Li-ion Batteries as Replacement for Standard Lead-acid Batteries in the 12V Automotive Powernet

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There is no stopping the relentless march of Lithium-ion (Li-ion) batteries in e-vehicles (EV) and hybrid e-vehicles (HEV). In the meantime, nearly every vehicle manufacturer develops a battery of this kind for its fleet and some have already launched series production. The use of Li-ion technology is no longer limited to high-performance batteries for e-vehicles and hybrid vehicles. Li-ion batteries are now also available on the market for 12V automotive on-board power supply systems.

In the initial phase, the target market was motor racing and technology-minded customers of sports car makers. The strongest motivator was a reduction in weight of over 60%, which could be achieved by using Li-ion batteries compared to standard lead-acid batteries. As is frequently the case, motor sport merely plays a pioneering role, and several major carmakers are now working on 12V Li-ion on-board power supply batteries for their fleet of production vehicles. This comes as no surprise given the obvious benefits offered by Li-ion technology. In addition to their lower weight, Li-ion batteries reduce the load on the alternator as they retain more power and are able to handle the charge faster than lead-acid batteries. This results in reduced fuel consumption and thus reduced CO_2 emissions.

In addition, Li-ion batteries offer distinct benefits with vehicles featuring start-stop systems. While the life expectancy of lead-acid batteries—which are subject to constant stress from repetitive engine starts—is only approximately 1.5 to 2 years, tests have shown that Li-ion batteries can withstand robust use for over 6 years or more. The longer service life combined with the far higher volume of Li-ion batteries anticipated in the future—due to their increased use in e-vehicles, hybrid vehicles, and vehicles with start-stop function—will inevitably result in considerable reductions in the cost of Li-ion technology, which currently is still admittedly expensive.

Nonetheless, Li-ion batteries also have weaknesses, especially when operated at cold temperatures. For example, cell manufacturers currently guarantee cell capacity for lithium iron phosphate ($LiFePO_4$) cells only down to approximately -25°C. Lithium-yttrium ($LiFeYPO_4$) cells (lithium-iron-phosphate cells doped with yttrium) enable guaranteed operation down to -35°C. However, tests on diesel vehicles, which probably place the greatest demands on the starter battery, showed that with a reasonable design a cold start at a temperature as low as -40°C or lower is easily possible. Incidentally, cold-starting capability is not a strength of lead-acid batteries. According to breakdown statistics of the world's largest automobile club, 70% of all starter problems in cold conditions are due to insufficient lead-acid battery performance.

Atmel now offers a complete system solution for 12V Li-ion batteries. As already pointed out in Vol. 7 of *Automotive Compilation*, modern vehicles featuring this start-stop function require charge-state monitoring to guarantee engines can be restarted, e.g., after being stopped at traffic lights. With the number of these vehicles rising, anything else would lead to chaotic traffic conditions. With the Atmel® ATmega32/64HVE2 Intelligent Battery Sensor (IBS), Atmel is now able to supply final silicon.

The ATmega32/64HVE2 incorporates a highly precise analog front end with two 16-bit Sigma Delta analog-to-digital converters (ADCs) for measuring the battery voltage and the charge/discharge current. A key benefit here is the wide range of only a very few mA up to 1000A within which current can be measured from the battery. This is ideal for battery fuel gauging. In order to efficiently determine the charge state of the battery based on the captured data, an 8-bit Atmel AVR® microcontroller with a high-performance 32-bit math extension module was integrated. In addition, the system includes a voltage regulator, watchdog and LIN transceiver. The LIN transceiver, which is based on the well-known Atmel LIN IP with approvals from almost every OEM worldwide, allows data about the battery's state of charge to be exchanged with the vehicle.

To achieve the nominal voltage of approximately 13V in the vehicle, 4 lithium-iron-phosphate ($LiFePO_4$) cells with nominal voltage of approx. 3.3V must be connected in series. This results in a nominal voltage of 13.2V for the entire battery. For such a serial connection, it is highly advisable to have single cell monitoring along with charge state monitoring of the entire battery. On the one hand, this protects the individual battery cells from overcharging or from deep discharge. At the same time, the information

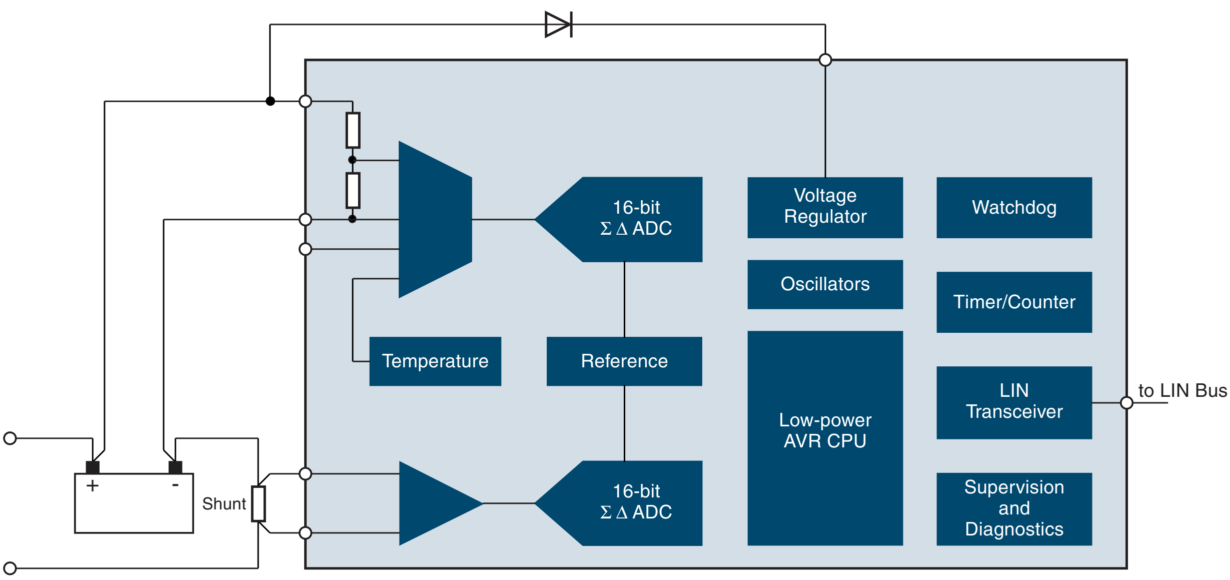

Figure 1. Application Circuit

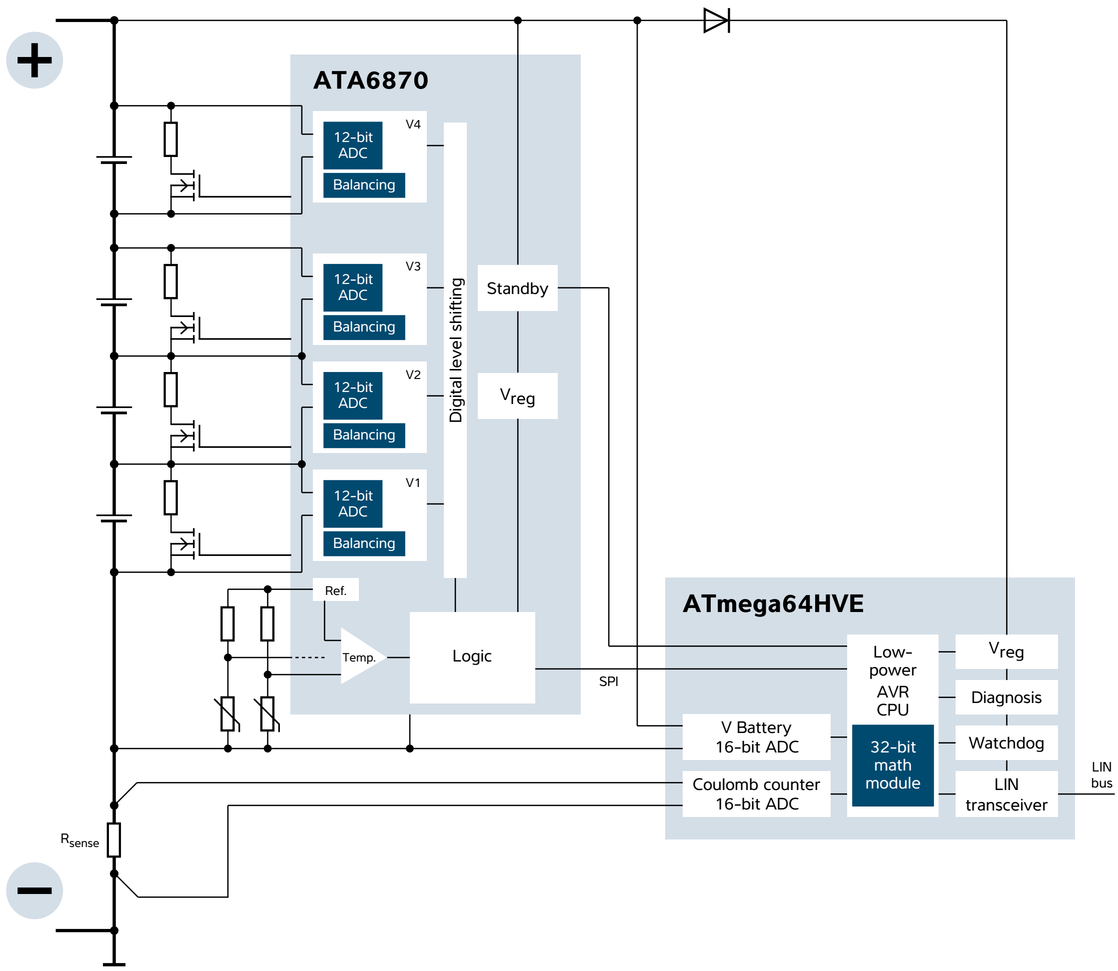

Figure 2. Application with ATA6870 and ATmega32/64HVE

collected in this way can be used to carry out charge compensation between more strongly and weakly charged system cells. For this function, Atmel offers the ATA6870, which is a circuit that can monitor 4-6 Li-ion cells. This circuit simultaneously performs cell balancing of individual cells. The ATmega32/63HVE2 takes over central control of the ATA6870 during this operation and evaluates the individual cell voltage values registered by the ATA6870 as well as the cell temperature recorded by the circuit. After this process, appropriate charge compensation between the cells is carried out via the cell balancing outputs of the ATA6870.

With these two devices, the ATmega32/64HVE2 and the ATA6870, Atmel provides a complete system solution for Li-ion batteries used in 12V systems consisting of:

- IC power supply directly via the 12V powernet
- LIN transceiver with outstanding EMC performance
- Precise current measurement in a range of only a very few mA up to 1000A and more
- Precise voltage measurement
- Powerful AVR microcontroller for fuel gauging and Li-ion battery cell management control
  - –Math extension module
  - –32/64k Flash memory
  - –Low current consumption
  - –16-bit analog front end
- Single cell monitoring
- Cell balancing: current transfer between different battery cells
- Cell temperature measurement