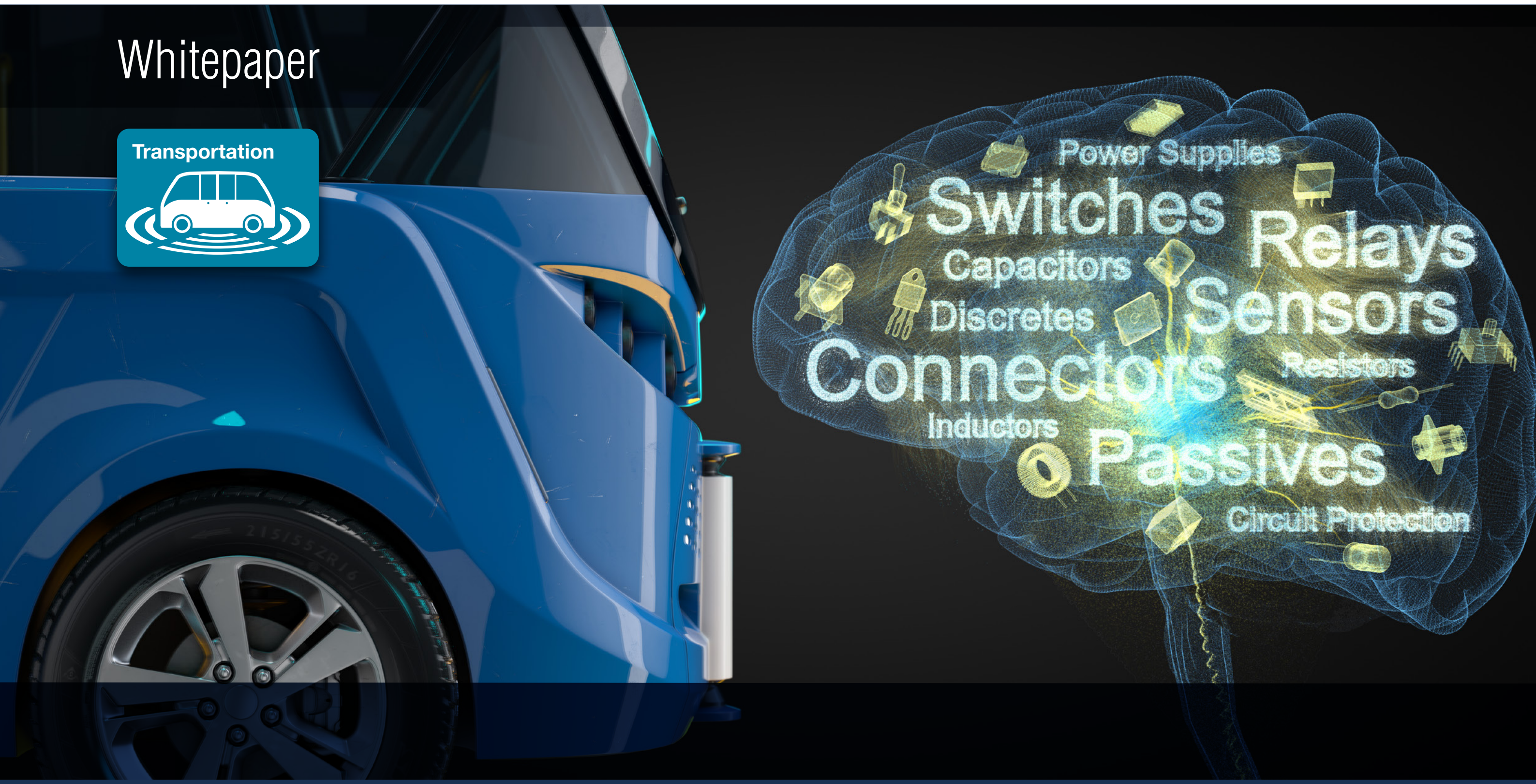
Whitepaper

Transportation



Battery Management for Electric Vehicles

Dermot Byrne, Director Industry Marketing, Transportation, TTI Europe

The Specialist in Electronic Component Distribution

Executive Summary

Governments, car makers, and markets all agree that the age of the electric vehicle is here. Global sales of hybrids and EVs are expected to surpass those of ordinary internal-combustion vehicles by 2038, and achieve cost parity even sooner, by 2025. Electrification of public transport, such as buses, also represents an exciting development in low-carbon transportation.

Markets are moving quickly, and so, too, is the technology. In particular, battery technology has perhaps the greatest potential to unlock rapid improvements in drivability, recharging times, and cost of ownership. While chemists and materials scientists strive to deliver new compositions and electrode structures that can store more energy, charge and discharge more quickly, and reduce size, weight, and cost, one subsystem has a critical role in unleashing the maximum potential of the battery and ensuring long-term reliability: the Battery-Management System, or BMS.

No research into exotic materials or processes is needed to deliver a cutting-edge BMS that is capable of managing and protecting the most advanced batteries in use today, or expected in the near future. A smart BMS can be realized using familiar components and design techniques, although it is worth mentioning that experts see the compute capability of the BMS rising quickly to manage an increasing variety of parameters with greater precision.

While the core BMS functions are well known and relatively straightforward to implement using standard ICs and/or microcontrollers, many additional sensing and protection components are needed to complete the design. These should be carefully selected to withstand the automotive environment and operating voltage/current ratings, and ensure proper protection for the battery, the BMS circuitry, and humans who need to come into contact with the system. This whitepaper describes those components, and their role in maximizing the performance of today's electric vehicles to help secure a lower-carbon tomorrow.

Introduction

The battery is arguably the most important part of an electric vehicle: its performance defines critical dynamic parameters such as electric driving range and acceleration, it constitutes a significant proportion of the vehicle's weight, especially in fully electric (non-hybrid) vehicles, and it also contributes significantly to the vehicle's overall cost. Moreover, while research in fields such as electric motors and power electronics is yielding only incremental improvements, the development of new battery chemistries, and anode and cathode material technologies offer hope for greater improvements in driving range, recharging time, and the price of EVs compared to conventional vehicles.

A good battery-management system (BMS) is critical for maintaining condition and optimizing performance to maximize the vehicle's dynamic abilities, ensure reliability, and deliver the best possible overall ownership experience.

The Battery and BMS in Context

Figure 1 illustrates the major parts of a H/EV battery pack, showing the general layout of batteries, connectivity, control circuitry, and packaging. It is worth noting that electric-vehicle technology is still relatively young and evolving quickly. A standard approach to battery-pack construction and BMS architecture has not yet emerged.

In addition, there are various approaches to cooling of the battery, ranging from heatsinks and forced-air cooling with fans, to liquid cooling with the familiar expedient of a front-mounted radiator in the nose of the vehicle. Tesla, for example, has adopted liquid cooling and, indeed, builds batteries using hundreds of individual standard-size Li-ion cells to maximize the surface area that can be exposed to the coolant channels. Other approaches advocate flexible battery pouches, or custom shapes, to help achieve the desired overall vehicle packaging.

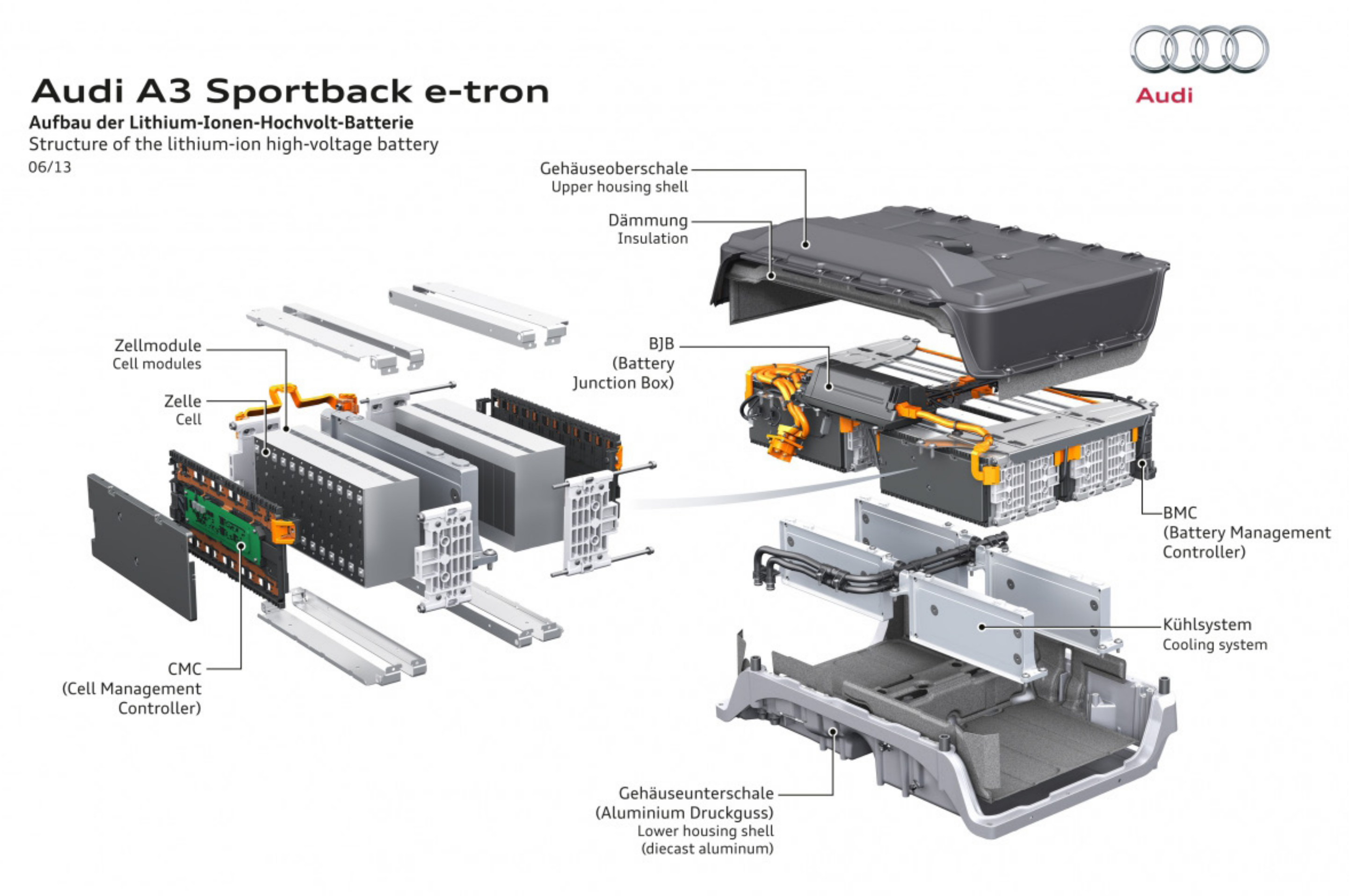


Figure 1: Main components and general layout of H/EV battery pack (Source Audi Technology Portal)

The battery pack is typically organized as groups of cells connected in series to create a module. Modules are then connected in series to reach the required terminal voltage, which may be 380V or more. Extra modules are added in parallel to achieve the desired capacity, which is usually quoted to the user in kilowatt hours (kWh). The battery capacity is restricted by factors such as the size and layout of the vehicle, weight, as well as cost. As the current dominant battery chemistry for consumer and battery-EV applications, the cost of lithium-ion batteries for automotive use has fallen significantly in recent years and is now about $200/kWh or less.

The BMS has multiple roles, including continuously controlling the charge/discharge rate and monitoring the state of charge (SoC), managing the balancing of cell voltages, and providing essential safety features such as over-temperature and over-discharge protection, safety isolation of critical electrical subsystems, and the ability to disconnect the battery to allow servicing of the vehicle. Advanced BMS features may include OBD-II support to simplify fault diagnostics, CAN-bus integration, data logging, and support for firmware upgrades in the field.

The BMS must capture data and distribute commands on a cell-by-cell basis. In addition to the underlying processing and communication, an array of sensing, isolation, protection, and signal-conditioning circuitry is needed, to enable accurate detection of the battery condition under any and all operating conditions, to manage the battery and integrate the system within the overall vehicle electronic infrastructure.

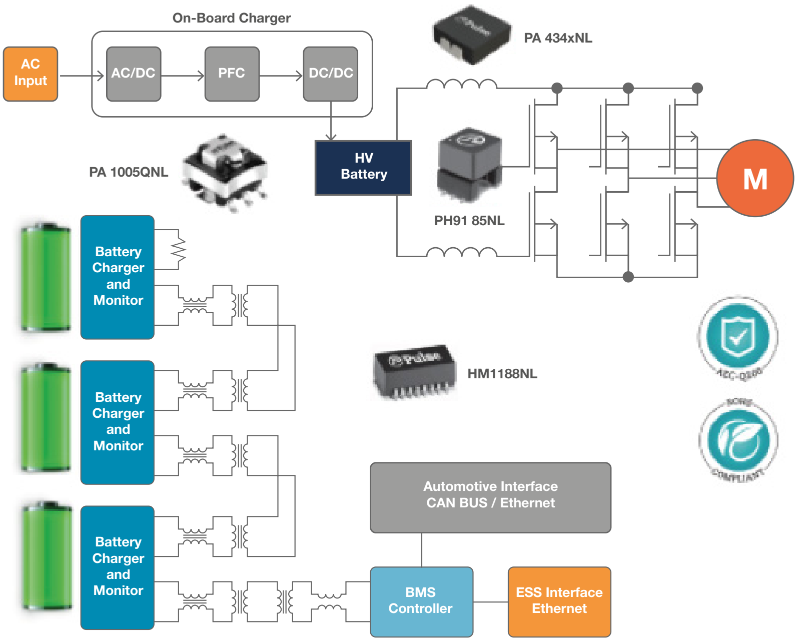
In practice then, the BMS is multi-faceted and complex, bringing together power switches, temperature and voltage/current-sensing elements, filtering and decoupling, isolation transformers, safety interconnects and others, to support the major functional blocks that include charge-control, fuel-gauging, balancing, data-processing and communication. The amount of processing in the BMS, to keep the battery in control and optimize performance and reliability, is increasing rapidly as the batteries become more sophisticated and demand more intensive control and management.

Monitoring and Protecting the Battery

The role of the BMS is to maintain the condition of the battery on a cell-by-cell basis to ensure safety and long-term reliability, as well as optimal performance. Ultimately, the BMS controls charging and discharging via two MOSFETs associated with each cell. Based on measured cell-condition data such as state of charge, terminal voltage and temperature and the power requested by the driver – moderated by vehicle control systems such as traction control – the BMS adjusts the charge and discharge rate of each cell through PWM control of these MOSFETs. The MOSFET control circuit needs to be separated from the battery, which can be achieved using a high-isolation transformer such as the Pulse Electronics PH9185.XXXNL series.

The circuitry for voltage and temperature sensing and monitoring the battery state-of-charge, often using Coulomb counting, is located close to each cell and communicates with main battery-management functions across a serial communication link such as an RS-485 bus. For safety, the monitoring/control circuitry for each cell is isolated using a bus-isolation transformer such as Pulse's HM1188NL (figure 2).

Figure 2: Bus isolation using a transformer such as the Pulse HMI1188N (source Pulse Electronics)
https://www.pulseelectronics.com/news/2017/09/using-battery-management-systems-for-more-reliable-evs-and-phevs/



Cell balancing is an important part of the monitoring and protection mix, to equalize the loading placed on the cells and prevent thermal runaway that can result from under- or over-voltage conditions on any individual cell. Sensing is needed on a per-cell basis to let the system apply an equalizing charge, and can be implemented using a component like the PA4334 series inductor by Pulse to help identify a drop or increase in cell voltage. Pulse also has a series of surface-mountable flyback transformers for handling balance-charge transfers, as well as push-pull transformers that help prevent cell-voltage imbalances due to loading.

For battery charge monitoring, Vishay offers an alternative in its WSLS Power Metal Strip shunt resistors. These 6W-rated sense resistors are produced using a process that allows extremely low resistance values down to 0.0003 ohm that permit high accuracy at a low cost.

Maintaining consistent cell temperature is essential to ensure safety and longevity. Over-charging or excessive power draw can raise the cell temperature. The temperature of the battery pack can be sensed at various points, such as at individual cells as well as interconnects and detecting coolant temperature, to let the system acquire a complete assessment of battery health. Detecting over- or under-temperature at any individual cell enables the system to restore the correct temperature by for example suspending regenerative charging, or limiting the output current.

Figure 3: Ring terminal sensors are used to measure surface temperature or temperature at busbar connections. (Source Amphenol.)

Figure 4: Amphenol CTS temperature sensors are inserted in pipes or unions to sense the coolant temperature directly (Source Amphenol) https://www.amphenol-sensors.com/en/thermometrics/assemblies/3292-coolant-temperature-sensor

The battery temperature can be sensed at multiple points to establish an accurate and detailed picture of the environment and the condition of the battery. These include not only the temperature at the surface of the cell but also the external battery casing, busbar connections, and temperature at various points in the liquid-cooling system, if featured. Sensing temperature in differing locations such as these presents a variety of challenges, such as extreme space limitations for measuring cell surface temperature, or insertion of temperature probes into the liquid coolant pipes.

Amphenol has a variety of temperature-sensing options designed explicitly for automotive BMS sensing applications, including extremely small sensors designed for insertion between cells and positioned against a flat surface, as well as sensors for external mounting on the battery case, or permanent connection to high-current busbars. Among these, ring terminal temperature sensors that contain an NTC thermistor and are screw-fixed in position (figure 3) can perform surface-temperature or terminal-temperature measurement and allow easy attachment of a lead wire or connector.

Also available are thin-film temperature sensors that must conform to non-flat surface topology, as well as Thermometric coolant temperature sensors (CTS) that can be inserted in inlet or outlet unions (figure 4).

Protecting the BMS Circuitry

While the core role of the BMS is to protect the battery pack against potentially damaging imbalances and over-temperature conditions, its own circuitry must be protected against hazards that pervade the EV, such as high-energy transients and high-voltage discharges. These can occur at multiple locations, such as close to cells or battery modules, or at terminations of cables. Devices such as transient voltage suppressors (TVS), which are already proven to protect sensitive electronic equipment against over-voltages, are now available in AEC-Q100 certified families such as the Littelfuse TPSMC series, which have 1500W peak pulse-power capability and satisfy IEC 61000-4-2 and IEC 61000-4-4 specifications. There are also AEC-Q101 qualified ESD protection diodes, such as the Littelfuse AQ1 series, which are ideal for protecting the connections between individual cell-monitoring units, as well as families such as the SM24CANA TVS Diode Array that provides industry-standard protection for CAN bus infrastructure.

Figure 5 identifies the major connections between functional parts of the BMS, which require protection against potentially damaging over-voltage, over-current, and ESD events. Table 1 clarifies the component types selected and their key properties.

Figure 5: Essential protection for BMS circuitry against high-voltage/high-current hazards that pervade electric vehicles. (source Littelfuse) https://www.littelfuse.com/~/media/electronics/application_guides/littelfuse_automotive_electronics_applications_guide.pdf.pdf

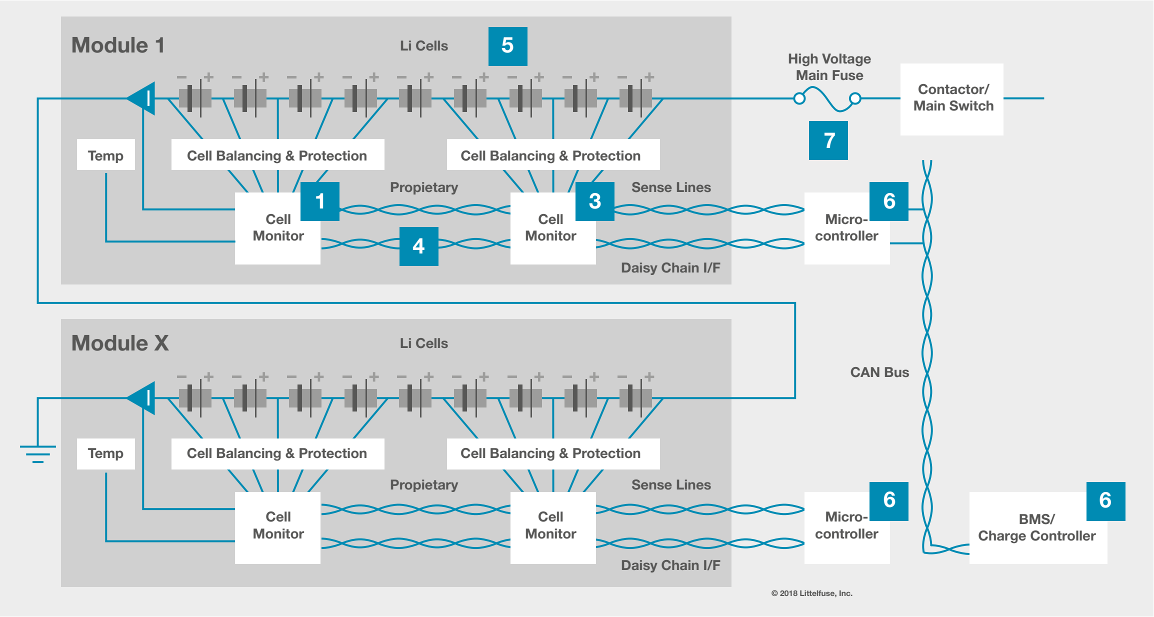


Table 1: General summary of protection devices in figure 5.

Location	Protection device type	Properties
1	Overcurrent / SMD fuse	Normal overcurrent protection up to about 8A. high-voltage protection up to 450V and 5A.
2	Overcurrent / fuse in wiring harness	Ceramic fuses up to 10A or greater, with high interrupt rating.
3	Overvoltage / TVS diode	Peak pulse capability up to 5000W
4	ESD / diode array	Uni/bi-directional 30/30kV ESD protection
5	Overvoltage / TVS diode	Designed to protect sensitive electronic equipment
6	ESD / diode array	Industry-standard CAN-bus protection
7	Main high-voltage battery fuse	EV-specific high-current fuse. Rated 60-250A/500V

Protecting People

Figure 6: The manual service disconnect is safe and easy to use by service staff and emergency response teams.

High-current, high-voltage connectivity is obviously needed between the battery system and the inverter that controls and drives the traction motor. While high reliability, low contact resistance, and protection against ingress and corrosion are extremely important, so, too, is a reliable and robust means of disconnecting the battery to enable the vehicle to be serviced safely, or if necessary for the safety of occupants or responders in the event of an accident.

Suitable battery connectors, therefore, are designed to allow fast and easy disconnection and reconnection without compromising the physical integrity or reliability of the connector assembly, or the integrity of the electrical interconnections. Personnel should also be protected against contact with battery-side terminals that remain at high voltage while the connection is unmated.

An example is the TE Connectivity AMP+ Manual Service Disconnect (figure 6), which features a two-stage finger-actuated lever system that allows the high-voltage contacts to be separated without using tools, and is designed to USCAR-2, USCAR-37, and IEC 60529 standards and specifications. The battery-pack HV cables are prevented from short-circuiting, and HV contacts are always finger safe.

Conclusion

The battery is the subject of some of today's most important advancements in electric vehicle technology, aiming to extend driving range, reduce charging duration, enhance performance, reduce cost of ownership, and drive cost parity between EVs and conventional combustion-engine vehicles.

The BMS has a critical role in maximizing the battery-pack performance under all driving and usage conditions. A well designed BMS detects possible threats to the battery, and the onset of sub-optimal performance through imbalances or overtemperature. It comprises multiple layers of safety and protection mechanisms, at the cell, module, and system levels to preserve the battery, maximize performance and reliability, with robust and reliable disconnection provisions to protect users, service personnel, and first responders in the event of an accident. On the other hand, the BMS itself requires robust protection against potentially damaging electrical hazards such as ESD and overvoltage or overcurrent events.

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European Headquarters:
TTI, Inc.
Ganghoferstr. 34
82216 Maisach-Gernlinden
Germany
Tel.: +49 (0)8142 6680 – 0
Fax: +49 (0)8142 6680 – 490
Email: sales@de.ttiinc.com
www.ttieurope.com