Experience the Hybrid Drive

- MAGNA STEYR equips SUV with hybrid drive
- Hybrid demo vehicle with dSPACE prototyping system
- MicroAutoBox and RapidPro control hybrid components

To integrate components into a hybrid vehicle drivetrain, extensive modification to the electronic and mechanical systems is required in order to ensure the global optimization of all systems by a hybrid drive strategy. MAGNA STEYR and its cooperation partners integrated the new hybrid components in a production vehicle and implemented a control system using a dSPACE prototyping system (MicroAutoBox plus RapidPro). The hybrid demo vehicle HySUV (Mercedes M-class) with a dSPACE prototyping system as the central drivetrain control makes the hybrid drive a reality. MAGNA STEYR and its partners use the demo vehicle as a platform for further optimization of driving behavior, consumption, and emissions.

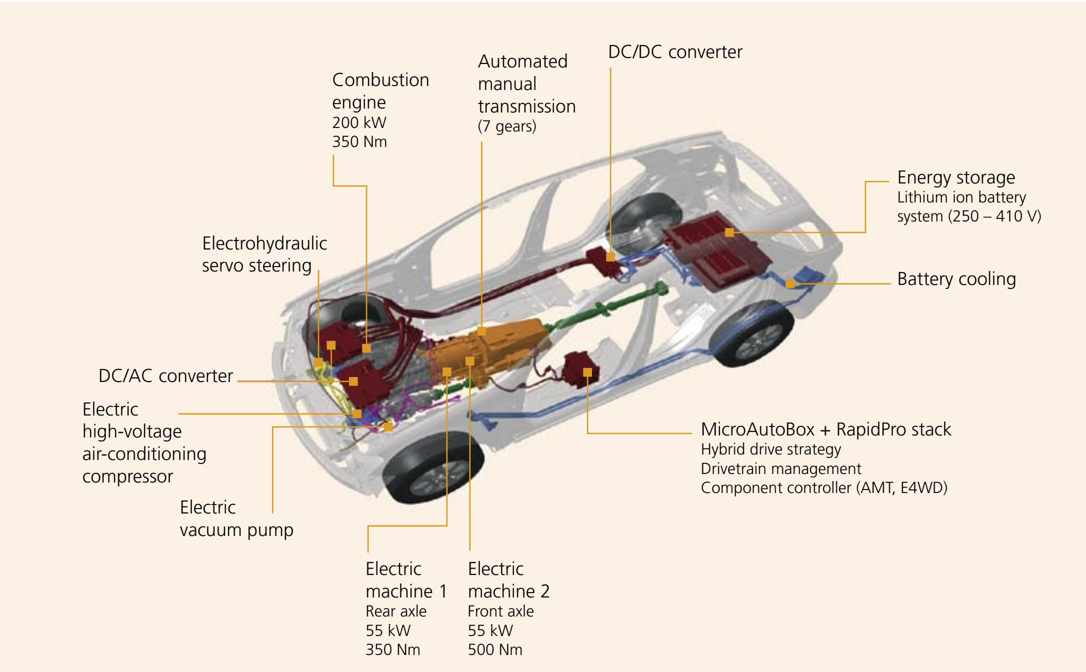
Drive Systems for the Future

When a combustion engine and an electric drive are combined in a vehicle, the use of optimized operating points for the two propulsion types can greatly improve the vehicle's consumption, dynamics, and emission behavior in comparison with a combustion-engine-only vehicle. MAGNA STEYR worked with MAGNA POWERTRAIN and Siemens VDO to develop modular hybrid drive systems, taking into account the research findings from K-net KFZ, the competence network for "Vehicle Drives of the Future". With the support of the OEMs, hybrid components developed by MAGNA are integrated in the drivetrain of prototypes to investigate the optimization potential of consumption, dynamics, and emissions. The control system and the cross-linking of new components in the drivetrain are implemented with the dSPACE prototyping system (MicroAutoBox plus RapidPro) on the basis of a central hybrid drive strategy. MAGNA STEYR has put this into operation in the hybrid demo vehicle HySUV (Mercedes M-class).

▲ *Hybrid driving experience with the demo vehicle HySUV (a modified Mercedes ML350): The display shows the driver and passengers the torque flow of the three propulsion units.*

Hybrid Components

In the HySUV demo vehicle, the automatic transmission and transfer case of an ML350 (Mercedes M-class) were replaced by an automated manual transmission and a hybrid module (E4WD module). A full hybrid drivetrain with electrical all-wheel drive was implemented in this way. Both the combustion engine and the electric motor drive the rear axle, while the front axle is driven purely electrically. The heart of this modularized drivetrain concept is MAGNA's E4WD module, which consists of two electrical machines with 55 kW each and four hydraulically actuated multi-plate clutches for controlling the torque flow. A 70 kW/360 V lithium ion battery system developed at MAGNA STEYR



◀ *All the components of the hybrid drivetrain in the demo vehicle are controlled via the dSPACE prototyping system (MicroAutoBox plus RapidPro hardware).*

provides energy storage. For purely electric propulsion, the accessory aggregates of the combustion engine are replaced by electrically operated components.

Selecting the Prototyping Hardware

The objective was to control all the components of the hybrid drivetrain with just one prototyping system. This objective made tough demands on processing power and hardware interfaces. The MicroAutoBox chosen for this has since become a standard tool at MAGNA STEYR, used for efficient implementation of prototypes for a wide range of drivetrain applications. Internal or external hardware development does not make sense due to the limited development time and the small quantity needed. At MAGNA STEYR, the RapidPro system is therefore used in addition to the MicroAutoBox. RapidPro is a freely configurable, extendable driver hardware solution that meets all of MAGNA STEYR's requirements. The flexibility provided by software- and hardware-configurable signal I/O is an advantage, particularly in early phases of prototype development, when the sensor and actuator systems are not yet completely defined. Together with the diagnostic components that can be integrated into the function software, the proven RapidPro hardware has the reliability needed in order to concentrate on crucial aspects of function development. MAGNA STEYR is using a stack consisting of three RapidPro Power Units and one RapidPro Control Unit (MPC565) for the HySUV demo vehicle.

"The MicroAutoBox has become a standard tool at MAGNA STEYR, allowing us to implement prototypes efficiently for a wide range of drivetrain applications."

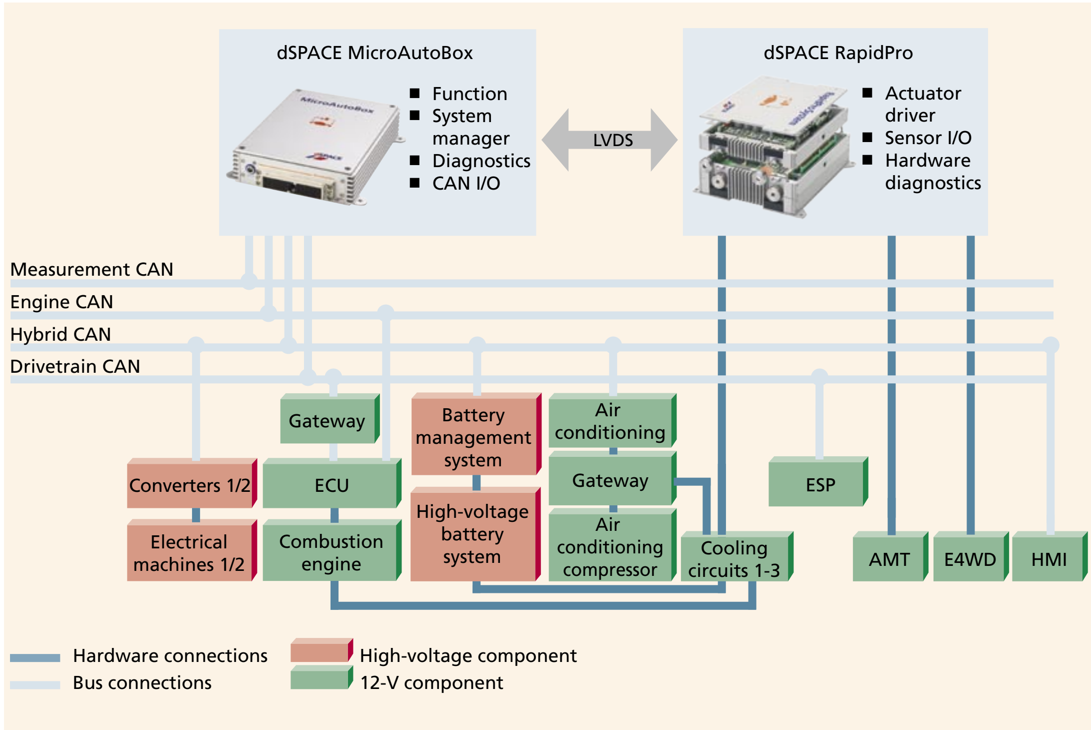
Dipl.-Ing. Theodor Schöberl, MAGNA STEYR Fahrzeugtechnik AG & Co KG

RapidPro System Data

- 13 valves controlled via PWM signals, with PWM-synchronous current measurement
- 4 PWM-controlled pumps
- 12 digital inputs for pressure, displacement, and engine speed measurement
- 8 analog inputs for temperature and pressure measurement

Integrated Development Process

From the beginning, the function and software development process is geared to achieving a seamless transition to production development, especially to production code generation. At MAGNA STEYR, TargetLink is used for production code generation. The requirements for this are taken into account as early as configuration management, during the design phase, and in the modeling guidelines and model libraries. The Simulink®/Stateflow® development environment was extended to allow modularization across several



▲ *System architecture: The dSPACE prototyping system networked in the vehicle.*

hierarchy levels, providing a working platform for multiple engineering teams. It also supports variant management for simulation, rapid prototyping, production code and test bench operation.

Function Development

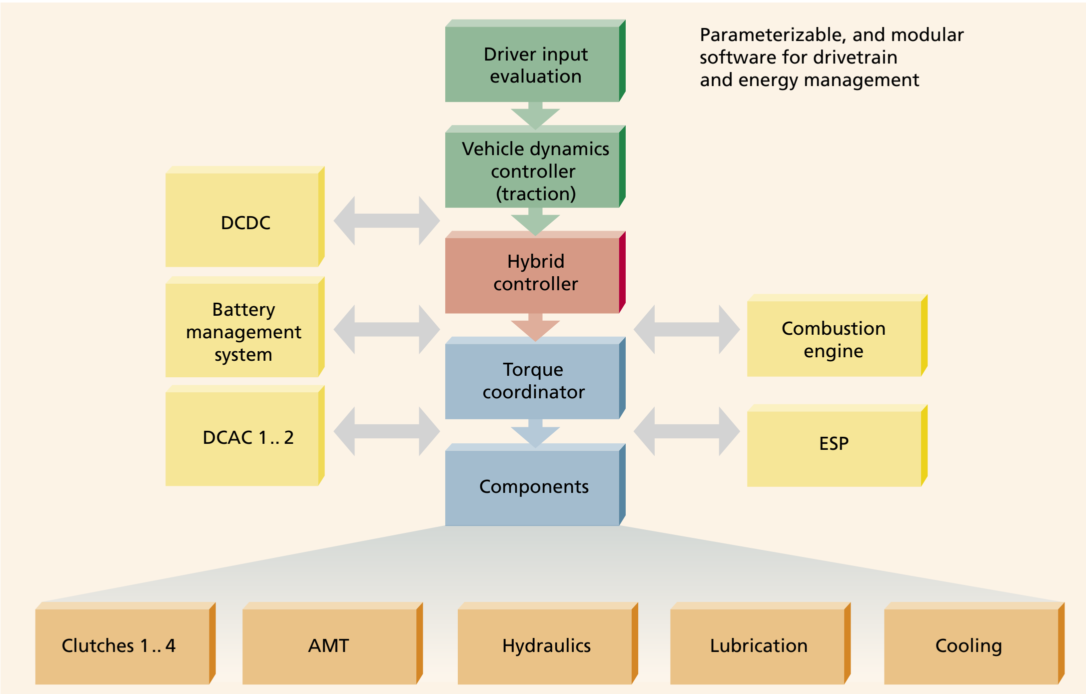
The modular design of the drivetrain components is reflected in the software design. This is scalable to a large number of hybrid drivetrain configurations and covers aspects of customer-specific functionalities in production projects. The control software comprises the functions and interfaces of the entire torque path in the drivetrain, from capturing driver input to selecting the operating point for drive components, to traction-optimized distribution of drive torque, up to component control for couplings, the automated manual transmission, and accessory aggregates. Added to these are central functions for controlling the operating states of components in the drivetrain, and for capturing and evaluating diagnostic information from the function software and the RapidPro stack.

Software Components

- **Driver input capture:**
  The torque required by the driver is determined by the accelerator pedal, the brake pedal, and the gear lever.
- **Vehicle dynamics controller:**
  The traction-optimized distribution of the driver's torque demand to the axles is based on the availability of the three propulsion units.
- **Hybrid controller:**
  The torque distribution and required gear are obtained with reference to efficiency, dynamics requirement, the battery charge status, comfort, and thermal operating conditions.
- **Torque coordinator:**
  Manages the configuration and controls transient processes in the drivetrain.
- **Component control:**
  Controls the components in the automated manual transmission and the E4WD module.

Component Testing

Hardware-related functions like component control and transmission control are tested and optimized on the components in early project phases, using the prototyping hardware. The hybrid controller, representing the core of the driving strategy, cannot be tested until a functioning vehicle is available. Even so, its functionality still has to be validated in early project stages, so a simulation environment has to be provided. This environment was produced by adapting models



▲ *A large number of software components ensures that the hybrid drive optimally responds to the driver's demand indicated via accelerator pedal, brake pedal, and gear lever.*

of the drivetrain and the hybrid components that were used for concept evaluation at the beginning of the project. A parameterizable driver model makes it possible to implement various driving profiles to assess driving behavior during start-up maneuvers, in accelerating and trailing throttle condition, in gear changing, and to investigate system behavior in extreme situations. The resulting model can be executed with the hybrid controller on the MicroAutoBox, allowing the effects of code generation and run-time properties to be studied at an early stage.

Optimization Steps

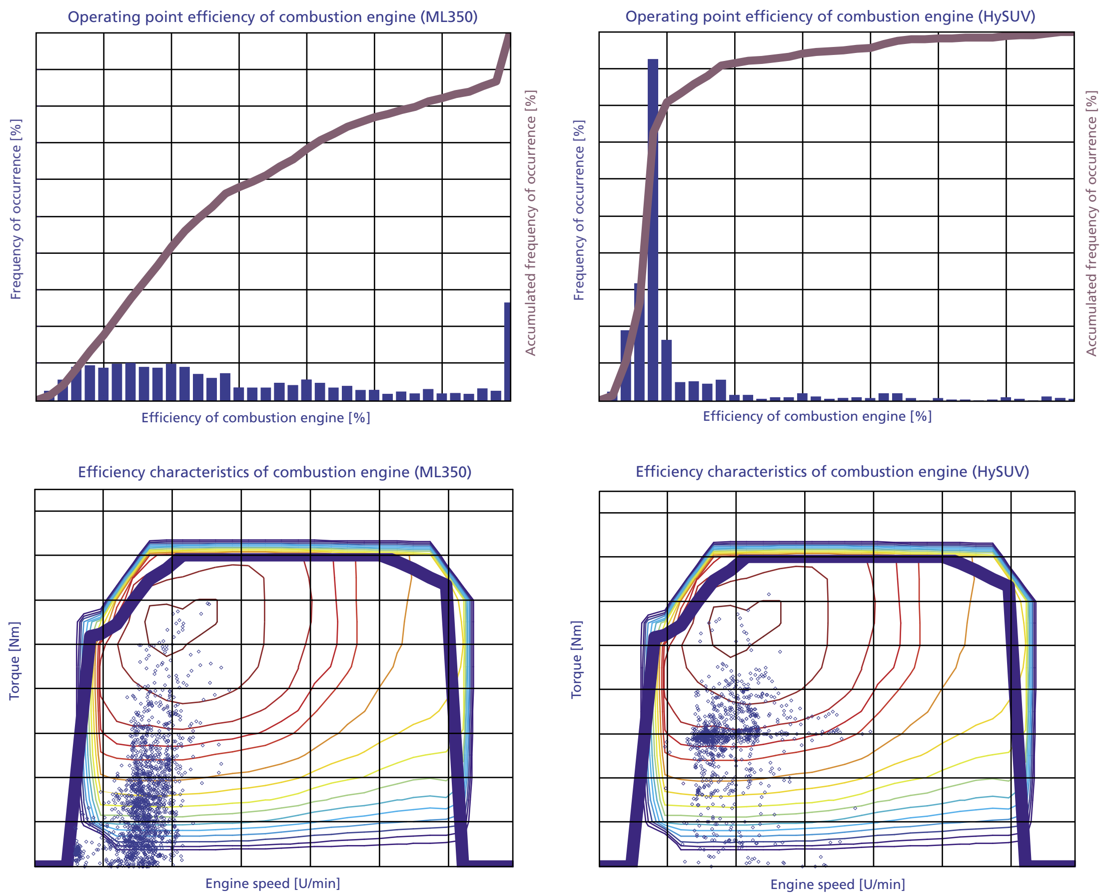
The complex calculations needed for the large number of different drivetrain configurations in the hybrid controller, which all had to be computed in parallel, demand considerable processing power. Even though a multi-tasking system for systematic resource distribution had been implemented, the extensive model pushed the MicroAutoBox to the limits of its performance during the integration phase. However, the CPU execution time guzzlers were identified in the model by studying resource consumption and performing code reviews. Further modeling had to be carried out to enhance code efficiency, in addition to making the optimization adjustments in the code generator (Real-Time Workshop®).

Current Model Data

- 44,000 blocks
- 257,000 lines of generated C code (Real-Time Workshop®)
- Code generation time: 1 h 40 min on a Core 2 Duo 2.67 GHz; 4 GB RAM
- 4.5 MB MicroAutoBox application
- 4 tasks with 95 % CPU load on the MicroAutoBox

Commissioning the Control System in the Vehicle

The system was put into operation in the vehicle step by step. The initial parameter set already showed the positive effect of the operating strategy on the combustion engine's operating point distribution. Operating points with low efficiency are replaced by purely electric operation or load point shifting of the combustion engine. One current focus of commissioning work is on drive-off strategies and boosting. Vehicle development is supported by simulation of the hybrid controller based on adapted simulation models and real measurement values.



▲ *Customer-oriented comparison drives show the positive effect of the operating strategy on the combustion engine's operating point distribution. Operating points with low efficiency are replaced by purely electric operation or load point shifting of the combustion engine. The result: An obvious shift in operating points towards the combustion engine's optimum operating range.*

Next Steps

Now that the function software has been successfully implemented and tested, we are in the test drive phase, with the objective of further optimization. The proven modular dSPACE prototyping system gives us the necessary reliability and flexibility. The planned activities include:

- Investigating and optimizing dynamic processes in the drivetrain
- Extending the drivetrain model to study dynamic processes and developing the traction controller in the simulation further
- Optimizing the operating strategy in terms of performance, consumption, and emissions
- Further integrating the brake system into the operating strategy for optimum braking energy recovery
- Developing the lithium ion battery to production level. TargetLink is being used for developing function software for the battery management system.

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