Power Systems Design: Empowering Global Innovation

Trends in Automotive Power Electronics

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Categories: Motors & Motion Control, Power Modules

Using power modules for HEV, PHEV & EV

Thomas Parker built the first production electric car in London in the late 1800's. Electric cars were very popular in the early 1900's but this did not last very long thanks to infrastructure and technological developments (Due to better roads, cars were now required to go longer distances and gasoline engines did not need a hand crank starter anymore).

The green revolution or the intent to reduce carbon emissions and the need to reduce commute costs was the big driver for re-development in the 21st century. There has been a general improvement in technologies critical to development of Electric and Hybrid vehicles such as in Batteries, Charging and the motor drive.

Fuji Electric has greatly contributed to this change with the bulk of our advancements being made in the Power Electronics that go into the Inverter of the car and in the area of Commercial Charging stations for EVs (Electric Vehicles) and Plug-in Hybrids.

Motivation for development

Government Agencies worldwide have acted as catalysts for re-development of EVs (Electric Vehicles) & HEVs (Hybrid Electric Vehicles). Notably, the Euro Emission standards have instituted stringent requirements for Auto manufacturers to adhere to. This combined with the increasing oil prices is enough economic incentive to look at alternative solutions.

Fuji Electric was established in 1923 and has since been an innovator in Energy Technologies. The company's first mass produced an automotive module in 2005 and has since shipped close to a million units with a <10 ppm failure rate.

Fuji Electric strives to achieve a Zero Defect future and is implementing a combination of Design & Process Control techniques combined with Screening and focused reliability engineering to this end.

The first module to be mass-produced was a 2-in11 buck-boost for a major Japanese automaker. Since then, Fuji Electric has gone on through numerous iterations and currently offers the M651 & M652 as standard offerings. These modules are 6 in 1's and are rated at 650 V, 400A & 600A respectively as shown in Table 1. The modules pictured in Figure 1 are direct liquid cooled with copper pin-fins that are optimized for maximum thermal conduction and minimum pressure loss of the coolant.

Module	Voltage Rating	Current Rating
6MBI400VW-065V	650V	400A
6MBI600VW-065V	650V	600A

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Table 1 Fuji Electric Automotive Module Standard Offering ***One & two motor systems***

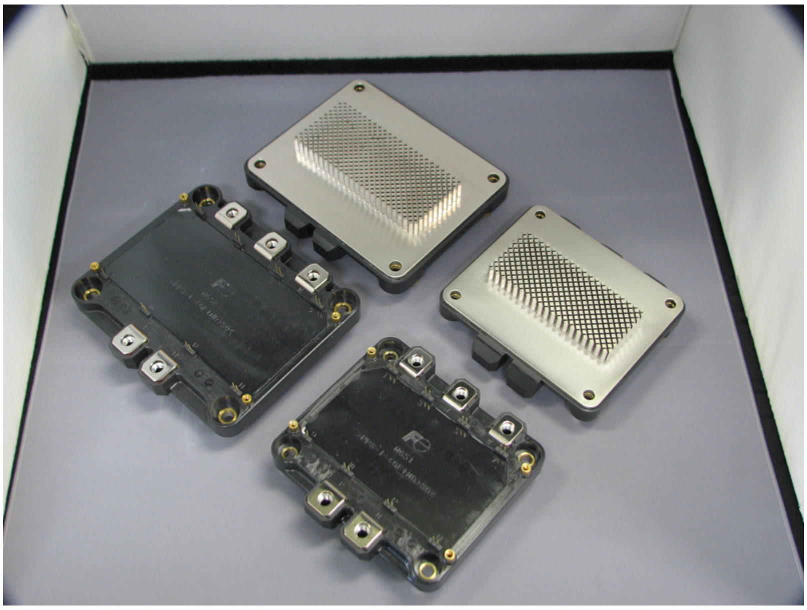

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Figure 1: M651 & M652 Front and backside

One & two motor systems

The system topology dictates the size and functional requirements of the Power Module. One motor systems for Hybrid Vehicles have a parallel connection of the combustion engine and the electric motor/ generator. This means that the Electric system can either be in Motoring/ Generation mode only but not both. For a 1 motor system implementation, a combination of Boost + 6 in 1 (Total of 8 switches) module can effectively produce the required output.

On the other hand, for a 2 motor system implementation the car can have Generating and Motoring simultaneously. In this case a Buck-Boost + 6 in 1 + 6 in 1 (Total 14 switches) produces the required results. Figure 2 shows a custom 1st Generation 14 in 1 Intelligent Power Module (IPM) built for Honda AccordTM Hybrid. This module has been in production since December 2012

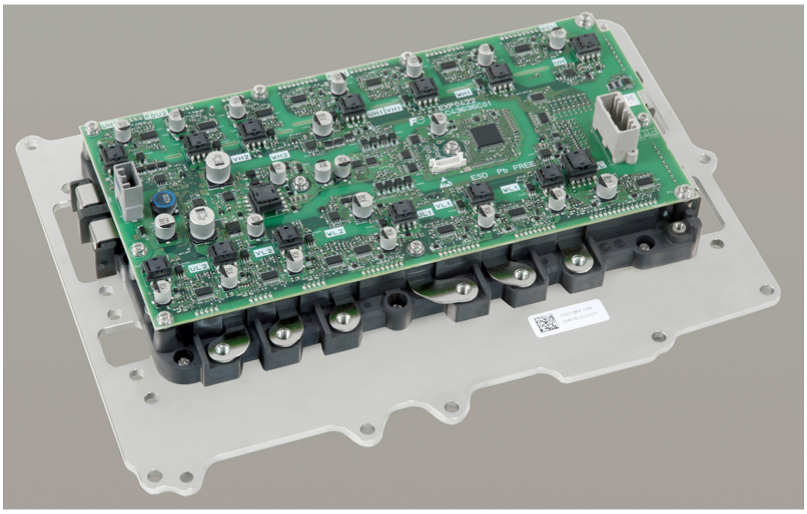

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Figure 2 Fuji Electric Intelligent Power Module for Honda Accord

Fuji electric next-generation technology

Fuji Electric has taken a two-pronged approach to quickly adapt to market requirements, with a portfolio of “Standard” Automotive Power Modules built to automotive standards of reliability, and the “Custom” Power Modules/ IPM’s (Example shown in Figure 2). With every passing model year, the requirements on the Power Modules increase, Table 2 shows requirements and the Fuji Electric Solution.

Car	Inverter	Module
High Fuel Efficiency	Light Weight	Light-Weight
High Power Density	High Power Density	Increase chip electrical and thermal capacity
Compact	Compact	Improve chip electrical and thermal performance
High Reliability	High Reliability	High Reliability Packaging

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Table 2 Requirements of Car boiled down to power module

Lightweight

Design Engineers always face trade-offs between cost and performance and this is a classic example, with Aluminum competing to be a low cost high performance alternative to Copper. The challenge that Fuji Electric faced was to develop an Aluminum cooling solution that would be equal to if not greater than to the performance of a Copper cooling system.

With innovative structural design of the cooling fins, Fuji Electric was able to achieve a dramatic reduction in thermal resistance and thereby a 70% reduction in weight moving from the 1st Gen Copper cooling to 1st Gen Aluminum cooling with an innovative cooling fin structure (Density of Al = 2.7 g/cm3 v/s Density of Cu = 8.96 g/cm3). With this innovation, the manufacturer was able to satisfy the weight requirement and contribute to higher fuel efficiency.

High power density & compact design

One of the main reasons for the downfall of Electric Vehicles in the early 1900's was the low range of the vehicles. With advances in Battery technology and more efficient power conversion from the inverter, this range has grown magnitudes.

This has been achieved by improving IGBT (Insulated Gate Bipolar Transistor) & FWD (Free Wheeling Diode) design. With each passing Fuji Electric chip generation, a reduction in IGBT Vce(sat) (Saturation Voltage) and Eoff (Turn off Loss) has been realized. Fuji Electric has also optimized the gate structure with the introduction of the Trench gate in its 5th generation IGBT's. Reduced conduction and switching losses were achieved with the thinner wafer (result of the field stop optimization) and lifetime control respectively.

The improvements in chip technology effectively increase the current density. This may raise an important concern in the minds of the reader, that of thermal conduction. Logically, as the chip area reduces, the Rth should increase and that is true. The effect is nullified using advanced innovative cooling devices

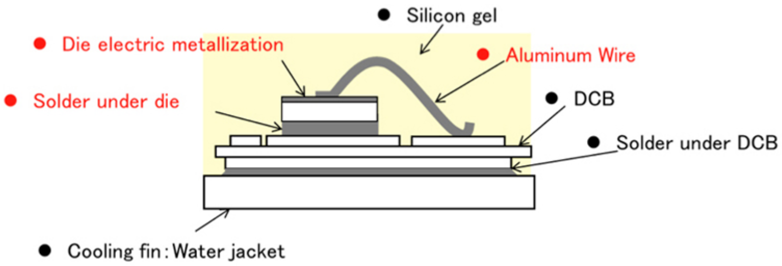
Tight lifetime control in the diode has also resulted in significant reduction in the dynamic loss of the FWD and the thinner wafer has reduced conduction losses.

High-reliability packaging

The Power Module like the other components is expected to last a "Car Lifetime" and manufacturers are expected to design for this. The lifetime of the module varies strongly with the drive profile and there is a trade-off between reliability required and cost, but Fuji Electric strives to achieve a low cost – high reliability solution.

The causes of failure in a power module are many, arising mainly due to the CTE (Co-efficient of thermal expansion) mismatch between the materials used in packaging. Repeated thermal cycling stresses the material, causing eventual failure. It helps to have a model to accurately predict this time to failure, and Fuji Electric provides lifetime curves based on a combination of experimental results and extensive simulations.

Referring to the module cross-section in Figure 3:



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1) Aluminum (Al) bond wire lift-off

The most common failure mode at lower delta Tj's (Junction Temperature). Failure occurs due to grain growth, which weakens the bond between the chip and the Al wire. Fuji Electric solved this problem by changing the re-crystallization temperature of the Al wire, limiting the growth of grains.

2) Solder Layer cracking

In the middle delta Tj range, the common failure mode is cracking of the solder layer. Fuji Electric has solved this issue by developing a Sn-Sb chemistry (Tin – Antimony) and other elements to suppress growth of cracks.

3) Electrode Metallization

This failure mechanism usually occurs in the higher delta Tj ranges. Fuji Electric has solved this problem by passivating the AlSi layer with a Nickel layer.

With the technologies mentioned above and other advances, Fuji Electric will soon announce its next Generation of Automotive Power Modules for the General Market.

Fuji Electric is also actively working with partners to optimize its solutions and help in the Automotive Green Revolution.

With increasingly stringent emissions requirements, auto manufacturers are looking at more innovative solutions to certify their products. Increased fuel costs are making consumers think twice about a gas-guzzler and this seems to be the right combination of manufacturer intent & consumer need!

In the recent past, some luxury automakers have introduced a range of Electric and Hybrid vehicles. These high performance vehicles have more range and power than before and address the performance hungry clientele. LaFerrari (who, incidentally, uses Fuji Electric IGBT & FWD chips) is probably the most exclusive Hybrid vehicle in the market! We are yet to see the golden age of the Electric Car and we at Fuji Electric believe, that day is not too far away and we are prepared to serve.

Fuji Electric