

TRW: Heading for the Future with Steer-by-Wire

- **Steer-by-wire systems for passenger vehicles**
- **Algorithm development with dSPACE Prototyper**
- **TRW Automotive working on production-intent solutions**

As the world's leading supplier of steering systems for passenger vehicles, TRW Automotive is already working on developing steer-by-wire concepts for future generations of production vehicles. Using dSPACE Prototyper meant that only a short time was required to develop all the essential functions of a steer-by-wire prototype system on a component-in-the-loop test bench and map them in a test vehicle.

Unlike the hydraulic or electric servo steering systems in use today, steer-by-wire systems use an electronically controlled actuator to convert movement of the steering wheel into front wheel movements. So that the driver has the 'feel' of steering, feedback on the lateral forces is provided by a force feedback actuator connected to the steering wheel.

System Architecture: Fail-Safe or Fault-Tolerant

Steer-by-wire systems can be either fail-safe or fault-tolerant. Fail-safe systems have an independent mechanical backup system. The electronic control in such systems can take the form of a fail silent unit (FSU). In other words, system safety is sufficiently guaranteed if the electronics have a fault recognition mechanism that reliably ensures automatic shutdown when a fault occurs.

A fault-tolerant system architecture, on the other hand, is based on distributing the hardware across several redundant subsystems to ensure that system

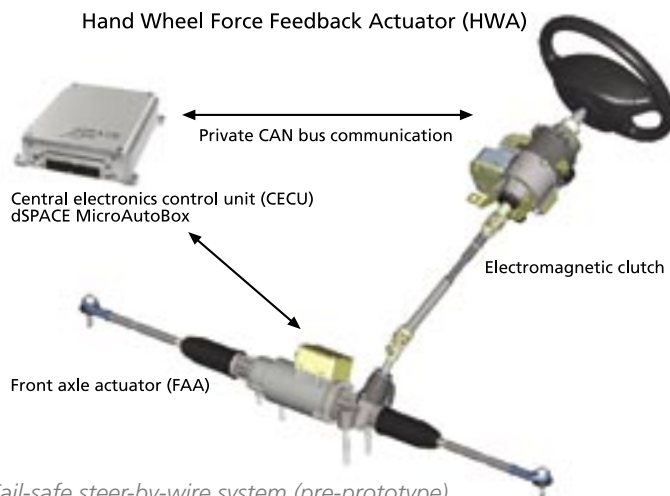
functions are maintained. The subsystems have their own electronic control units (ECUs) and are networked via a real-time-capable, fault-tolerant data bus.



▲ *Steer-by-wire front axle actuator.*

Pre-Prototype with a Fail-Safe System Architecture

Recently, many automotive manufacturers and suppliers have come to regard fault-tolerant systems as the future of steer-by-wire. It is now a major field within steer-by-wire development. However, it is just as important to choose the right hardware components for the sensor and actuator systems and the ECUs. These hardware components have to perform their tasks largely independently of later integration into a fault-tolerant system architecture, so they can also be tested independently in the early phases. The same applies to the software algorithms that define the dynamic transmission behavior of the steering system and the feel of steering. So to cut the development time until the first prototypes are implemented, at TRW we decided to first set up a pre-prototype system for a steer-by-wire application with an electromagnetic clutch in the steering column. The system control was designed to be 'fail silent'. This means that the pre-prototype has a fail-safe system architecture. From the beginning, however, all the hardware components



▲ *Fail-safe steer-by-wire system (pre-prototype).*

in the pre-prototype, except the central ECU, were selected with a view to producing a fault-tolerant system. In the pre-prototype, dSPACE's MicroAutoBox performs the tasks of the central ECU.

From Component-in-the-Loop (CIL) Simulation to the Test Vehicle

Three core areas were vital in the development of the pre-prototype system software:

- Higher-level steer-by-wire system functions (for example, variable steering ratio and force feedback characteristics at the steering wheel)
- Lower-level position control circuit for the front axle actuator and lower-level torque control circuit for the steering wheel actuator
- Sequence control and safety logic for system initialization and for switching between manual steering and steer-by-wire mode.

The algorithms for the higher-level system functions and the lower-level actuator control circuits were first represented in MATLAB®/Simulink® and then tested and optimized by offline simulation of the steer-by-wire system. The control of the steering wheel actuator is vital to the feel of steering. Right from the start of software development, we optimized the feel by using a CIL environment that includes the steering wheel actuator in the simulation to allow a subjective evaluation of the steering process.

This was done by connecting the integrated ECU of the steering wheel actuator to a dSPACE signal processor via a high-speed CAN bus. This enables the reference values for response torques at the steering wheel to be determined by means of a real-time-capable vehicle dynamics simulation model (ve-DYNA). Parallel to that, we also visualized the vehicle responses to steering wheel inputs with an on-screen dSPACE 3-D animation. The sequence control for the pre-prototype system was represented with MATLAB/Simulink/Stateflow and also first tested via offline simulation. To try out the pre-prototype in a test vehicle, the algorithms for the system function and the sequence control were finally implemented on dSPACE's MicroAutoBox. Just as we did with the CIL test bench, we also used dSPACE's ControlDesk in the test vehicle so that we could easily adjust parameters and acquire measurement data. Taking the results from the pre-prototype development as our basis, we are currently working on the next development stage, a production-close steer-by-wire prototype with a fault-tolerant system architecture. From our present point of view, the first steer-by-wire launch could be in 2007. However, we do not anticipate going into large-scale production until 2010.

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▼ CIL test bench with force feedback actuator.

