EVS27
Barcelona, Spain, November 17-20, 2013

Components and tooling to reduce complexity and cost in E/E powertrain system design for hybrid electric vehicles

Khaled Douzane[1], Fabien Vidal-Naquet[2], Nicolas Pernet[2], Cyril Straub[2]
[1] Scaleo chip, 1681 route des Dolines, 06560 Valbonne, France, khaled.douzane@scaleochip.com
[2]IFP Energies nouvelles, 4 avenue du Bois Préau, 92852 Rueil Malmaison, France, {fabien.vidal-naquet, nicolas.pernet, cyril.straub}@ifpen.fr

Abstract

When designing an energy efficient and highly reliable hybrid electric vehicle, the complexity of the electronic / electrical systems and the amount of such systems embedded tends to dramatically increase. Indeed rapid adoption of emerging technologies is required. Consequently, the cost of the solution does not meet the expectations for an affordable and innovative vehicle. The solution, introduced in this paper, proposes to group functions within fewer but more capable and scalable ECU relying on a powerful and flexible MCU. The solution comes with a development framework shortening the development cycles and enabling both design scalability and optimizations in terms of efficiency, complexity and cost.

Keywords: powertrain, HEV, component, modelling.

1 Introduction

When designing an energy efficient hybrid electric vehicle, the complexity of the Electronic / Electrical (E/E) systems and the amount of such systems embedded tend to dramatically increase. When only focusing on the powertrain system, the origin of this inflation comes from several parameters: actuators and sensors are multiplied; measurement precision and actuation frequency are increased; algorithms are much complex and application software codes are also getting bigger. Optimizing such E/E system is getting harder when the same system must handle several variant of motors, engines and vehicles. Adding flexibility to a system is often translated by adding more electronics/electrical resources. This is not compatible with the necessity of components and developments cost control to provide an affordable vehicle.

This paper presents a solution which address Tiers1 and Carmakers expectations in terms of capability, performances, flexibility and optimization for the design of energy efficient hybrid and electric powertrain while rationalizing cost of the E/E systems.

2 Solution presentation

The proposed solution is based on the combination of an innovative powertrain microcontroller so called OLEA; a distribution of powertrain control functions on three ECUs integrating this MCU within the vehicle and a development framework which enable design on complex powertrain system.

2.1 Hardware flexibility and function segregation reliability within a unique MCU

The hardware solution relies mainly on Scaleo chip's OLEA [1] multi-core Microcontroller Unit (MCU) integrating breakthrough technologies addressing the hybrid powertrain requirements either for internal combustion engine, transmission, electric motor and supervision functionalities.

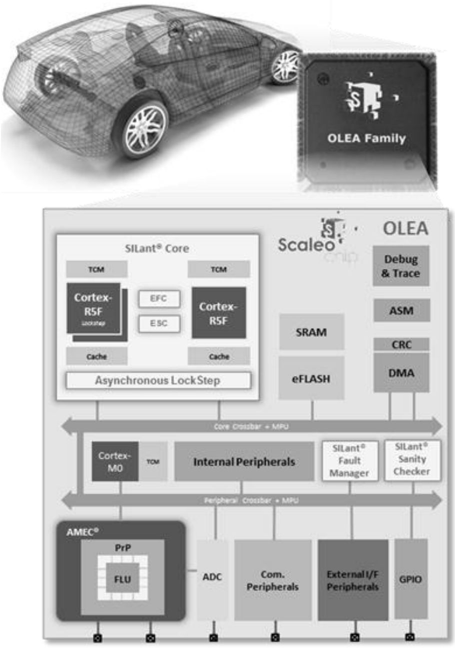


Figure 1: OLEA MCU block diagram

OLEA MCU offers key benefits to the systems to support affordable, reliable and innovative Hybrid Electric Vehicle (HEV) with:

- Fixed event timings whatever the number of events to be processed in parallel;
- High system integration capability enabling powertrain functions grouping;
- Hardware flexibility enabling integration of sophisticated functions elaborated directly from models (eg: Matlab Simulink);
- High computing performances gains;
- High system scalability to adopt (eg: new emerging actuators technology).
- High safety integrity level.

2.2 Advanced Motor Event Control module enabling a new Hardware/Software partitioning

Among OLEA's embedded technologies, AMEC®[2], for "Advanced Motor Event Control", is a unique hardware flexible engine and motor control technology.

AMEC® core technology relies on the combination of a Flexible Logic Unit (FLU) and a set of Powertrain-ready Peripherals (PrP), off-loading the microcontroller's CPU units from actuators and sensors control-loop management. AMEC® can be seen by powertrain system engineers as en extra DSP resource.

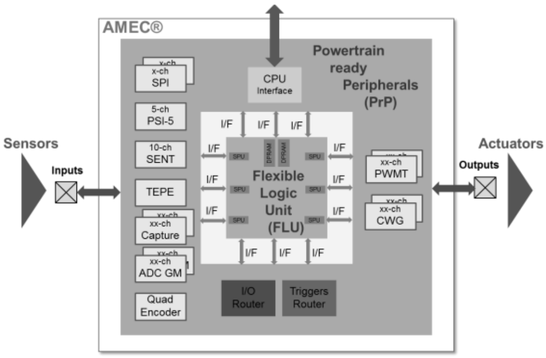


Figure 1: AMEC block diagram

The FLU is a hardware programmable area which can host, with the support of the PrP, any autonomous control-loop. Users can embed within the FLU virtually any state machines and/or combinational logic to build their own custom signal processing to port their own added value algorithm. It allows the support of any sophisticated mathematical function resolution as well as the support of any specific or emerging sensor/actuator interface. By extension, it allows the control of all, existent or yet to build, elements that need to be handled and managed in an engine environment.

As an example, FLU can be used to implement algorithms such as decimation filter or Proportional-Integrated-Derivative (PID) or complex mathematical processing such as Clarke & Park transforms, sinus & cosines transforms and internal engine combustion analysis algorithms. The FLU constitutes a highly capable DSP resource embedded in the MCU that saves the need for an additional Digital Signal Processor device for highly demanding application.

The FLU can be used to hardwire complex state machine implementations and control logic requiring close interaction with the CPU. To support such implementations, the FLU includes standard logic cells, DSP and memories resources fully programmable for maximum flexibility. The FLU is interconnected with the PrP through multiple flexible data paths (named I/F in the figure above) and hardware triggers to provide large control-loop parallel processing capabilities and fixed events timing guaranty.

FLU system integration capability enables to handle simultaneously sophisticated knock detection algorithms, In-Cylinder-Pressure-Sensor pre and post-data acquisition processing with thermodynamic crank-angle combustion analysis and several autonomous electric motor control loops including their associated events sequencing state machines. The FLU integrates a secured programming function combined with a SHE (Secure Hardware Extended) V1.1 compatible security module to protect the FLU interfaces and any fitted custom Intellectual Property. It also provides support of encrypted FLU programming.

The Powertrain-ready-Peripheral (PrP) includes programmable and highly capable peripherals supporting the acquisition and actuation functions. With its set of inputs, the PrP is in charge of the signals acquisition (e.g. position capture and high precision engine position prediction, analogue sensors interfacing such as pressure, temperature, air-fuel mixing rate and knock). On the actuation side, the PrP integrates the peripherals supporting the control of ignition, injection, valve and electric motor.

A typical use case of AMEC is the implementation of In Cylinder Pressure Sensing (ICPS). In this case, ADC Group Manager (ADC-GM) and Thermal Engine Position Estimator (TEPE) peripherals, parts of the AMEC's PrP, are used. The ADC-GM is acquiring the in-cylinder sensing measurements and the TEPE for engine position prediction. On a defined angle window of sampling (every 1/2 Crank Angle degree) the ADC-GM is activated for a new pressure signal acquisition by the TEPE through a hardware trigger. The FLU hosts the CA Heat algorithm from ADC-GM data inputs. It transfers the appropriate CA Heat data to the software application which calculates the next engine commands parameters.

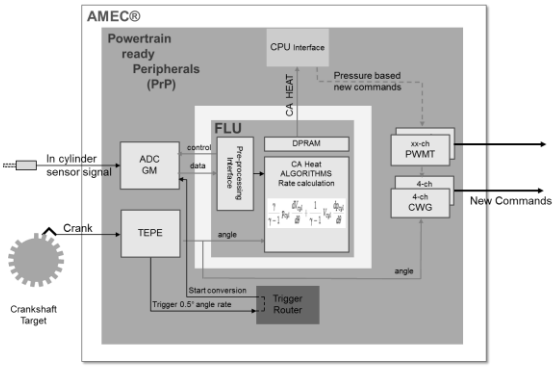


Figure 3: In-cylinder pressure sensing use case

Another typical example is in electric motor control. Usage of electric motor is getting more and more common in powertrain systems. This is used nowadays for ICE with Stop & Start, or electrified transmission, HEV, or a global energy management strategy as in air conditioning. In numerous cases, new powertrain microcontrollers must include generic and flexible features for electric motor. One key prerequisite of efficient electric motor control resides in the adequacy of the control-loop algorithm in relation with the selected motor. Each algorithm needs to be customized not only for high-energy efficiency, but also to avoid irregular running and excessive noise when adjusting the commutation.

In this use case, AMEC uses the ADC-GM for winding current acquisition from the IGBT (Insulated Gate Bipolar Transistor) and cosine/sine resolver acquisition. The ADC-GM acquisitions are triggered respectively by the PWM driving the IGBT and the resolver. The FLU integrates the angle tracking algorithm to estimate the current motor angle position. For the actuation function, the FLU hosts the Clarke & Park transform to compute the next PWM commands from the winding currents (Ia and Ib), the motor angle position and the "driver order" inputs.

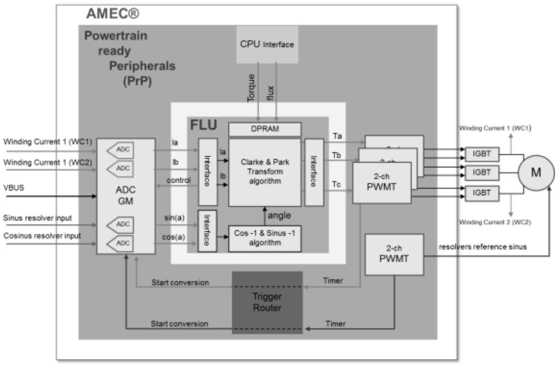


Figure 4: AMEC for electric motor control use case

By integrating an autonomous control-loop with sophisticated algorithms, this implementation enables high-resolution and high-timing accuracy for measurements inputs and output commands. It provides an optimal alternative to DSP based solutions. It also significantly simplifies the system design and saves CPU resources for the ECU software application.

2.3 Targeted Vehicle E/E Architecture

The suggested powertrain Electric/Electronic Architecture (EEA) relies on three ECU integrating an OLEA MCU and interconnected with an Ethernet network:

1. One ECU grouping the robotized transmission control, the stop & start and the engine management system functions.
2. A second ECU for the electric motor control and the associated energy dc-dc conversion chain.
3. And a third ECU for the global powertrain supervision and the energy management [7] also grouped with other body control functions.

This suggested EEA concept raises the application functions distribution, functions grouping, functional safety and scalability challenges at system level.

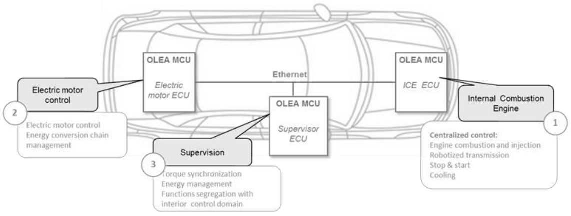


Figure 5: Targeted Vehicle EEA

3 Targeted Hybrid Electric Vehicle

This OLEA MCU flexibility is essential for the control of highly complex hybrid powertrains. IFPEN manufactured an hybrid electric vehicle prototype, FlexHybrid (see Figure 6), which is a parallel full hybrid vehicle, powered by a 1.4L gasoline engine of 63 kW and an electric motor of 37 kW. Hybrid management strategy, as well as engine and transmission control algorithms were designed by IFPEN and integrated into the vehicle to enable rapid design explorations and optimizations.

Figure 6: FlexHybrid prototype on a vehicle test bench

The integration of three OLEA MCUs into this vehicle demonstrates their strong benefits for energy efficiency and total EEA optimization as shown in Figure 5. Ethernet communication permits the distribution of the control algorithms between MCUs, and their implementation adaptability is essential. For example, the fast execution needed for the hard real-time control of an electric motor or engine combustion analysis is provided by Flexible Logic Unit (FLU) of AMEC, saving computing power for the heavy calculations needed for hybrid supervision, hosted on OLEA processors.
OLEA MCU versatility and computing capabilities grant to IFPEN a very powerful tool. As a result FlexHybrid enable rapid development of optimized and energy efficient hybrid powertrain solutions.

4 Hybrid powertrains development tools

In order to address the system sophistication, it is necessary to enable development from models thanks to a complete tool suite enabling short design cycles and efficient system optimizations.

4.1 Code generation

IFPEN developed high frequency and high resolution control algorithms for hybrid applications. These algorithms are handled by IFPEN development framework starting from Simulink models. These models are used among a simulation based process [5] until the final targeted architecture: simulation, software-in-the-loop and hardware-in-the-loop are frequent steps of the process. This approach requires being able to obtain automatic implementation of the models.

In order to take benefits from the OLEA processors, IFPEN has developed a code generation solution to make easy and efficient the translation of the models onto the target. Efficiency requires being able to translate control algorithm into OLEA AMEC FLU or software code for the OLEA processors targets. This translation has to be automatic to be easily and quickly proceeded during the early stages of the development process.

Algorithms from models can be automatically transformed into tasks and assigned either to the different OLEA processors or to AMEC's FLU and directly integrated with the software services layers. Parameters and internal signals of the algorithm are accessible thanks to a rapid prototyping/calibration solution.
These approaches address the system complexity at the right level to offer both design optimization and scalability together with reduced design cycle.

In order to reach these goals, IFPEN adapted the Mathworks tools Simulink Coder and HDL coder, and use these tools to prototype the control implementation of hybrid electric its vehicle prototype.

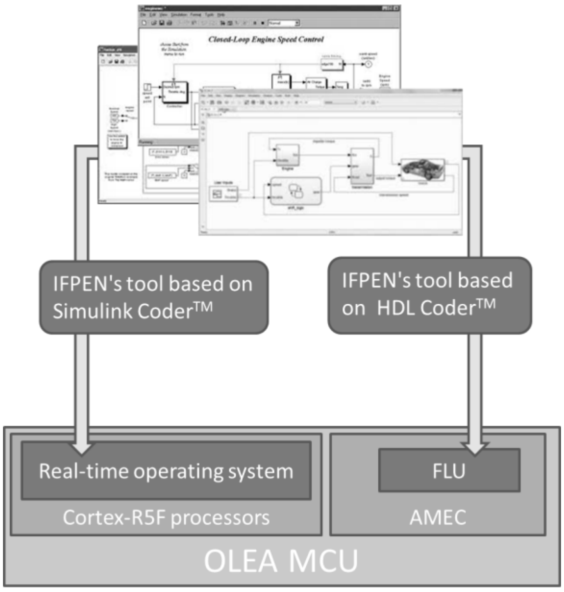


Figure 7: IFPEN code generation solution for OLEA MCU

However, this is not always obvious to determine which algorithms are well-suited for AMEC FLU. In one side the main interest of translating an algorithm into hardware flexible logic is to be able to process data at frequencies unreachable via software. In the other side, choosing hardware flexible logic instead of software implementation consists in trading rate against silicon surface: this inefficient to translate low rate complex algorithm into hardware flexible logic. This is consequently useful to be able to prototype the different algorithms implementation onto validation platforms.

4.2 Chain of validation tools

The systems complexities also force the adoption of simulation tools to enable early validation in a representative and accurate test environment with models. For example, a Hardware-in-the-Loop (HiL) platform was developed in order to test OLEA MCU and its associated ECUs. AMEC functionalities, such as Thermal Engine Positioning Estimation (TEPE), as well as the high level control algorithms are interfaced through a developed hardware board to a computer running, using the HiL tool xMOD-HiL[1] [4], the engine, vehicle and driver models. As a result, any homologation cycle can be simulated.
IFPEN xMOD-HiL platforms are able to simulate the complete vehicle, and taking into account the numerous systems interactions. This powerful tooling enables real hybrid powertrains designing, calibration and optimizations. The combination of this comprehensive powertrain development framework combined with the OLEA MCU innovative features provides a versatile solution for the realization of innovative vehicles.

Figure 8: IFPEN HiL platform xMOD-HiL GUI

In order to test the implementation of algorithms onto the AMEC FLU, IFPEN has developed for Scaleo chip an electrical synchronous motors control demonstrator. The obtained platform consists in two electrical synchronous motors connected to an OLEA MCU. Each one is controlled by a logical implementation of a

---

[1] xMOD, xMOD-HiL are distributed by D2T, member of the IFPEN group : http://www.d2t.com

Simulink Field Oriented Control Algorithm. These algorithms acquire analog-digital converters values and update PWM command settings to control the motors speed. By using, an implementation onto the AMEC FLU, the control is performed at high frequency without requiring software computational resources on OLEA processors.

In the IFPEN hybrid electric vehicle prototype, FlexHybrid, the electrical motor is planned to be control with a similar algorithm onto the AMEC hardware Flexible Logic of the corresponding OLEA MCU.

Then, the previously HiL platform has been upgraded with the vehicle version of the thermal engine control algorithm running on a OLEA MCU with robotized transmission control, and connected to another OLEA MCU where different hybrid powertrain energy supervisor have been prototyped, thanks to automatic code generation tools. This HiL platform also permits to test different task/function allocation among the processor of one OLEA MCU or among the different MCUs, thanks to real-time Ethernet connection. The OLEA MCU targets, used with these tools (code-generation, HiL platforms) succeed to develop the next generation algorithm of the IFPEN FlexHybrid vehicle.

5 Conclusion

This paper has introduced a novel solution for designing Electrical/Electronic architecture of powertrain system for hybrid electric vehicle. By combining the integration of OLEA within a three ECUs based architecture for engine and motor control, and the usage of dedicated development tooling, the solution presents a simplified powertrain architecture which reduces the complexity and cost of the system enabling energy efficiency improvements.

References

[1] *OLEA Family brief*, http://www.scaleochip.com, accessed on 2012-01-06

[2] *AMEC White Paper*, http://www.scaleochip.com, accessed on 2012-01-06

[3] *SILant brief*, http://www.scaleochip.com, accessed on 2012-01-06

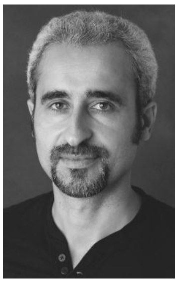
[4] *"Heterogeneous Model Integration and Virtual Experimentation using xMOD: Application to Hybrid Powertrain Design and Validation", M. Ben Gaïd & al. 7th EUROSIM Congress, Prague (Czech Republic), September 2010.*

[5] *"Multi-model integration from MiL to HiL : a new simulation approach to address the modern powertrain development challenges", A. Albrecht & al., Virtual Powertrain Conference, Sao Paulo (Brazil), 2012.*

[6] *"Advanced Hybrid Vehicle Simulation: from "Virtual" to "HyHiL" test bench", A. Del Mastro & al., Society of Automotive Engineering World Congress, number 2009-24-0068, 2009.*

[7] *"Supervisory Control of Hybrid Powertrains: an experimental benchmark of offline optimization and online energy management", A. Chasse, A. Sciaretta, Contol Engineering Practice, vol. 19, n°11, November 2011.*

Authors



Khaled Douzane has 13 years of experiences in the semiconductor industry. He is currently in charge of product marketing management for body, driver-information and powertrain microcontrollers at Scaleo chip. Khaled Douzane is graduated from Nice Sophia-Antipolis POLYTECH engineering school in electronics.

Fabien Vidal-Naquet is Research engineer in the automotive control field at IFPEN since April 2010, with a focus on engine control and hybrid power-trains energy management. Graduated from Ecole Centrale des Arts et Manufactures de Paris, specializing in energy and propulsion.

Nicolas Pernet is Real-time Software project manager at IFPEN since 2006. In 2002, he received the Dipl-Ing. degree in embedded systems from ESIEE-Paris, France, and the M.S. degree in distributed computing from the UPMC (Paris, France). In 2006, he defended his Computer Science Ph.D on real-time systems in the same University.

Cyril Straub is Research engineer employed by Safran Engineering Services. Currently working on automotive control strategies at IFPEN. Graduated from Telecom Physique Strasbourg, studied in various fields of engineering with a focus on control topics.