

ELECTRIFYING A MOVEMENT: CONNECTIVITY FOR ELECTRIC VEHICLE CHARGING, ENERGY STORAGE, AND CONTROLLED POWER MANAGEMENT



Handheld, battery-powered devices are pervasive in our daily lives. Cell phones, tablets, laptops, leaf blowers, webcams, and drones (to name a few examples) are a part of everything we do. What once seemed like magic, are now common and ordinary. These devices all have several things in common:

1. they need to be charged quickly and conveniently;
2. they need to efficiently and safely store energy in a battery; and
3. they need to operate and function effectively and intelligently.

The same story holds true for Battery Electric Vehicles (BEVs), yet they are not as pervasive as handheld devices because we are only at the early stages of making the necessary technological advances to meet their extremely demanding consumer and societal needs. This is because there is a fourth (4) characteristic to the bat-

tery-powered electric vehicle: the need to operate flawlessly in extremely harsh environments and never leave an owner stranded.

In a well-known quote attributed to Gene Kranz, former Chief Flight Director of NASA: “Failure is not an option.”

The automotive industry is focused on these four points, developing new and improved vehicle architecture approaches to efficiently address these challenges.

Connectivity, from power to propulsion, is a key enabler of bringing the Electric Mobility vision to reality. TE Connectivity’s team of engineers and scientists collaboratively engage with our customers and other technology leaders from across the industry, focusing on all aspects of connectivity – from the car charging inlet, to the battery through to the electric motor.



CHARGING A BATTERY ELECTRIC VEHICLE

Today's available fast chargers, providing between 50 to 200 kilowatts of power, typically can add just under 200 miles of driving range in an hour's time. Currently the industry is developing High-Power Charging (HPC) to provide the same amount of charge (200 miles of range) in 10 minutes or less, producing an experience similar to filling up your gas tank in your internal combustion engine (ICE) vehicle. Compared to a typical cell phone, this means that the requirements for charging an electric vehicle is 1000 times more demanding (today) and another order of magnitude (10,000 times) more demanding tomorrow.

These demands are driving the industry to focus on a broad range of solutions to challenges never before seen in the automotive industry. Charging inlets are needed that can handle 10-20 times the power of the current generation of electric cars. Trying to push up to 500 kilowatts of power through an inlet sized to handle 50 kilowatts is likened to someone drinking from a firehose. Connections, cables, and switches / contactors must be able to intelligently manage this power transfer, dealing with heat, arcing, and safety issues. New thermal modeling and simulations techniques need to be developed, allowing for optimized design of components and subsystems that can be stressed by the high charging voltage and current needs.

STORING POWER IN A BEV

The demands placed on an electric vehicle's battery are tremendous compared to that of a typical smartphone. It needs to have on the order of 200X the capacity and operate at 100X the voltage, making an electric vehicle's battery quite complex. If that's not tough enough, automotive battery packs must fit within the dimensions of the car and safely operate in an extremely harsh environment. Thanks to the demand for more and more battery powered devices and green energy technology, there is a tremendous amount of investment taking place to dramatically improve battery technology in order to store the energy that is needed to operate the car.

Key challenges are doing so safely, reliably, and in small packages. This drives the need for high voltage, physically compliant, battery module contacts and connection interfaces for cell-to-cell and module-module connections enabling battery pack scalability.

To keep size down, sub-assemblies with integrated sensing capabilities are under development to enable smart

control for battery management (state-of-charge and state-of-health). Automotive manufacturers and system suppliers therefore need solutions for miniaturized and compliant interconnect technology enabling small, robust packaging for high capacity battery packs.



ELECTRIFIED AND CONTROLLED PROPULSION

Maximizing driving range on a single charge is critical. We've already discussed one half of the challenge – battery capacity. The second and equally critical part of the story is efficient operation of the car. How do we get from point A to point B using as little power as possible?

Intelligent control of the electric motor (not over-driving nor under-driving the e-motor), and regenerative braking (recovering and storing energy during a vehicle slowing event) are key approaches for energy-efficient operation. Additionally, car manufacturers are looking at ways to bring more and more outside data into the vehicle to help with the efficiency. One simple example is traffic management information. If my vehicle can route me most efficiently (avoiding traffic, road closure, etc.) I can minimize the energy consumed.

Another example could be my vehicle “talking” to intelligent traffic signals. Less “full stops” leads to minimized energy consumption. All of this drives the need for a new suite of sensors to enable control of EV's to ensure optimized power management and control. With this high

degree of control comes a high degree of integrated electronics solutions – minimizing size (and weight) while maximizing design flexibility for our customers. New EV architectures need a single component that combines sensing, intelligent data processing and communication, and robust connection all in one robust package. These architectures need actuators (electronically-controllable switches) that can be used to switch various loads, controlling and minimizing energy waste. They also need high speed data connectivity, both wired and wireless, enabling vehicle-vehicle and vehicle-infrastructure communications and intelligent vehicle control.



BEV harsh environment where failure is not an option. The operating environment of an electric vehicle is orders of magnitude more harsh than that of a cell phone or laptop computer. Rain, snow, desert sun, arctic cold, rough roads can not stop a vehicle. High voltage switching can cause electromagnetic interference (EMI), disrupting communications and signals on low voltage circuits.

A phone or laptop computer failure is a terrible inconvenience. A vehicle failure can mean serious injury or even death. Phones are never subjected to the harsh environmental nor electromagnetic stresses that an electric vehicle sees each and every day.

Electric vehicle architectures and basic operating principles are closer to airplanes, energy grids, and consumer electronic devices than they are to ICE vehicle approaches. It's critical that the auto industry leverage across multiple industries to bring new automotive-focused solutions for their customers.

Material scientists and contact physicists need to push physical boundaries to bring viable, robust solutions to the fast-growing EV market. Automotive testing will be pushed to physical and safety-critical limits usually reserved for aerospace and industrial applications.

TE CONNECTIVITY AS THE PARTNER OF CHOICE

TE Connectivity is “all in” when it comes to vehicle electrification and enabling the success of Battery Electric Vehicles (BEV's). Our team of engineers and scientists engage closely with our customers to ensure their success by providing robust solutions tailored to their specific needs and vehicle architecture. We accomplish this by leveraging three key strengths of TE:

- **We leverage our depth and breadth across the company.** We have a strong portfolio of connectors, contactors, sensors, and wireless solutions that serve multiple industries. We leverage our global footprint, to ensure we design where our customers design. We invest extensively in upfront R&D, looking to solve industry challenges before they become problems. Our engineers and scientists are actively engaged in various standards committees and industry consortia. We have an extensive network of test and validation laboratories worldwide, to ensure we can support our customers how they want to be supported.
- **We leverage our physical connectivity expertise.** We are a component supplier that invests in system knowledge, enabling us to speak our customer's technical language. We have developed thermal modeling tools, allowing us to work with our customers and address system-level issues to optimize component design. Our application tooling team ensures that our connectivity components align with our customers' manufacturing methodology. We have power management experience and know-how across many industries, with the ability to bring that capability to the automotive market. We leverage our miniaturization know-how from the semiconductor and consumer electronics colleagues, and the high power knowledge from our Aerospace and Energy Industry colleagues. TE's team of scientists and contact physicists have been leading the world in connectivity technology solution development.
- **We leverage our electronics architecture and functional integration expertise.** We work with our customers, providing application support, to optimize their systems by providing the pieces to the puzzle for optimized integrated component solutions. In many cases

we provide components that are in actuality a sub-system of components. We can provide sensor clusters with localized processing and serial data connectivity, making our customer's system easier to manufacture and more flexible / scalable. We provide complete inlet assemblies with a high power connector for charging, actuators to lock the cable nozzle to the vehicle, sensors to provide temperature and current information to the battery module to control charging, and LEDs to provide state of charge and state of health information to the vehicle operator. As our customers develop new and improved vehicle architectures, we are partnering to ensure optimized design of scalable sub-systems and components for them.



Looking for EV Battery Connectivity Solutions? Let's Connect.



CHARGING A BATTERY ELECTRIC VEHICLE

To address these challenges, TE Connectivity works closely with our customers to provide a broad range of solutions to address the needs today and well into the future:

- Charging inlets, with integrated sensing and actuation capability, to safely and reliably allow for intelligent charging control while providing touch-safe operation and charging state feedback. These inlets are scalable to fit varying customer electrical/electronic architectures inside the vehicle, from discrete point-to-point operation, or via distributed intelligent control. TE's architecture and electronics teams delivers solutions to fit varying charging station approaches.
- High voltage contactors (electronically-controllable switches) and connectors enabling safe and efficient power switching and distribution for intelligent and optimized charging.
- Thermal modeling and simulation capability, allowing for optimized design of components and subsystems that can be stressed by the high charging voltage and current needs.
- Application tooling expertise, ensuring manufacturability focus on TE's customers. We turn theory into practice by working directly with our customers' manufacturing methods and practices.

STORING POWER IN A BEV

TE's areas of focus include:

- High voltage, physically compliant, battery module contacts and connection interfaces for cell-to-cell and module-module connections enabling battery pack scalability for our customers.
- Robust, harsh environment interconnects with integrated current, voltage, and temperature sensing enabling smart control of battery management (state-of-charge and state-of-health).
- Design, manufacturing, and application tooling expertise in miniaturized and compliant interconnect technology enabling small, robust packaging for high capacity battery packs.

ELECTRIFIED & CONTROLLED PROPULSION

TE Connectivity is proud to be working with our customers to help develop optimized solutions for the industry's needs. Areas of focus for TE include:

- A suite of sensors enabling intelligent control of EV's. These include: position sensors, wheel speed sensors, motor speed and position sensors, current sensors, temperature sensors, voltage sensors.
- Integrated electronics solutions – minimizing size (and weight) while maximizing design flexibility for our customers. The ability to supply a single component that combines sensing, intelligent data processing & communication, and robust connection all in one robust package.
- Actuators (electronically-controllable switches) that can be used to switch various loads, controlling and minimizing energy waste.
- High speed data connectivity, enabling vehicle-vehicle and vehicle-infrastructure communications and intelligent vehicle control. The ability to leverage across multiple industries when it comes to high speed data connectivity, both wired and wireless.

BEV HARSH ENVIRONMENT WHERE FAILURE IS NOT AN OPTION

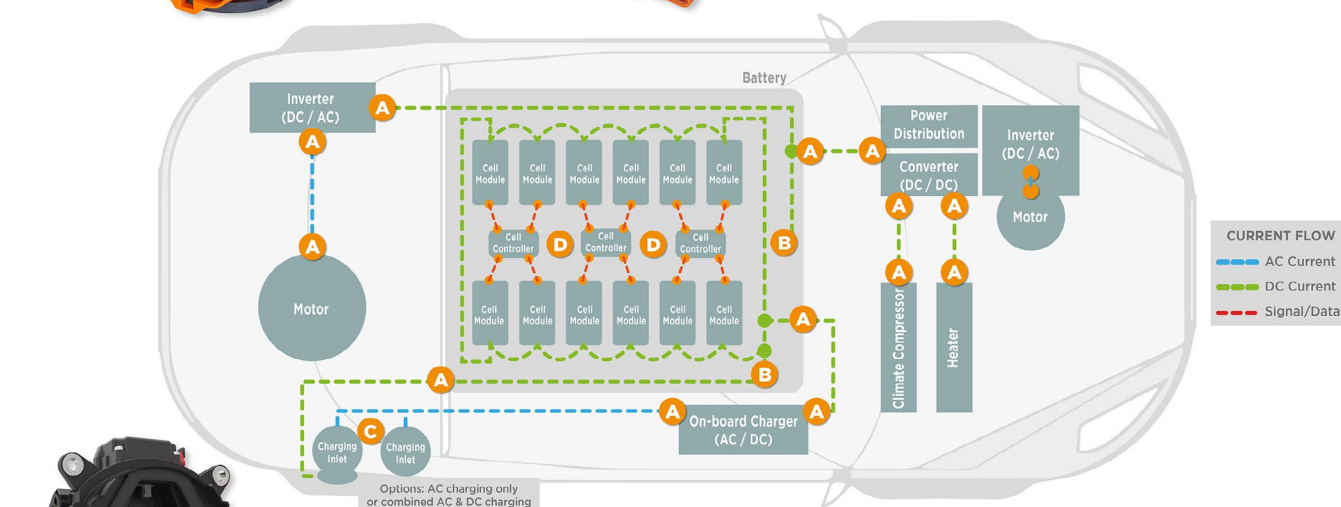
TE Connectivity is focused on providing connectivity solutions for the harshest of environments:

- Leveraging across multiple industries (Commercial and Heavy-Duty Trucking, Aerospace and Defense, Energy, Consumer, Appliance) to bring automotive-focused solutions for our customers.
- Material Scientists and Contact Physicists working closely with our customers and pushing developments forward with proactive investment.
- Environmental test and development laboratories at our design locations to support both ends of the product development cycle.
- Investing in tools and equipment to optimize designs to ever-evolving operating environment needs.

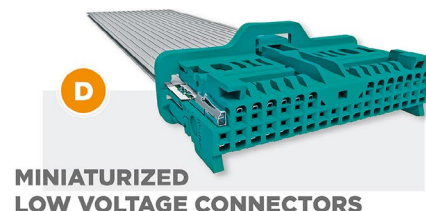


ELECTRIFYING A MOVEMENT

Connectivity Solutions - From the Charging Inlet through the Battery to the E-Motor



“CONNECTIVITY, FROM POWER TO PROPULSION, IS A KEY ENABLER OF BRINGING THE ELECTRIC MOBILITY VISION TO REALITY.”



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Looking for EV Battery Connectivity Solutions? Let's Connect.



ABOUT TE CONNECTIVITY

TE Connectivity is a \$13 billion global industrial technology leader creating a safer, sustainable, productive, and connected future. Our broad range of connectivity and sensor solutions, proven in the harshest environments, enable advancements in transportation, industrial applications, medical technology, energy, data communications, and the home. With nearly 80,000 employees, including more than 8,000 engineers, working alongside customers in approximately 150 countries, TE ensures that EVERY CONNECTION COUNTS. Learn more at www.te.com and on LinkedIn, Facebook, WeChat and Twitter.

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