Whitepaper

AB Mikroelektronik and the KTM Freeride E Motocross Bike; Getting an Exciting Advanced Electric Vehicle Project off the Ground

Abstract

Interest in hybrid-electric vehicles (H-EV) and fully electric vehicles (EV) is undoubtedly growing as the motor industry and consumers look to find an environmentally friendlier and more cost effective alternative to vehicles powered solely by internal combustion engines. Although widespread use of pure EVs as routine daily consumer transport remains a vision for the future, fully electric recreational vehicles such as off-road motorcycles are practical and can offer equivalent or better user experiences.

The KTM Freeride E electric motocross bike is one of the first such machines to be made publicly available. Quieter than a conventional 2-stroke off-road bike, it produces zero emissions, is significantly lighter, and not only offers similar peak power but enhances driveability by producing high torque even from very low motor speeds.

AB Mikroelektronik was involved in the development of the KTM Freeride E from an early stage. The bike has already been ridden by impressed motorbike trade journalists and is scheduled for market launch in 2014. Since becoming involved in the project in 2008, AB Mikroelektronik has taken responsibility for transforming the bike’s main electronic control unit from the prototype built by KTM in conjunction with its research partner into a robust and reliable module suitable for series production.

To create the production-ready design, the team built on its competencies in hardware design and packaging, including sensor integration, thermal management, software design, ISO 26262 safety-critical automotive systems, and ISO 16949 automotive Quality–Management System (QMS), and enhanced its in-house facilities for simulation, testing and maintenance of high-voltage power systems.
Introduction

The arguments surrounding electric vehicles generally focus on when – rather than whether – they will come to represent a significant proportion of the overall market for passenger cars and other types of vehicles powered by internal combustion engines, including motorcycles, recreational vehicles and utility vehicles. When the time comes, those vehicle manufacturers and powertrain systems integrators that have established the best intellectual property, technical knowledge, and product-realisation infrastructure will be the most able to take a leading position.

AB Elektronik is a major supplier of sensing and control technology to the global automotive industry, both for combustion-engine and hybrid/electric applications. Keen to strengthen its position in electric vehicle technology, AB Elektronik has become involved in a number of EV projects with innovative partners. In late 2008, AB Mikroelektronik was invited to join championship-winning Austrian motorcycle manufacture KTM’s Freeride E electric motocross project. The team was asked to help develop the Electronic Control Unit (ECU) from early prototype stage into a design suitable for mass production meeting KTM’s targets for weight, size, reliability, usability, safety and maintainability.

The ECU, developed by AB Mikroelektronik, controls all of the bike’s electronic functions, in addition to containing the controller/inverter for the main traction motor. The non-traction functions comprise managing the instruments, lights and horn, communication with the Battery-Management System (BMS), driving the electric water pump, and the interface with the e-gas system that translates the rider’s demands received at the throttle into instructions for the motor controller.

To begin developing the ECU, the technical team was provided with a 3D model describing the physical space available within the bike’s chassis, the specification of the inverter, and the datasheet for the motor; a brushless synchronous motor with disc-armature design giving the advantages of high power, high torque and low wear rate in a compact and slim form factor. The project drew on AB Mikroelektroniks’ established knowledge and processes in areas such as sensor integration, bare-die assembly, motor-control hardware and software design, A12O3 ceramic substrates, high-voltage design and power electronics.

To complete the project, AB Mikroelektronik also invested in enlarging its High-Voltage Laboratory, an area dedicated to simulation and testing of high-voltage electronics including EV motor drives. Enhancing this facility, has strengthened its long-term position as a partner capable of working with EV OEMs and powertrain systems integrators to develop, build, simulate and test advanced modules ranging from subsystem components or high-performance drives to complete vehicle electronic control systems.
The KTM Freeride E

Aiming to achieve dynamics similar to those of a 125cc two-stroke motocross bike, KTM chose a 300V permanent magnet synchronous motor for the Freeride E motocross bike (figure 1). The motor has a disc armature design enabling compact and slim dimensions, and is capable of producing 42Nm torque from as low as 500rpm, and power of at least 7.5kW (around 10hp) from rest. Peak power is 22kW (30hp) at 6000 rpm.

Figure 1. The KTM Freeride E delivers a riding experience rivalling that of a high-performance two-stroke motocross bike

The electric bike does not need a gearbox, and incorporates an e-gas system of a proven design that translates the rider’s instructions from the throttle into motor commands allowing convenient twist-and-go operation. The gearbox-free design also helps to achieve weight savings and maximise reliability.

Energy is supplied from a 2.1kWh lithium-ion (Li-ion) battery that is designed to be easily replaced with a fully charged unit when depleted. The battery management system (BMS) is incorporated in the battery pack, and takes responsibility for monitoring battery temperature and state of charge, maintaining battery condition, and managing emergency cut-off when required.

The battery is sized to allow a run-time of over 40 minutes, which is the typical duration of a motocross race. It is designed for easy removal, allowing the user to replace a discharged battery with a new fully charged unit in around one minute. The maximum total recharge time for the battery is around 90 minutes.

During the development project, KTM upgraded the basic design from air cooling to water cooling to extend the bike’s operating range. Changing to a water-cooled scheme dramatically extended this operating envelope to accommodate up to around 15 battery changes if required.
Designing the ECU for Production

Figure 2 shows the main functional blocks of the ECU for the Freeride E. In its prototype form, the unit had been built with active cooling, using a fan. For the technical team, eliminating the fan was an obvious requirement, not only to save bill-of-materials costs and reduce noise and power consumption, but also to eliminate the possibility for ingress of dust, dirt and water that may otherwise damage the control unit as the bike is used off road. Figure 3 shows the complete module, ready for assembly on the bike.

Figure 2. Basic functional blocks of Freeride E ECU as determined by KTM and implemented by AB Mikroelektronik.

Figure 3. The complete KTM-branded ECU, ready for delivery to the Freeride E assembly line.
Packaging

To build a passively cooled ECU providing all the required control functions, within the physical dimensions defined by the 3D model provided, the AB Mikroelektroniks team created a multi-level design as outlined in figure 4.

![Figure 4](image)

Figure 4. The multi-level ECU design achieves high standards in terms of packaging, thermal management, energy efficiency, robustness, reliability and maintainability.

Organising the ECU as a multi-level assembly allowed all the required hardware to be built within the tight size restrictions imposed by the narrow width of the bike. Consolidating the high-power electronics on the lower level adjacent to the copper baseplate helped to optimize thermal management. Moreover, established capabilities were utilised for assembling bare die to attach the main power components in the high-voltage electronics board directly to the substrate and attach heatsinks directly to all dies using glueless soldered connections for optimum thermal transfer. Direct attachment of the bare die to the substrate also ensured effective relief of stresses imposed by Coefficient of Thermal Expansion (CTE) mismatches, helping to enhance the reliability and longevity of the ECU.

Efficiency

In addition AB Mikroelektronik reviewed the motor controller and software to maximise energy efficiency, in fact raising the inverter’s efficiency to over 95%. The reduction in heat dissipation thus achieved, combined with effective thermal management and – ultimately – the change to a water-cooled design all contributed to achieving a fanless ECU capable of delivering the required power to the synchronous motor.
Thermal Management

The move to water cooling of the bike’s major components, including the ECU power electronics, demanded significant changes to the original air-cooled design. The key challenges surrounded the delivery of control and power to the electric water pump. The team uprated the 12V DC/DC converter used to supply the lights, instruments and other electronics in order to provide a high-current supply to the water pump. Cables of suitable power rating were also added to supply the water pump, within the prevailing space constraints. The change to water cooling yielded a reduction of 10-20°C in the ECU’s typical operating temperature, which proved critical in enabling the bike to operate continuously for extended periods defined by as many as 15 battery changes.

Functional Safety and Quality-Management System

During the development of the ECU, the ISO published its automotive functional safety standard ISO 26262. Taking a long-term view, the project team made the decision to implement the design changes necessary to allow the ECU to comply with the emerging automotive safety standard. To accomplish this, the team undertook a major redesign of both hardware and software, to add hardware redundancy for failsafe operation and implement the necessary supervision subsystems hosted on safety microcontrollers. In the same vein, AB Mikroelektronik took responsibility for normalising design procedures and documentation in accordance with the ISO/TS 16949:2009 automotive quality management system.

Figure 5. Functional safety of an ECU (source: Norm ISO 26262)
AB Mikroelektronik Infrastructure and High-Voltage Laboratory for Future e-Vehicle Development

During the course of the ECU design project for the KTM Freeride E, the team not only applied existing competencies but also extended and enhanced the Group’s in-house resources dedicated to EV design. This investment has strengthened available design skills in critical fields like power electronics, thermal design, software and firmware design, packaging and mechanical design, thereby enhancing its ability to work collaboratively with diverse types of customers such as e-vehicle OEMs or powertrain systems integrators.

Moreover, on-going investment in the High-Voltage Laboratory at AB Mikroelektronik technical centre in Salzburg, Austria has strengthened the company’s dedicated facility for simulating and testing any high-voltage equipment. The electric motor and drive system of the KTM Freeride E operates at a nominal voltage of 300V. The specialists working in this high-voltage laboratory can apply isolation tests significantly above this voltage, to ensure the safety both of the equipment and of end users.

The laboratory also provides the facilities needed to set up test benches for running motors and motor-drive electronics, to simulate and test various operating modes, and observe system behaviour under various speed and torque conditions, which is run by engineers specially trained in high-voltage technology, procedures and safety practices. AB Mikroelektronik expects its High-Voltage Laboratory to be a major asset in the long term, providing a unique resource for e-transportation projects of all types, from off-road recreational motorcycles such as the KTM Freeride E to many types of electric road cars spanning the economy / performance spectrum.

Conclusion

Working closely with KTM, AB Mikroelektronik fulfilled a central role in delivering a successful project that exercised the entire range of technical skills needed to take an e-vehicle from the early prototype stage to production, and ultimately allowed KTM to realise its vision for the Freeride E: a quiet, zero-emissions machine capable of delivering riding experiences equal to or better than those of a 125cc two-stroke motocross bike. Already a well regarded producer of conventional motocross bikes, KTM set itself a high target, and achieved its goals by partnering with AB Mikroelektronik.

The competencies, technologies and in-house facilities that have been assembled to complete this project successfully are applicable across the spectrum of EV applications, not only recreational vehicles such as the Freeride E and similar vehicles such as quads and snowmobiles, but also scooters, road motorcycles, utility vehicles such as street sweepers and factory utility vehicles, and passenger cars ranging from economy to high-performance models.

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