the Microsoft Visual Studio 2005. Interesting physical variables of a vehicle may also be displayed in various representation forms and analysed to evaluate the vehicle control performance.

7. CONCLUSION

In this paper, a CAN controller unit of an embedded system is used and it is applied to an experimental set-up for battery bank efficiency monitoring. Next generation vehicles usually require a lot of communication data between subsystems or ECUs [Electronic Control Units] to improve the battery economy and the advanced safety. Unexpected transmission delay on a data bus may be a cause for an unstable operation of a vehicle which may also yield a serious result.

Moreover, in this paper, a simple timing analysis method has been presented and applied to the experimental set-up for CAN-based subsystem of electric vehicles. The analysis was done using a PCI-CAN board and a Windows platform-based monitoring program to calculate the computation time and communication time for each task. The worst case response time to determine the sampling period for stable operation in a vehicle was found and it was shown that the predetermined sampling time can be effectively modified in the event of high priority task occurrence in the network.

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