Automotive Integrated Power Module . . . A Key Enabling Technology for Hybrid Electric Vehicles

A key element toward making Hybrid Electric Vehicles (HEVs) practical is the development of low-cost integrated power electronic modules capable of handling up to approximately 100 kilowatts of power for vehicle operation within necessary size and weight parameters. The key to achieving this is a device called an Automotive Integrated Power Module (AIPM), one of a new class of Power Electronic Building Block (PEBB) technologies that integrate a complex power electronics system into a single modular package. The U.S. Department of Energy (DOE) and the Office of Naval Research initiated the joint PEBB Program in 1995 to develop advanced power electronics technologies for use in automotive, defense, and other industrial applications.

The AIPM Is a PEBB Specifically Configured to the Automobile

Current commercial vehicles require highly technological control schemes in order to perform efficiently. These systems are responsible for controlling the performance characteristics of the combustion engine (fuel-air mixture, valve timing, etc.) and other performance aspects of the vehicle (traction control, electronically controlled suspension, etc.). On an HEV, all of these characteristics apply, but additionally the AIPM would control the transmission of power into and out of the electric drive motors, the internal combustion engine's power output, and the energy storage interface. Other electronics control requirements include: collecting and implementing power recovered from regenerative braking, determining the state-of-charge of energy storage devices, making a determination as to whether charging is necessary, and configuring the correct start-up procedure for low emissions.

In the broadest of terms, power electronics can be explained as the control of the flow of electric power by shaping the supplied voltages by means of power semiconductor devices. HEV powertrains will require control devices with faster semiconductor chip operation, higher power density, and more power dissipation per device without adding substantially to vehicle cost or weight. AIPM power capacity will range between 10 – 100 kW.

An AIPM can replace the large number of individual and complex power electronic circuits with a single, lightweight package.

Converters, inverters, rectifiers, and frequency changers condition the electrical signal between the power generation unit and the electric motor to provide power compatibility between the inputs and outputs of the various components within the HEV. For example, converters match the DC voltage of the power supply to that of the motor. Rectifiers convert AC power to DC through the use of diodes and filters to smooth the input signal, and a frequency changer matches the input AC power to the required AC output.

What Are Tomorrow's Goals for the AIPM?

Many challenges exist in power electronics if the aggressive goals of the Partnership for a New Generation of Vehicles (PNGV) are to be realized. The DOE focus is on developing higher efficiency electronic materials processing and fabrication to reduce the cost of production.

- ***Heat dissipation*** – Expected underhood temperatures, ranging from -40º to ~225ºC, are a harsh environment for power electronic modules. The increasing chip density in the packages will also increase the heat density. Choosing adequate materials to dissipate heat generated from power devices to the substrate is becoming more important.
- ***Volume and weight reduction*** – Reduction of volume and weight can be achieved by applying materials science and processes to capacitors, the development of metal matrix composites, high thermal conductivity packaging, and higher-temperature solders. For example, SiC devices could significantly improve power electronic performance under heavier loads and more severe environment by providing a substantial increase in thermal conductivity compared to more common semiconductor materials.
- ***Cost*** - The AIPM reduces the number of connections and components required to build automotive power systems by using integration and a modular systems approach. Integration typically lowers cost. The objective is to develop and validate power electronic technologies that cost less than $5 k/W by 2004.
- ***Size*** - Capacitors typically make up two thirds of the controller volume. The AIPM will integrate functions by using advances like multi-layer nano-structure technologies to shrink size.
- ***Reliability and ruggedness*** - Connection durability will be improved by reducing the number of interconnects to modules and reducing or eliminating the internal wire bond structures within the module. High-temperature solders will enable operating temperatures to increase above 200ºC without loss of long-term reliability. The use of metal matrix composite materials improves heat dissipation and reliability of packaging by allowing optimization of dielectric and thermal properties. Significant effort is underway to predict the mechanical reliability of materials to improve their quality.

A Successful PEBB/AIPM Effort Could Create a New American-Led Industry

The development of an American-manufactured PEBB technology, such as the AIPM, would change the face of the electronics industry and put American industry in a more competitive position worldwide. However, the current market for advanced automobiles is not large enough to drive AIPM research and development. Combining vehicle power electronics requirements with those of critical high-power military and other power electronics applications into a single, flexible, modular design will help to ensure the market. PEBB technology is very beneficial to any process utilizing electric power such as power electronic systems for advanced ships and aircraft. Many experts believe that the development of cost-effective PEBBs would change the way the world designs and uses power devices as dramatically as did the move from transistors to integrated circuits.

For additional information, contact:

David Hamilton
U.S. Department of Energy, EE-32
1000 Independence Avenue, SW
Washington, DC 20585
(202) 586-2314
david.hamilton@ee.doe.gov

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