Enhancing real chassis system performance in the Networked, ISO and Autosar compliant environment

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What do Full Electromechanical Brakes Offer ?

- They bring;-

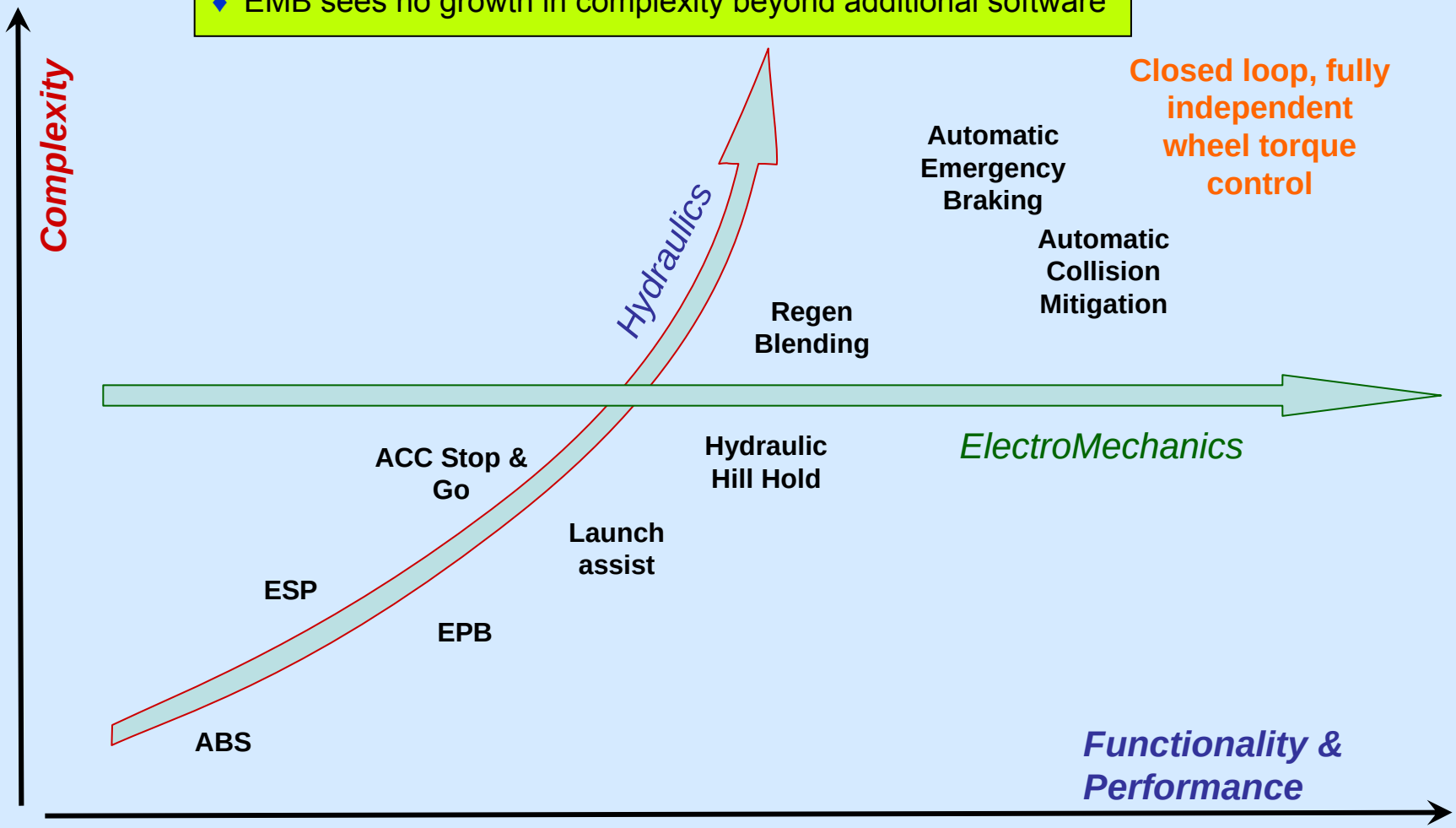
– High-speed, intelligent actuation	➔ Transparent implementation of function
– Elimination of hydraulics and fluids	➔ Lower manufacturing, maintenance and environmental burdens.
– Decoupled from Driver Interface	➔ Simplified autonomous functionality
– Zero engine bay packaging	➔ More space for Hybrid PT requirements
– Software command arbitration	➔ No centralised actuation compromises
– Corner ‘closed-loop” operation	➔ Reduces effects of efficiency variation.
– Totally open function platform	➔ Easy implementation of OEM functionality.
– Fault Tolerant architecture	➔ Progressive degraded operating modes.
– Software based functionality	➔ Eases application to all vehicle architectures.

Functional Growth in Braking

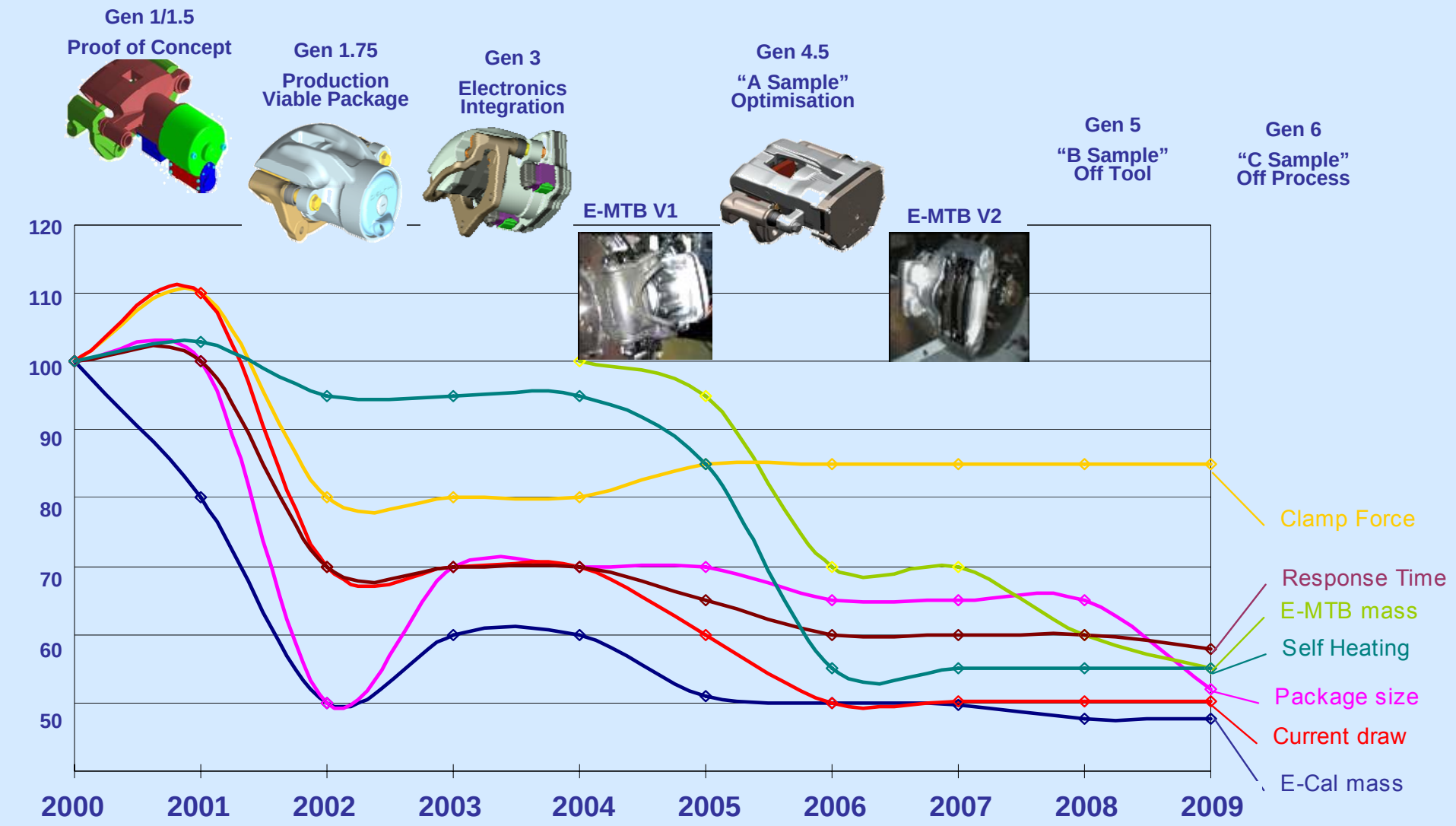
- '*Functional Creativity*' has outpaced hydraulics ability to deliver
  - Faster actuation
  - Lower leakage
  - More accurate control
  - Pedal Decoupling
- Many 'new functions' were first developed & demonstrated with ElectroMechanical actuation
  - Hill Hold & Launch Assist
  - Soft Stop
  - Automatic Park Brake application
  - Etc,etc
- '*Quality of function*' with electromechanical actuation has been hard to match with hydraulics.

Brake Architecture Crossroads

- Hydraulics get progressively more complex with function
- EMB sees no growth in complexity beyond additional software



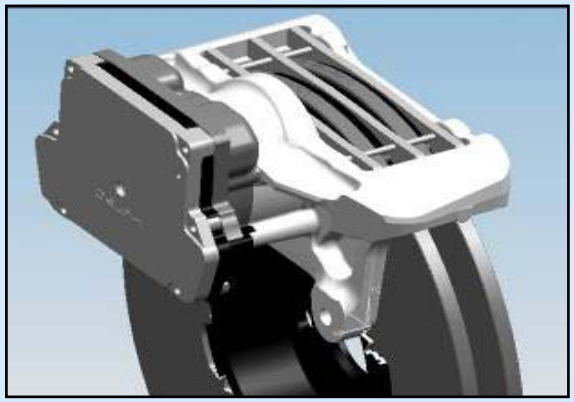
Delphi EMB: Evolutionary Performance



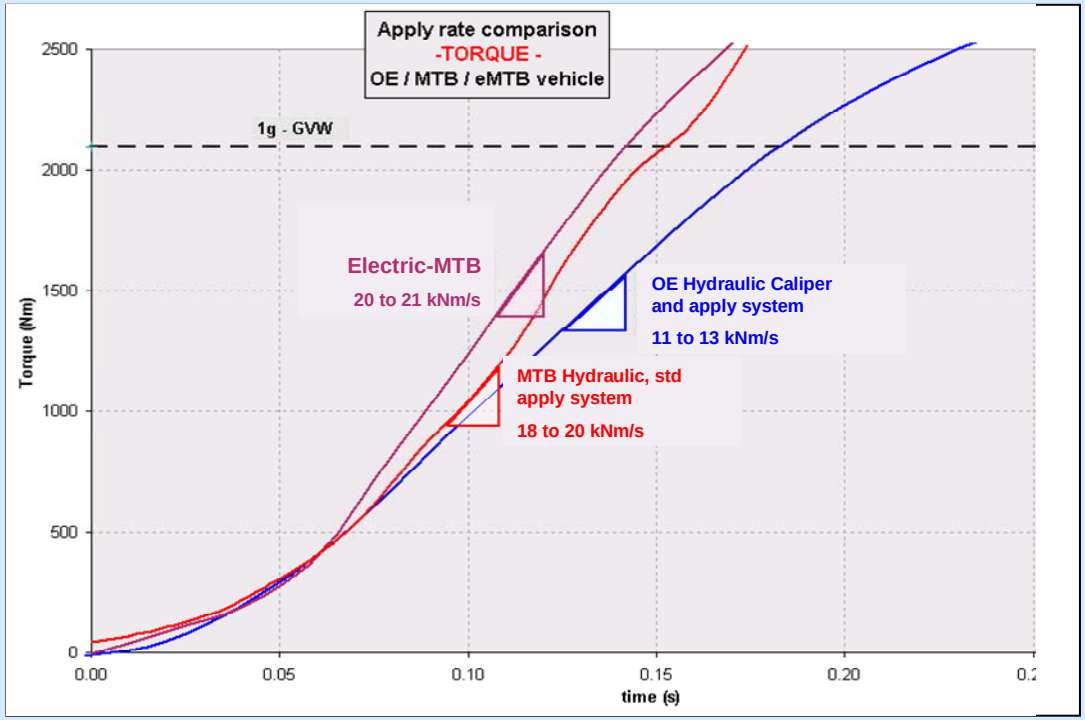
EMB performance

- Torque Capability
  - Used to be well below ElectroHydraulic capabilities and require 42 volts.

  Now
  - Specific torques are equal-to or greater-than traditional, e.g. E-Max Torque Brake
  - Torque build rates are as-high or higher than traditional, typically 20kNm/sec +
  - Achieved at modest currents at 14volts

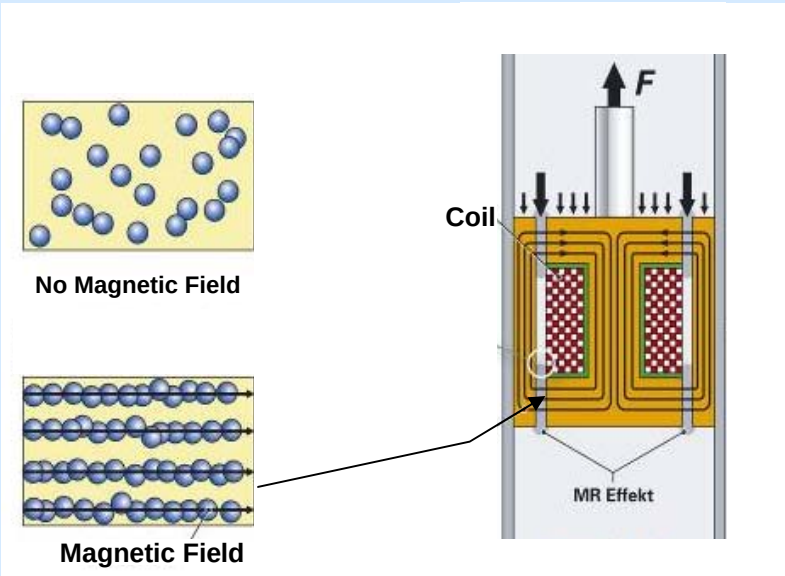


Speed & Performance comes at a price.
Traditional centralised controls are too slow to provide smooth actuation and refinement.



MR Suspension

- Arguably the fastest and most powerful of variable ‘damping’ systems
  - Sub-millisecond Fluid response
  - High Turn-up ratios
- Not fundamentally a viscous damping device
  - Requires very fast, real time control to achieve required performance
  - Additional performance potential with further enhanced control.



Speed & Power again have a price.
- Latency in signal processing or data transmission to central control can cause phase shifted response
- Wheel control at traditional bus speeds is not practical (currently hard-wired @ 1ms loop time)
- High speed synchronisation with braking, steering and road holding should enhance vehicle performance

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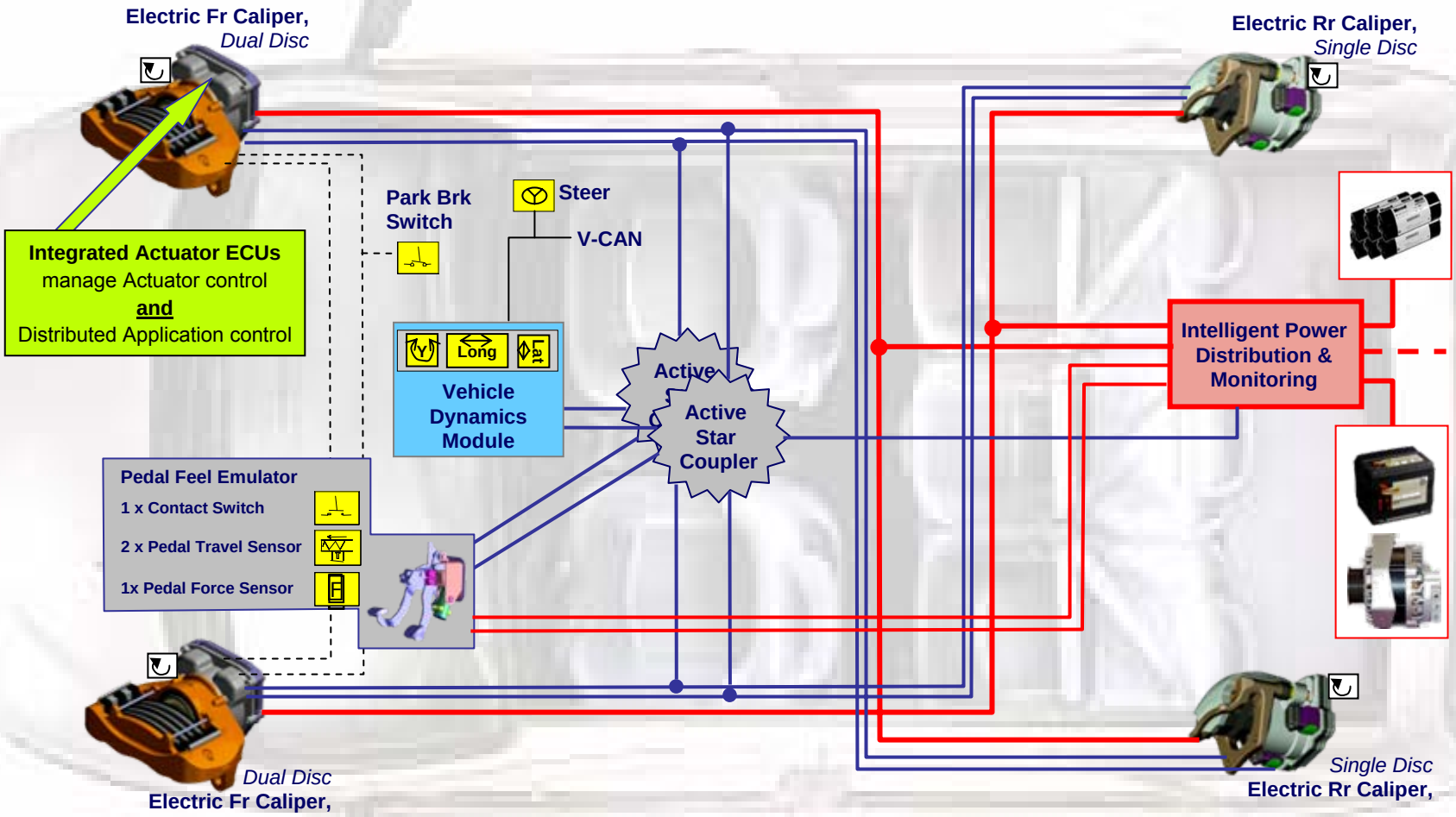
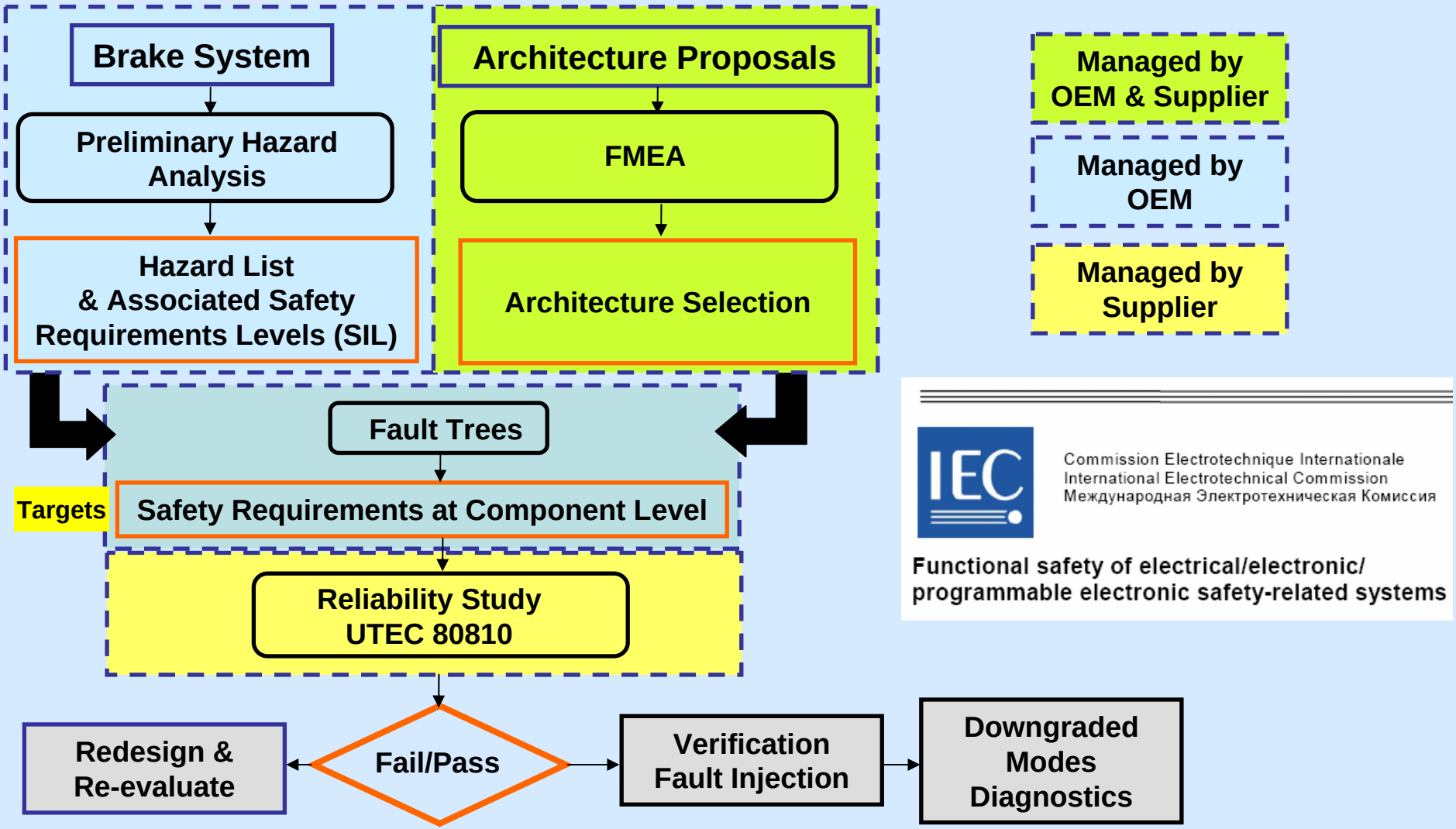
Brake-by-Wire Safety Architecture

- BBW Safety Analysis requires significant control redundancy
- This redundancy can be achieved in many ways
- Combined Hardware-Software redundancy has been the traditional way
- Parallel distributed redundant computing is another and the route chosen by Delphi
  - Takes advantage of the multiple actuators inherent to the system
  - Does not add significant additional hardware (complexity and cost)
  - Mandates Time Triggered system
  - Does not, on it's own, address Actuator control issues

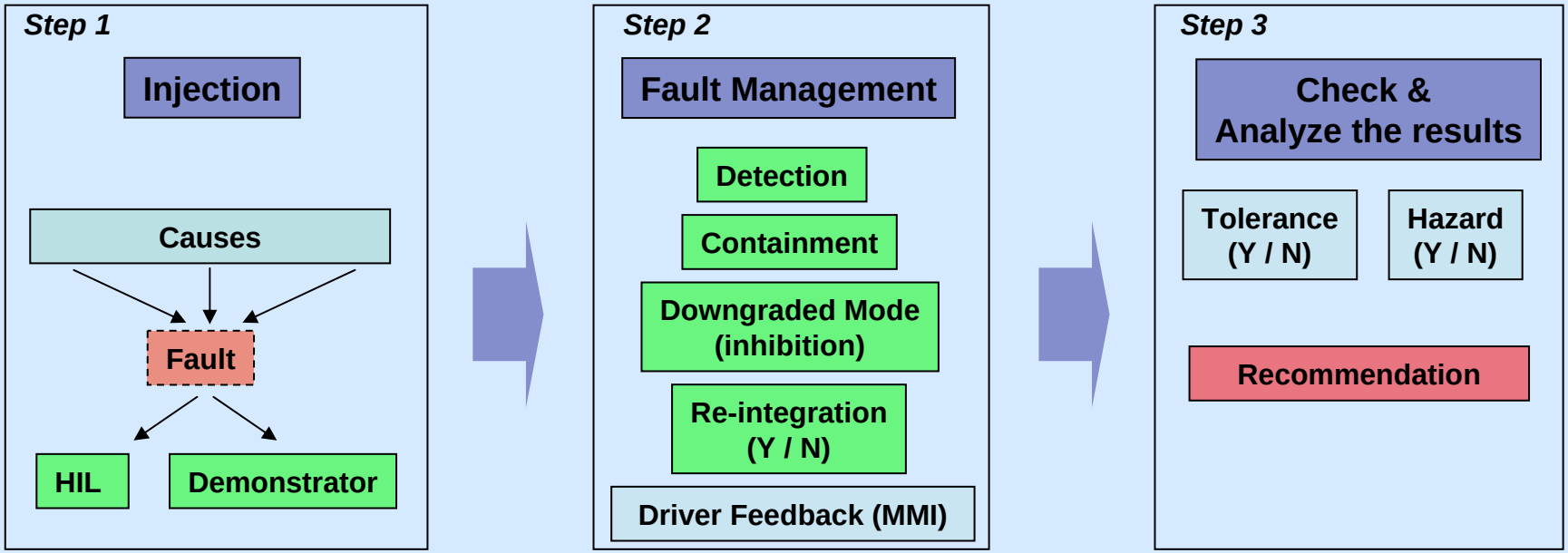
DEB4.3: Fault-tolerant Brake-By-Wire architecture



Flow Chart: IEC 61508 application on Brake-By-Wire



Fault Injection Architecture verification process



HIL
Easier for actual faults
CAR
Less easy
Provides Driver feedback
Convincing
Real Fault & Simulated Faults
TT bus disturbance node
Programmable charges…

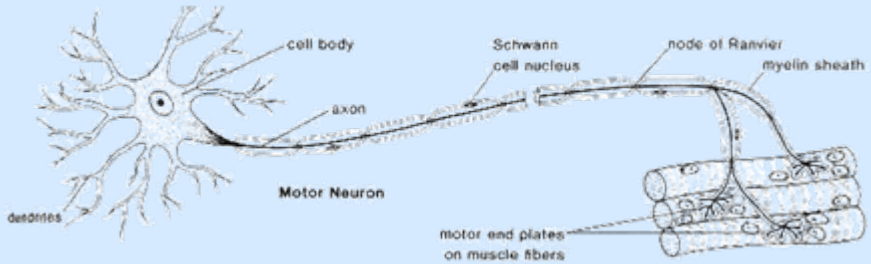
Dormant fault detected dangerous failure or loss of safety barrier not reported to the driver
Independence Physical implementation
Re-integration
Especially linked to availability
Downgraded Modes
Check the impact of the fault Management process on functionality

Tolerance
- Check implementation correctness
- Check system behavior beyond its specifications (higher order cuts)

Recommendation Next system specification

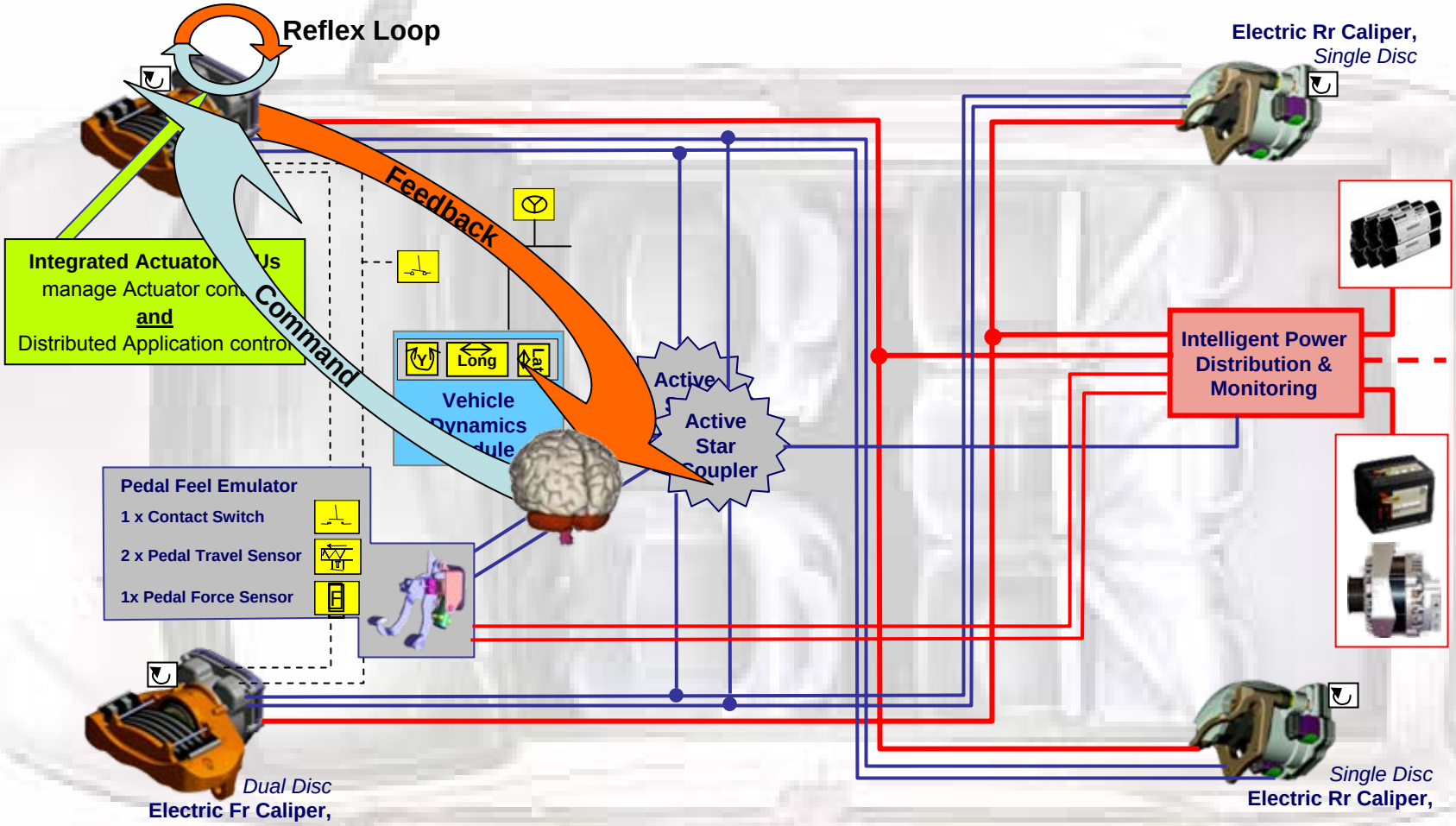
Managing EMB performance

- A Biological analogy:- The Reflex Arc
  - Most reflex responses don't have to travel to the brain to be processed, which is why they take place so quickly. A reflex action often involves a very simple nervous pathway called a Reflex Arc.
  - A reflex arc starts off with receptors being excited. Signals are sent along a sensory neuron to your spinal cord, where they directly trigger a motor neuron which actuated a muscle.
  - Reflex arcs can manage relatively complex tasks not just simple reflex actions

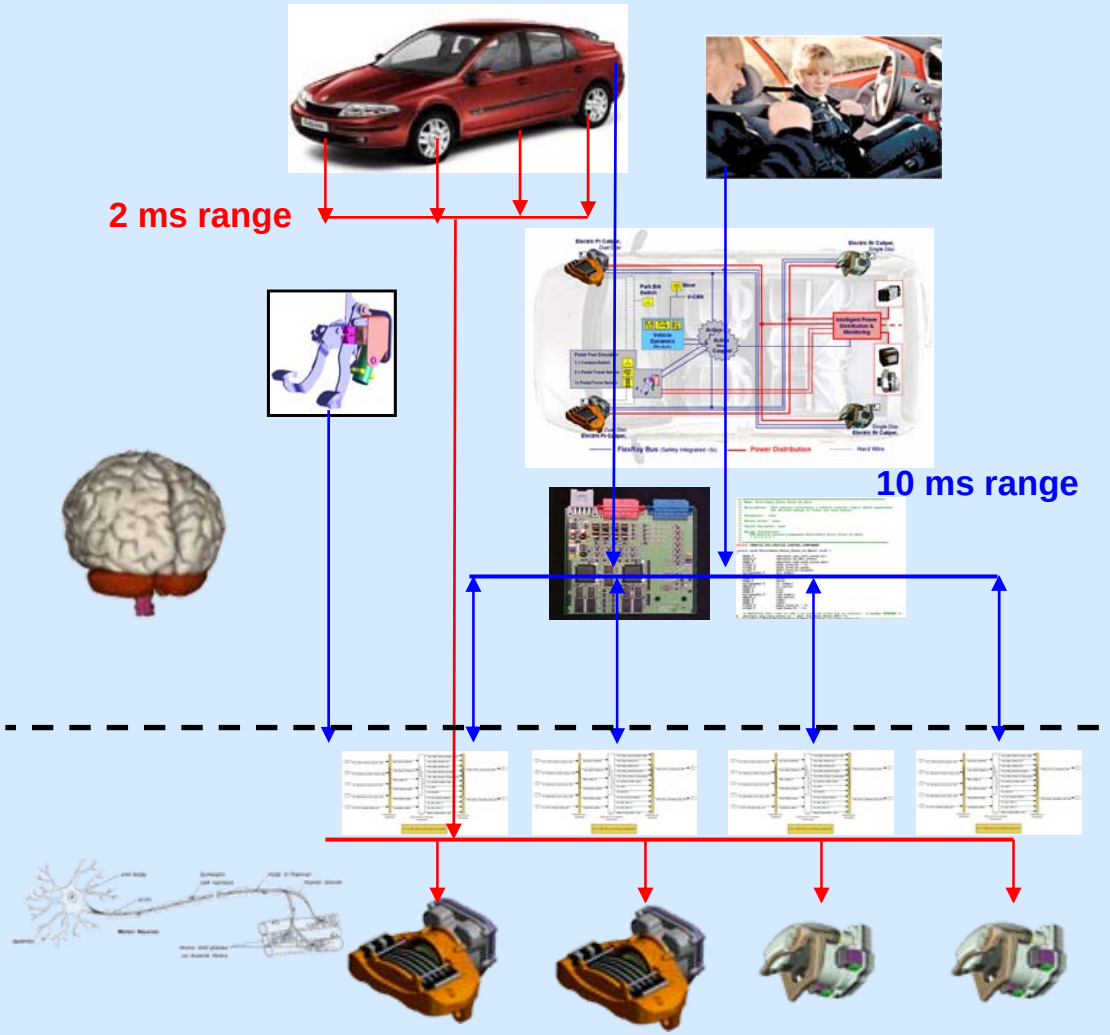


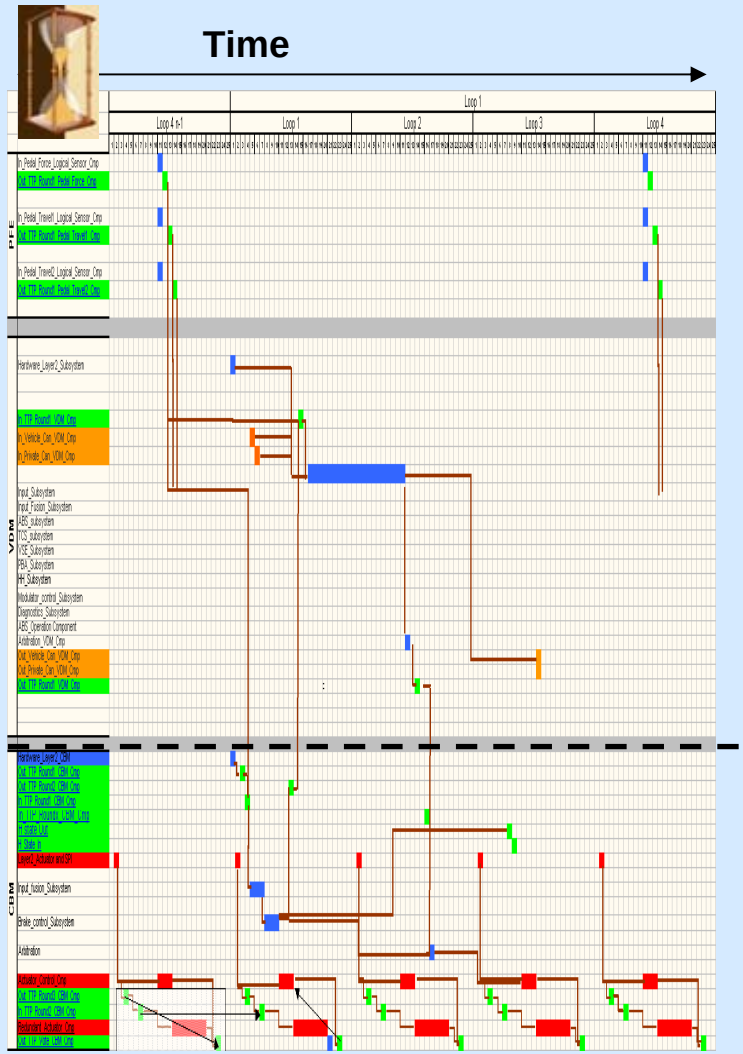
- This localised response loop can be applied directly to the distributed computing architecture.

DEB4.3: Fault-tolerant Brake-By-Wire functional architecture



Brake by wire : Data flow & time domain





Delphi EMB: Evolutionary Functionality

Systems (DEB4.0)

GEN 0 Arch 42v.

GEN 1 Arch 42v.

GEN 0 Arch EMTB 14v.

GEN 2 Arch 42v.

GEN 2 Arch EMTB14v.

GEN 3 Arch 14v.

Continuous functional Growth

2000	2001	2002	2003	2004	2005	2006	2007
Gen 1 42v E-Calipers on **CAN** communications. Base Brake and limited ABS. Powerful but very digital and slow. Stopping dist ok. Comfort poor	Gen 1.5 42v Electric Calipers on **TT-CAN** communications. Base Brake and **ABS**. Bus-Latency hurts performance. First use of central Vehicle ECU for OEM functionality. Stopping dist ok. Comfort poor in ABS	**EMTB V1** Electric Calipers on CAN communications. **Distributed Electronics** integral to calipers. Base Brake, ABS, **EPB** **Legacy Hydraulic controls** Hi-Co Stopping dist ok. Huge torque apply rate causes control and severe comfort problems	**Gen 3 42v** Electric Calipers **TTP** deterministic communications bus. Distributed Electronics integral to calipers. Base Brake, ABS**, ESP & Comfort Fns** System faster but chip through-put limited. **Fault Tolerant w RPV**. Full **V**ehicle **D**ynamics **M**odule supervision. Legacy hydraulic control Stopping dist ok. Comfort better but not ok	Gen 3 14v E-Cal & V1 EMTB Calipers on **TTP** communications bus. Distributed Electronics integral to calipers. Base Brake, ABS, ESP & Comfort Fns System still chip through-put limited. Fault Tolerant w RPV improved robustness. Full **VDM** supervision. **New 2.5ms distributed wheelspeed & ABS controls** Stopping dist improved. Comfort now acceptable for ABS and all functions.	**Gen 4 14v E-Cal & V2 EMTB** Calipers 10mbs **FlexRay** bus with emulated, **Integral Safety Services** Distributed Electronics. Base Brake, ABS, ESP, Comfort Fns & **CMB** Fault Tolerant w RPV **Enhanced Dependable Power system**. **Reliability for Public Road use** Full **VDM** supervision and system integration New 2.5ms distributed wheelspeed & ABS controls **Closed loop, individual Wheel-by-Wheel Decel control.** **Comfort projected good for all functions.**

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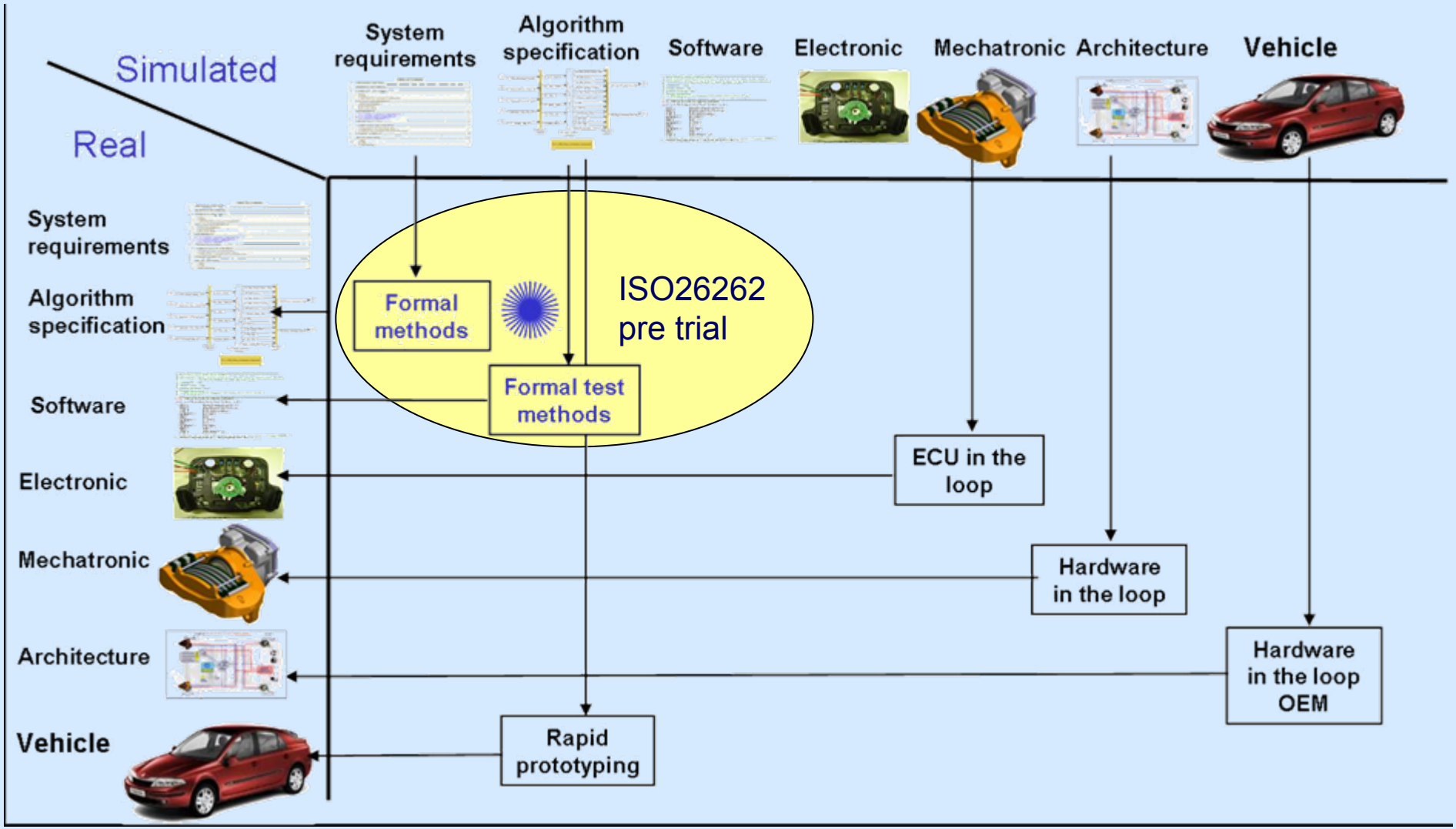
Software Process: Moving toward ISO



Software Process: Moving toward ISO

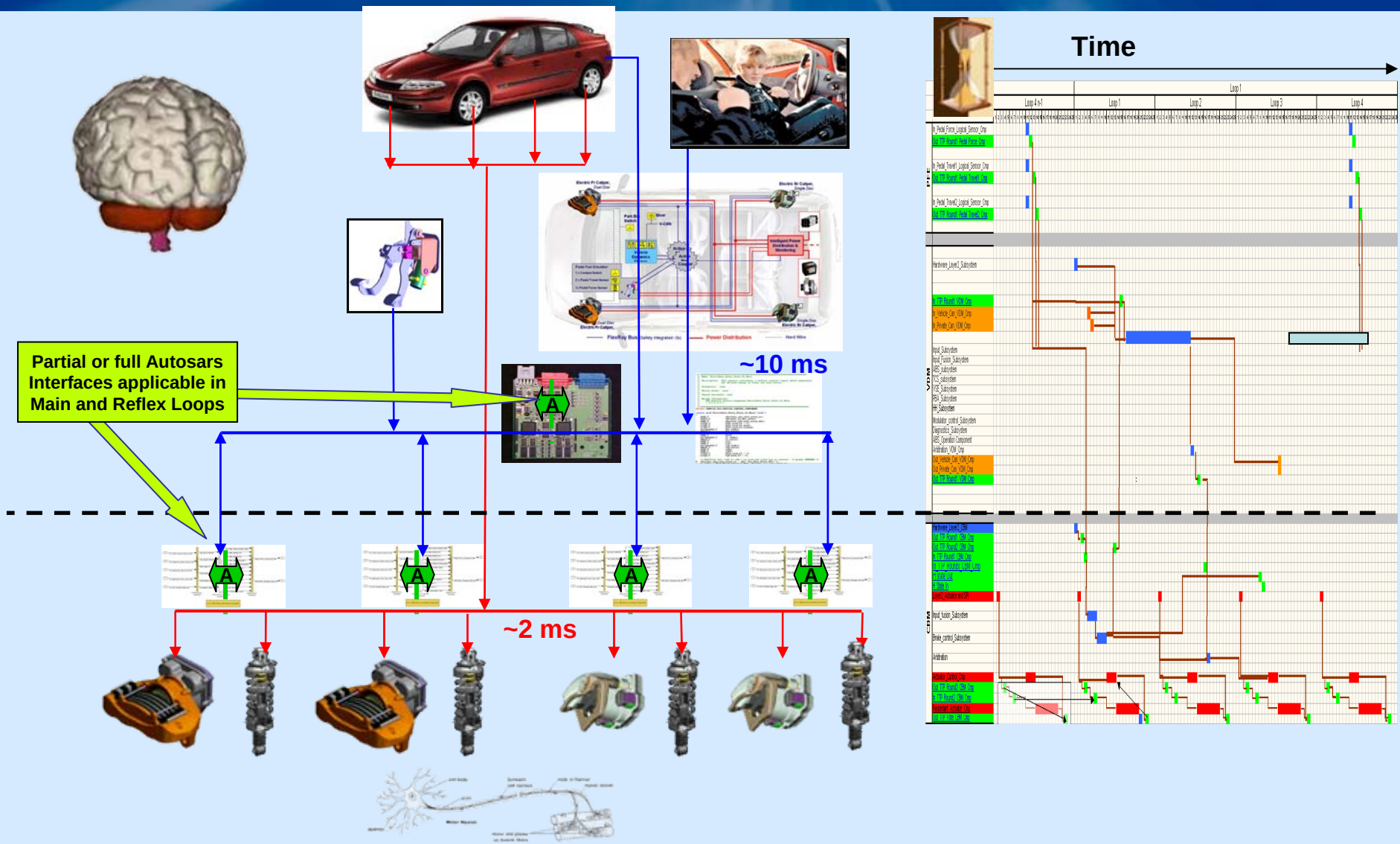
- Application of Formal Tools to distributed code
  - Conducted on Fully Autocoded portions of new or revised code
  - Beta releases of code verification tools used
  - ~10k code lines exercised
- Results valuable at many levels
  - Greatly accelerated and improved debug
  - Simulation results easily integrated
  - Fully functional upon first integration
  - Has allowed a useful level of production intent Electronic Integration
- Only early stages of implementation
  - Tool development and refinement urgently needed

Extending the concept

- As only a BBW central supervisor the VDM spends 75% of is life doing nothing.
- The “brain” can obviously handle brakes, suspension and steering with the appropriate internal Autosar interfaces
- This arrangement is fully compatible with Distributed Computing and Reflex Loop type controls

- Delphi is pursuing development of this approach to the MR suspension system.
  - Initially in a stand-alone mode to explore fundamental performance benefits
  - Integration with BBW will explore benefits of fully synchronised control with a cross-system reflex loop

Combined BBW & MR : Data flow & time domain



Conclusion

- By-Wire actuation is fast, powerful and fully feasible at 14 volts
- The power of By-Wire systems pose unique control problems
- The safety-based distributed architectures, correctly selected, can also offer enhanced control opportunities.
- Quasi-biological, localised *reflex loops* can be implemented to better match actuator capabilities while maintaining effective centralised supervision.
- Local loop control can be extended across multiple sub-systems with Autosars interfaces at each level.
- Use of formal methods, even though immature, can greatly enhance software development and ease of integration.

Thank you