EE Cars Architecture & Linked ECU: Constraints and New Needs

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Abstract

The embedded EE systems complexity is still growing. During this decade, it is even going to accelerate with the deployment of Hybrids and Electrical Vehicles. To control the physical EE architecture complexity and ECU cost, car manufacturers must extend the functional perimeter of ECU and decrease the ECU number. This paper illustrates the needs and constraints on EE systems, notably linked to the Hybrids and Electric Vehicle. It is likely to foresee technological breakthrough in term of assembly and packaging for embedded EE systems over a 5 to 10 years period.

Keywords: Electrical vehicle, EE architecture, ECU reduction

1. Context

The major trend in current vehicle development is the increasing number of electrical and electronic systems in vehicles. These systems are being introduced in order to provide more comfort and safety functionalities to the customer.

The first part of this article describes the context of ongoing EEA (Electrical Electronic Architecture) solution with examples and a technical overview on ECUs (Electronic Control Units) of current EEA solutions. This description is completed with market trends for the coming years where ADAS systems and HEV/EV have a stronger potential to ECU proliferation.

However, to cut off this ECU increase in order to cope with a mere vehicle integration and to control electronic systems costs, the article second part will illustrate a target hypothesis of an EEA design which introduces future technological challenges for the automotive industry.

In today's vehicles, the addition of a new function in the EEA systems is mainly achieved by the addition of one to several ECUs with their own Sensors/Actuators (S/A) components. The ECU build-up is mainly due to the EEA structure where current ECUs are maintained to support vehicle constraints during:

- Development phase where design legacy and strong integration requirements, tools, technical capabilities and internal organization are kept as it with few evolution.
- Production phase where ECU and wiring harness implantation and assembly operations are well known.

This situation of ECU growth becomes critical in term of integration into the vehicle while available space for electronic is no longer maintained because of comfort issues. In term of complexity it also leads to an increase of communication networks and gateways, wires, energy management and so forth. Thus a disruptive solution is required to reduce numerous ECUs.

2. Ongoing EEA

There are several patterns of architectures in use from low-end vehicles with few electronic modules up to luxury vehicles with numerous ECUs. Manufacturers often distinguish five main domains for functional allocations on EE systems: Chassis, Power train, Body (lighting, doors, seats …), Passive Safety and Telematics/Multimedia. A sixth domain is on the way with Advanced Driver Assistance Systems (ADAS), which is growing faster on the edge of security assessment for clients. The ADAS domain or better saying ADAS functions strengthen the use of inter-domain communication. Trends that belong to ADAS:

- Larger number of decentralized control tasks
- More extensive monitoring and diagnostic tasks

- Scalability and variety (High number of options and variants)
- Broader communication bandwidth between control units and between sensors/actuators and control units

Vehicle functions handled by electronic is a cluster of numerous atomic functionalities, which are distributed amongst the vehicle. The definition provided applies for one OEM; granularity of functions may vary from one OEM to another one depending on legacy. For instance, an European vehicle main stream might be based on more than 35 ECUs which represent more than 70 functions for about 500 functionalities. Currently a functional reference may combine about 100 vehicles driven functions for 1000 functionalities, these figures are increasing each year with the introduction of innovations in addition of former functions.

The State Of The Art for each domain is described below based on a 3 ECUs categories approach: S/A ECU, Medium ECU and Large ECU.

The **Power train domain** is composed of components related to the longitudinal propulsion of the vehicle (internal torque sources). In today's conventional fuel-propelled vehicles, the power train domain often relies on two ECUs: an engine control unit and a gearbox unit. For specific functions such as "stop and start" (e.g. micro hybrid), alternative fuel engines (e.g. LPG) or shift-by-wire, additional ECUs are added to the main network.

The Engine control unit includes up to13 functions for a gasoline engine controller but there are many possible ECU variations (size and fuel type) which introduces the management of ten hardware variants (e.g. about thirty for a "generalist") and more than 200 variants for software. Nevertheless the architecture of the ECU is very similar for each application. Typically this is a two-chip design with a different dimensioning of the microcontroller and the power stages and with the management of safety modes (monitoring and limp-home modes). In this domain the main processor is typically a 32 bit device with a second processor, an 8 bit device or an ASIC, for protection strategy. The internal clock can be higher than 100 MHz, the Flash-ROM can be upper than 1.5MB and an EEPROM space is needed. The power consumption of the ECU can be less than 1A in operation and less than 100µA in a sleep mode. To manage the sensors and the actuators of a basic engine there are about 20 analogue sensor inputs, few logical inputs and about 15 outputs. This varies with the type of engine and the electro-valves are more numerous for diesel or powerful engines for instance.

The gearbox control unit includes around five functions. The architecture of the ECU is a two-chip design for the semi-automatic gearbox (single processor for the automatic gearbox) with a different dimensioning of the microcontroller and the power stages. In this area the main processor is typically a 32 bit device with a second 8-bit processor for protection strategy for the semi-automatic gearbox. The external clock can vary up to 40 MHz with a flash up to 1 MB and a RAM up to 1-kBytes, EEPROM space is also needed and the smallest cycle time is around 2 ms for a servo-control basic function. The power consumption of the ECU is under 1A. However, the power stage can control between 4A to 30 A. The stages to manage the sensors and the actuators are composed by about 10 analogue sensors (up to 20 for a semi-automatic gear box), 10 logical inputs and more than 10 outputs.

The power train ECUs are generally connected with the chassis domain ECUs in a same main network and for several further functions as electro-magnetic valve control, controlled alternator, diesel warm up, etc. a local networks can be implemented on the engine control unit.

The **Chassis domain** is related to the four wheels and their relative position and movement such as steering or braking for longitudinal, lateral and vertical vehicle dynamics. In the chassis domain, there are typically between 1 and 6 ECUs. However, if you look at the very-low-end of car segments, there can be no ECUs in the chassis domain at all. In low-end vehicles, there is normally at least one ECU, i.e. for the Anti-lock Braking System (ABS). The all ECUs to consider in this domain are the Braking System ECU (ESP, Electronic Stability Program and EPB, Electromechanical Parking Brake), the Electrical Power Steering (EPS) ECU, the Adaptive Damper System (ADS), the Tyre-pressure Monitoring System (TPMS). These systems require control loops that are distributed over several ECUs, synchronous and deterministic system behavior, and high system availability. Nowadays and in the near-future, the most commonly used architectural elements will be CAN and Flexray as bus systems.

As example, the Electronic Stability Program (ESP) is a regulation system in the brake system and power train which prevents uncontrolled sideways vehicle movement. In the ESP ECU until 10 different functions are realized. It consists of an integrated electronic control with redundancy concept and "two-chip" design with a main processor of 32 bits device up to 64 MHz and 1MB Flash-ROM. The number of inputs of an ESP is around 10 analogue sensors and few logical inputs.

The ECU is generally integrated into the hydraulic unit (mecatronic) needing less than 10 outputs.

The **Body domain** is related to the mechanical entity of the car which do not belongs to the vehicle movement, but supports the user of the car, such as airbag, wiper, lighting, door locks, window lifter, air condition, seat equipment, etc. In today's architecture, as electronics integrates more and more power elements, it is becoming more common to distribute body electronics which can be split into two or three major modules (ECM or Electrical Controller Module). Normally one ECM is defined for the under-bonnet or front area, (F-ECM), a second one for cockpit (C-ECM), and a third one for the rear area, (R-ECM). This third one may be integrated in the C-ECM if there are very few elements to manage in this rear area but for the future it is a high potential to grow (new functions in this area and less implementation constraint). We have to differentiate C-ECM is left as a main "brain" of the vehicle and usually includes the main gateway, the vehicle power life, etc. In the near future, with the high voltage architectures, these ECMs will probably include the global energy management (see HV).
Today ECMs can be characterized with a 16 or 32 bits microcontroller with less than 1 Mbytes of Flash memory and less than a 64 MHz clock. The inputs and outputs can vary from 60 to 200 wires with logical and analogue inputs and basic or PWM power outputs from 200 mA to 30A.

As regard small electronic modules like those for seats, doors or smaller, (mirrors, wipers…), the tendency is to specialize the microcontroller peripherals. Only 8 bits are needed and memory sizes up to 128 Kbytes, but as the module size is critical, and versatility is a need, the type of other elements inside the microcontroller has to be carefully selected: one or two bus drivers, output controllers, timers, voltage supply, RF…

The **Telematics-multimedia** is related to information exchange (data transfer) between the vehicle (human or application triggered) and the outside world. It is one of the most recent emerging technologies within the automotive industry which can offer the following services among others: navigation, emergency call and roadside assistance, vehicle security notification and stolen vehicle tracking services, travel information, phone module, video module, audio module (tuner/amplifier), head unit/display, voice recognition & microphone, gateway, nomad connections (Bluetooth, USB…).

The **Human-machine interface (HMI)** is related to the information exchange between vehicle systems and vehicle occupants, for instance by switches and displays. Often, HMI is assigned to telematics but with the increasing need of HMI in other domains this is taken as a separate domain. For some applications there is no clear relationship to only one car domain for such components / phenomena as engine brake or electric supply.

The **ECU Description** is limited in this article to:
- The number of functions
- The µC type and the type of power stages
- The ECU package with environment vehicle (and location) and IOs (Inputs/Outputs) numbers

And to resume the SOTA below, only three ECU categories are considered: S/A (Sensor/Actuator) ECU, Medium ECU and Large ECU.

Large ECU:

- Functions: 10 to 30 for 100 to 300 functionalities
- Components: a 32 bits main µC and a 8 bits µC for safety or for gateway, the electric power is composed by 15 to 40 relays or smart MOS from 200mA to 30A for a total of less than 100A
- Package: Cabin area (+85°C) or engine area (105°C and fluids), 3 to 10 connectors for 60 to 250 wires

They are composed by "supervisors" (e.g. mix of signal and power technologies) with the 3 ECMs and their integrated junction box (junction box is not always integrated with ECM), the primary power management (primary junction box with state of charge, voltage regulation…), the engine unit, the gear box unit, the ESP, the EPS, the airbag, the ACC, the radio navigation. So **until 11 large ECUs** are considered for the main stream vehicles.

Medium ECU:

- Functions: from 1 to 10 for a maximum of 30 functionalities
- Components: 16 or 8 bits µC (few exceptions with 32 bits) with several or not smart MOS for a total of less than 10Amps
- Package : Cabin area (+85°C) or engine area (105°C and fluids), 1 to 3 connectors, less than 50 wires

They are composed by the TPMS, EPB, ADS, pedestrian collision, pre-crash, UPA (Ultrasonic Park Assistance), Keyless access, climate control and panel, dashboard driver, antitheft module, door module, memory module, roof control, trunk module, seat modules, urea injection, seat belt warning, panel control, top column, head up display, radio, phone module, emergency call, etc. **More than 20 medium ECUs** are considered in a main stream vehicle.

Sensor/Actuator ECU:

- Function: 1 or a part for less than 10 functionalities
- Components: simple 8 or 16 bits µC with or not few smart MOS, less than 2A for sensor or actuator electronic (not included the load)
- Package : 1 to 2 connectors, less than 20 wires

They are composed by the alternator, NOx sensor, battery state of charge, gasoline addition, sensor angle, gyroscope, belt retractors, door panel, lift actuators, wiper/washer, antennas, badge reader, ultrasonic alarm, horn alarm, light/rain sensors or camera, screen, etc. **About 20 S/A ECUs** can be considered.

3. Main market trends

For the next years the ADAS new domain is going to really increase as the exchanges between domains (distribution of functions in several domains).In the same way the enhancement of domain will be strongly motivated by the hybrid and electrical vehicle emergence and the enforced regulations.

The **ADAS** comes with large environment sensing and so needs fusion of different sensors as radar, camera and RF infra to reach a high reliability for detection and classification of objects. Moreover, the future systems for accident free driven will extend the dependability requirement for electronic systems because they connect domains (power train, chassis, HMI and telematics) which are only loosely coupled in today's in-vehicle systems. For the first generations, the ADAS are deployed with several ECUs as the UPA (Ultrasonic park assistance), the City Park (UPA+EPS interactions), the ACC (Adaptive Cruise Control with front radar), the LCA (Lane Change Assist with rear radar), the SRD (Sign Road Detection), the night vision (infrared camera), etc. Except the ACC considering as **one large ECU**, the other ECUs are considered as **5 medium ECUs** in this article.

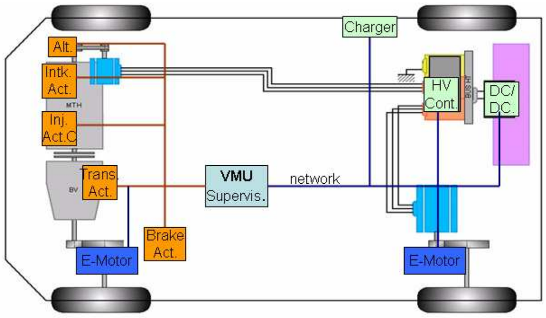
As example, the ACC is an enhancement of the traditional cruise control. The basic functions of Adaptive Cruise Control (ACC) are based on conventional vehicle speed regulations (cruise control), which maintains a speed specified by the driver. ACC can furthermore alter the speed through automatic acceleration, deceleration, or braking to adapt to changing traffic conditions. This system thus permits the vehicle to maintain a distance from the preceding vehicle, dependent on speed.
The automotive systems involved in the realization of the ACC functionality include motor management ECU, radar sensor control unit, brake functionality by ESP, central display unit, and wheel and acceleration sensors. The most important part of the ACC is the radar sensor, which measures the distance, angle and speed difference to the car in front, the ECU uses DSP and µC. A typical ACC radar sensor uses a 3-ray 77 GHz Pulse-Doppler with an average sending power of 200 µW and a measuring distance of roughly 150 m with an accuracy of 1 m. The actuators with which the ACC ECU communicates are the engine ECU, the gearbox ECU and the ESP ECU. To enhance the ACC performance, a link to the car's GPS satellite navigation system to read a digital road map is also needed and a next step will be a communication with the steering etc.

Hybrid and Electric Vehicles add more functions within keeping all the "conventional" vehicle functions for the HV and a majority for the EV (only power management is different). For the current generations of hybrid two more ECUs are added, one for the Electrical motor control and another for the high voltage management. The coming generations will add ECUs for the charger function or for the increasing number of electrical machine and for the electrical converter.

The new challenges to consider are:

- The High Voltage and the management of the bi-voltage
- The thermal dissipation with components solutions to avoid the implementation of a cooling system solution
- The extension of the life cycle for few components as the charger which can be used more than half a day per day and an enhancement of the low power mode control

These new functions are resumed and illustrated below regarding the ECUs existing in the current or nearest versions of HV-EV and using the previous description of the ECU categories:
- HV/EV supervisor (or VMU) is considered as **a large ECU** and can be located in the cabin area
- E-motor (1 to **4**) is considered as a **S/A ECU** in cabin area or external area
- The charger is considered as **one medium ECU** and is located in the cabin area
- The high voltage regulation and the DC/DC are considered as **2 S/A ECUs** in the cabin area



Future HEV architecture hypotesis

Norms & Regulations impact all the domains within adding new ECUs as the pedestrian safety, the urea injection, the NOx sensor, the recorder box, etc. or increasing the penetration rate of existing ECU as the ESP, the airbag, the TPMS, the pedestrian Safety, etc.

They also introduce new constraints to manage and that impact the EEA solution and so the ECUs. For instance regarding the diagnosis evolution, impacts on the networks, software services etc. can introduce new gateway mechanisms, new hardware memory requirements etc. In the same way the engineering process norm (ISO 26262) combined to the merge of functions in one ECU can introduce new µC mechanism for the higher ASIL (Automotive Safety Integrity Level) or mix of ASILs. In the other hand, software norms as AUTOSAR for the body, power train and chassis domain can facilitate these functions merged. However there are too few norms regarding the hardware interfaces of the ECUs because only the networks are standardized and few loads as halogen lights.

4. EEA design: a breakthrough

To break with the current rule, one or several new addition functions is one ECU addition, the only way is to integrate more functions in a same ECU. Due to the first R&D development impact is better to start this integration phase for the functions having a large penetration rate. In the same way it can be easier to make these integrations for the new function whereas the solution is not yet available but with higher risk due to this novelty even if mechanism can limit the impact for the other functions. Another important point to optimize the wiring harness (a large part of the EEA cost and weight) is to consider the merger with a geographical approach regarding the connections of the large ECU to their loads and S/A (ECUs or not). Whatever the process, a future target for the next ten years is given below as a hypothesis.

Merger study case for the future

As mentioned before a today vehicle main stream can count about 35 ECUs and the higher range vehicle can totalize until 50 ECUs. Considering our definition of large, medium and Sensor/Actuator ECUs whereas the S/A are well integrated in the vehicle, the large ECUs can be reduced and the medium ECUs can be taken off within a dissemination in the larger ECUs or in an S/A. A target example is described below with a maximum of 8 larger ECUs, 25 S/A ECU and 10 medium ECU.
The SOTA with the added of market trend notably the HV-EV for a main stream vehicle is composed by 12 large ECUs, 25 medium ECU and less than 25 S/A ECU. So in comparison of the SOTA is a reduction about 30 % for the number of the large ECUs and a stabilization of the S/A ECUs (an increase number of 20% can be normally considered from today to the next decade). And the major breakdown is done for the medium ECUs within a 60% reduction target mostly disseminated in the large ECU and a short part in the S/A.

Nota: for the high range of several premium vehicles the maximum number can reach the 70 ECUs, these cases are still exceptions.

A short description of the large ECU target is given, each ECU is defined due to a geographical approach of the functions to merge in and of course is dedicated to a domain or a very limited number of domain. With each large ECU area the S/A ECU are listed below.

Power train and energy supervisor is:
- Located in engine area: -40 to 105°C, it needs insulated connectors with 150 to 200 pins and metal package and it can drive until 80A
- Equivalent to these current ECUs: F-ECM, engine unit, battery state of charge, primary junction box management (primary junction box is outside the ECU), HV-EV supervisor and charger management, alarm horn and pedestrian collision
- Connected in a dedicated network to “super” actuators, the thermal/gearbox engine (intake, injection and transmission), the electrical engines and the high voltage regulation and the DC/DC. Several S/A for regulation as NOx sensor, gasoline addition or alternator are also connected by network

Chassis and safety supervisor is:
- Located in cabin area (tunnel) : -40 to 85°C in a « dry » area with less than 100 pins and 60A
- Equivalent to these current ECUs: EPS, sensor angle, airbag, gyroscope, ESP high level and belt retractors

- Connected in a dedicated network to 4 "super" actuators in each wheel (for brake-damping and potentially steering)

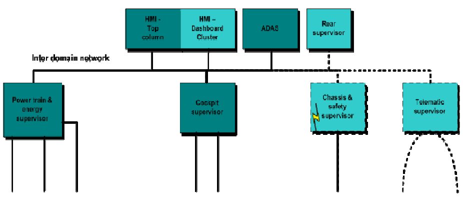
ADAS or fusion (strong links with safety supervisor) is:
- Located in cabin area : -40 to 85°C in a « dry » area with less than 60 pins
- Equivalent to these current ECUs: ACC, UPA, pre-crash, light/rain sensor, ultrasonic alarm, LCA, etc.
- Connected in a dedicated network to four radars and two or more cameras

Cockpit supervisor is:
- Located in cabin area : -40 to 85°C in a « dry » area with about 150 pins and 80A
- Equivalent to these current ECUs: C-ECM, keyless access, climate control, memory module, part of the door module, clock, gateway

Rear supervisor is:
- Located in rear cabin area : -40 to 85°C in a « dry » area with about 150 pins and 80A
- Equivalent to these current ECUs: R-ECM, EPB, urea injection, ADS, roof module and trunk module

HMI as two modules (strong links to telematics and ADAS) is:
- Located in dashboard area : -40 to 85°C in a « dry » area with about 150 pins and 30A
- Equivalent to these current ECUs: the Top column module with RF module (RKE & TPMS) and the dashboard restitution module with dashboard cluster, seat belt warning, screen, head up display

Telematic/Multimedia (strong links to HMI)
- Located in dashboard area : -40 to 85°C in a « dry » area with about 150 pins and 30A
- Equivalent to these current ECUs: emergency call, radio, navigation, amplifier, control panel, badge reader
- Connected in dedicated network to color screens and nomad connection



Example of the large ECUs of a future EEA

5. Technology update for the future

The expectation is to limit the ECU proliferation to enhance cost reduction, space shrinking and maintenance. To reach this expectation and regarding the increasing functionalities the only way is to integrate more functions in a same ECU. That adds more hardware and software to one ECU. And in the same way, as the ECU available space in the vehicle will not increase in the next years, these additions will generate a stronger density component for these ECUs within a higher treatment requirement. The current technologies are not yet answering to these challenges with an optimized cost.

Ongoing technologies:

- Environment: - 40 + 105°C or +85°C, EMC, ESD, low voltage fluctuations and fluid projections in the thermal engine area are controlled

- ECU package: FR4 PCB are mainly used with size of 0,35µm for the "signals" (4 or 6 layers) and 0,7µm for the few "power" stages. The connectors have a large diversity (pin size from 0,635mm to 8mm large and until 14,5mm for the HV, mix of 2 or 3 different sizes in a same connector, insulated or not) and can impact the PCB layers in several cases of signal concentration (60 pins and more) as for µC packages.

- Wiring harness: the current trend regarding the reduction of the wire sections can also impact the thermal dissipation which be reduced in these wiring harnesses.

- Components: the double core µC with a main core and a second core for safety monitoring or management of the peripherals as the networks are increasing. A second main core for safety redundancy or performance is currently more in the research domain.
Smart MOS with RDSON about 8mΩ to higher values starts to be cost optimized for simple solutions.

- Miscellaneous: ten years maintainability within an used average of 500 hours by year and a sleep mode consumption of a ECU about 100µA maximum

The **ECU density** should be enhanced knowing the current limits listed below:

- Thermal dissipation: is it really a matter of component technologies and performance knowing the only software strategies or new networks as CPL can only limit several transient.

- Packaging and assembling: currently the packaging of components doesn't follow the rate reduction of the silicium size for numeric solution. What about the new bounding technologies and in a larger view what are the innovations regarding the line between the ECU connectors to the transistors? The mixing technology in a same die (analogue, power and numeric) is it realistic for automotive in this next decade?

- Connectors: they have a strong impact on the ECU size as the fuses and relays technologies, what are the progresses we can expect. Also to reduce the number of IOs, internals and externals to the ECUs what will be the new networks between silicium components and for the ECU external inputs or sensors?

- And at last, the S/A ECU will be enforced with mecatronic solutions where the environment constraint still stronger in term of vibrations (package impacts) or thermal environment (can be higher than 105°C with less volume for dissipation) or with another way of solutions as "smart connectors" for smallest mechanical components.

The **SoP and ECU complexity**: regarding software and the major domains the automotive define a standard with AUTOSAR to enhance the cost development and it also permit to facilitate the integration software of several providers with few hardware µC adding mechanisms as MPU (Memory Protection Unit). What about the hardware modularity except FPGA solutions for the future? The large increasing expectation of treatment for one ECU has to be controlled to avoid too higher power consumption and respect the EMC requirements, several solutions are possible more or less flexible, performing and cost effective (µC multi core to ASIC…).

In regard of this complexity the reliability must be maintain to the SOTA and the power consumption must be enhance with several modes and a lower consumption in the sleep mode.

6. Conclusion

We are convinced to go ahead in this breakthrough approach consisting in reducing the ECU while the function number still increases. We start in current innovative projects with this approach in Body and ADAS domains before to enlarge it to the all domains.

So we expect solutions to answer to the main technological challenges regarding the concentration of power and treatment in a large ECU and in a mecatronic ECU within keeping an optimized control of the thermal dissipation, the EMC constraints and the ECU modularity improvement.