2021-01-0786 Published 06 Apr 2021

SAE INTERNATIONAL

A Domain-Centralized Automotive Powertrain E/E Architecture

Victor Bandur, Vera Pantelic, Matthew Dawson, and Alexander Schaap McMaster University

Bryon Wasacz FCA US LLC

Mark Lawford McMaster University

Citation: Bandur, V., Pantelic, V., Dawson, M., Schaap, A. et al., "A Domain-Centralized Automotive Powertrain E/E Architecture," SAE Technical Paper 2021-01-0786, 2021, doi:10.4271/2021-01-0786.

Abstract

This paper proposes a domain-centralized powertrain E/E (electrical and/or electronic) architecture for all-electric vehicles that features: a powerful master controller (domain controller) that implements most of the functionality of the domain; a set of smart actuators for electric motor(s), HV (High Voltage) battery pack, and thermal management; and a gateway that routes all hardware signals, including digital and analog I/O, and field bus signals between the domain controller and the rest of the vehicle that is outside of the domain. Major functional safety aspects of the architecture are presented and a safety architecture is proposed. The work represents an early E/E architecture proposal. In particular, detailed partitioning of software components over the domain's Electronic Control Units (ECUs) has not been determined yet; instead, potential partitioning schemes are discussed. A thorough evaluation of the architecture, based on a hardware prototype and in-vehicle analysis, is forthcoming.

Introduction

In order to successfully adapt to the trend of increasing complexity in modern cars, novel E/E (electric and/or electronic) architectures have been proposed. The general trend in the evolution of E/E architectures points toward centralization—consolidation of functionality over a smaller number of Electronic Control Units (ECUs). In one version of centralized architectures, for example, the functionality within each vehicle domain (powertrain, body, chassis and infotainment) is centralized on a single powerful master controller (domain controller) communicating with simple smart actuators. This architecture is called domain control architecture (alternatively, domain-oriented or domain-centralized architecture).

Centralized automotive E/E architectures have been investigated and implemented in the industry, with a number of automotive suppliers commercializing their solutions and OEMs leveraging them in their vehicles [1, 2, 3, 4, 5, 6]. However, not many detailed accounts of the centralized E/E architectures exist in the literature. The existing work mostly focuses on benefits, major high-level aspects and challenges of centralized architectural solutions such as hardware support for master ECUs, communication protocols, standards, *etc.* [7, 8, 9, 10]. Further, functional safety in centralized architectures has been discussed at a very high-level, focusing mainly on major safety concerns as per ISO 26262 [11], such as freedom from interference on multi-core controllers and safety mechanisms available in hardware [12, 10]. The literature proposing concrete safety patterns and safety architectures for centralized E/E architectures is scarce (for example, [13]). Also, to the best of the authors' knowledge, detailed domain specific discussions and indepth domain architectural proposals are completely missing from the currently available literature. Our paper aims to fill this void. In particular, we propose and discuss a detailed domain control E/E architecture for the powertrain domain of electric vehicles.

The proposed architecture, *Domain Controlled E/E Powertrain (DEEP)*, is a domain centralized powertrain architecture for all-electric vehicles. It consists of a Powertrain Domain Controller (PDC) and a set of smart actuators communicating over automotive Ethernet. However, the architecture is not specific to Ethernet—CAN (Controller Area Network) and CAN FD (CAN with Flexible Datarate) are potential alternatives for communication within the domain. The PDC hosts a large part of functionality of the domain, including powertrain supervisory functions. The ECUs corresponding to classical actuators of an all-electric powertrain domain, such as electric motors and battery pack, together with the actuators, are reduced to simple smart actuators. Further, a separate smart actuator is assigned the role of a gateway to the domain. Its function is to route all hardware signals, including digital and analog I/O, LIN, CAN *etc.* between the PDC and parts of the vehicle which, for practical reasons, cannot be converted into smart actuators (*e.g.*, accelerator pedal). While our proposal does not include the precise allocation of the domain functionalities and software

Acknowledgments

We would like to thank NXP Semiconductors N.V., specifically Andrew Ruf, Janna Garofolo, Lee Ann Seymour, Ingo Kissel, Randy Dees, and Curt Hillier for their support in building the prototype described in this paper, as well as for numerous fruitful discussions on the topic of centralization of vehicular E/E architectures.

References

1. Visteon Corporation, "Domain Controller—ECU Consolidation for the Cockpit," 2018, https://www.visteon.com/products/domain-controller/, accessed June 1, 2019.
2. Amend, J.M., "Delphi: Industry Must Go Digital or Die," WardsAuto, Sept. 2017, https://www.wardsauto.com/technology/delphi-industry-must-go-digital-or-die, accessed Oct. 29, 2019.
3. Robert Bosch GmbH, "Driver Assistance System Domain Controller (DASy)," 2019, https://www.bosch-mobility-solutions.com/en/products-and-services/passenger-cars-and-light-commercial-vehicles/automated-driving/driver-assistance-system-domain-controller/, accessed June 1, 2019.
4. Rosman, E., "Active Safety Teach In," 2018, http://q4live.s22.clientfiles.s3-website-us-east-1.amazonaws.com/336558720/files/doc_presentations/2018/Aptiv-Active-Safety-Teach-In-June-2018.pdf, accessed June 1, 2019.
5. Aptiv PLC, "Now Entering the Supercomputing Era," 2018, https://www.aptiv.com/media/article/2018/01/10/nowentering-the-supercomputing-era, accessed June 1, 2019.
6. Aptiv PLC, "The Autonomous Driving Platform: How Will Cars Actually Drive Themselves?" 2018, https://www.aptiv.com/media/article/2018/01/07/the-autonomous-driving-platform-how-will-cars-actually-drivethemselves, accessed June 1, 2019.
7. Reinhardt, D., and Kucera, M., "Domain Controlled Architecture - A New Approach for Large Scale Software Integrated Automotive Systems," *PECCS* 13:221-226, 2013, doi:10.5220/0004340702210226.
8. Navale, V.M., Williams, K., Lagospiris, A., Schaffert, M. et al., "(R)evolution of E/E Architectures," *SAE Int. J. Passeng. Cars - Electron. Electr. Syst.* 8(2):282-288, 2015, https://doi.org/10.4271/2015-01-0196.
9. Di Natale, M., and Sangiovanni-Vincentelli, A.L., "Moving from Federated to Integrated Architectures in Automotive: The Role of Standards, Methods and Tools," *Proceedings of the IEEE* 98(4):603-620, 2010, doi:10.1109/JPROC.2009.2039550.
10. Bandur, V., Selim, G., Pantelic, V., and Lawford, M., "Making the Case for Centralized Automotive E/E Architectures," *IEEE Transactions on Vehicular Technology*, 2020, to appear.
11. ISO, "Road Vehicles - Functional Safety," ISO Standard 26262, 2018.
12. Reinhardt, D., Kaule, D., and Kucera, M., "Achieving a Scalable E/E-Architecture Using AUTOSAR and Virtualization," *SAE Int. J. Passeng. Cars — Electron. Electr. Syst.* 6(2):489-497, 2013, https://doi.org/10.4271/2013-01-1399.
13. Sommer, S., Camek, A., Becker, K., Buckl, C. et al., "Race: A Centralized Platform Computer Based Architecture for Automotive Applications," in *2013 IEEE International Electric Vehicle Conference (IEVC)*, 1-6, Oct. 2013. doi:10.1109/IEVC.2013.6681152.
14. NXP Semiconductors N.V., "S32S24: Safety Microcontroller for Automotive Applications," 2019, [https://www.nxp.com/products/processors-and-microcontrollers/arm-based-processors-and-mcus/s32-automotive-platform/safety-microcontroller-for-automotive-applications:S32S24, accessed July 16, 2019.
15. Kanajan, S., Pinello, C., Zeng, H., and Sangiovanni-Vincentelli, A., "Exploring Trade-Off's between Centralized versus Decentralized Automotive Architectures Using a Virtual Integration Environment," in *Proceedings of the Design Automation Test in Europe Conference*, vol. 1, 1-6, 2006, doi:10.1109/DATE.2006.243895.
16. Kugele, S., Cebotari, V., Gleirscher, M., Hashemi, M. et al., "Research Challenges for a Future-Proof E/E Architecture - A Project Statement," in *INFORMATIK 2017*, Eibl, M. and Gaedke, M., Eds. (Bonn: Gesellschaft für Informatik, 2017), 1463-1474, doi:10.18420/in2017_146.
17. Continental, A.G., "Electronic Vehicle Management: Forward-Looking Vehicle Management Solutions," 2014, https://www.continental-automotive.com/getattachment/64cce29c-f517-4f70-81eac0b6a8e3249b/VCU_Brochure_EN_2014_final.pdf, accessed Apr. 9, 2020.
18. Wang, J.X., *Will Autonomous Cars Look Like Unmanned Aerial Vehicles (UAVs)?* (CRC Press, 2019), https://www.crcpress.com/authors/i351-johnwang/news/i5114-will-autonomous-cars-look-like-unmanned-aerial-vehicles-uavs, accessed June 6, 2019.
19. Brunner, S., Röder, J., Kucera, M., and Waas, T., "Automotive E/E-Architecture Enhancements by Usage of Ethernet TSN," in *13th Workshop on Intelligent Solutions in Embedded Systems (WISES)*, 9-13, IEEE, 2017, doi:10.1109/WISES.2017.7986925.
20. Bach, J., Otten, S., and Sax, E., "A Taxonomy and Systematic Approach for Automotive System Architectures - From Functional Chains to Functional Networks," in *Proceedings of the 3rd International Conference on Vehicle Technology and Intelligent Transport Systems - Volume 1: VEHITS*, 90-101, INSTICC (SciTePress, 2017). doi:10.5220/0006307600900101.
21. Stolz, W., Kornhaas, R., Krause, R., and Sommer, T., "Domain Control Units - The Solution for Future E/E Architectures?" SAE Technical Paper 2010-01-0686, 2010, https://doi.org/10.4271/2010-01-0686.
22. Guzzella, L. and Sciarretta, A., "Supervisory Control Algorithms," in *Vehicle Propulsion Systems: Introduction to Modeling and Optimization* (Berlin, Heidelberg: Springer Berlin Heidelberg, 2013), 243-276, https://doi.org/10.1007/978-3-642-35913-2_7.
23. Zhu, D. and Pritchard, E., "NCSU Year Three Final Technical Report," SAE Technical Paper 2014-01-2907, 2014, https://doi.org/10.4271/2014-01-2907.
24. Ulsoy, A.G., "Smart Product Design for Automotive Systems," *Frontiers of Mechanical Engineering* 14(1):102-112, 2019, doi:10.1007/s11465-019-0527-0.

25. Mallya, A., Pantelic, V., Adedjouma, M., Lawford, M. et al., "Using STPA in an ISO 26262 Compliant Process," in *Computer Safety, Reliability, and Security*, Skavhaug, A., Guiochet, J., and Bitsch, F., Eds. (Cham: Springer International Publishing, 2016), 117-129, doi:10.1007/978-3-319-45477-1_10.

26. Matheus, K. and Königseder, T., *Automotive Ethernet* First Edition (USA: Cambridge University Press, 2015), ISBN:1107057280.

27. OpenSynergy GmbH, "New Hypervisor for Real-Time Applications," June 2018, https://www.opensynergy.com/wp-content/uploads/2018/06/Hypervisor-for-latest-NXP-microcontroller.pdf, accessed Oct. 1, 2020.

28. Armbruster, M., Fiege, L., Freitag, G., Schmid, T. et al., "Ethernet-Based and Function-Independent Vehicle Controlplatform: Motivation, Idea and Technical Concept Fulfilling Quantitative Safety-Requirements from ISO 26262," in *Advanced Microsystems for Automotive Applications 2012*, Meyer, G., Ed. (Berlin, Heidelberg: (Springer Berlin Heidelberg, 2012), 91-107, doi:10.1007/978-3-642-29673-4_9.

29. Hanzlik, A. and Kristen, E., "A Generic Approach for Performance Evaluation of Vehicle Electronic Control Systems," in *Advanced Microsystems for Automotive Applications 2012*, Meyer, G., Ed. (Berlin, Heidelberg: Springer Berlin Heidelberg, 2012), 333-342, doi:10.1007/978-3-642-29673-4_31.

30. SAE International, "Time-Triggered Ethernet," SAE Standard AS6802, 2011.

31. IEEE, "Time-Sensitive Networking Task Group," 2017, http://www.ieee802.org/1/pages/tsn.html, accessed Oct. 29, 2019.

32. IEEE, "802.1AS-2020 - Timing and Synchronization for Time-Sensitive Applications," 2020, https://standards.ieee.org/standard/802_1AS-2020.html, accessed Sept. 8, 2020.

33. IEEE 802.1 Time-Sensitive Task Group, "IEEE 802.1Qav-2009 - IEEE Standard for Local and Metropolitan Area Networks - Bridges and Bridged Networks - Amendment 12: Forwarding and Queueing Enhancements for Time-Sensitive Streams," IEEE, IEEE 802.1Qav, 2009.

34. IEEE 802.1 Time-Sensitive Task Group, "IEEE 802.1Qbv- 2015 - IEEE Standard for Local and Metropolitan Area Networks - Bridges and Bridged Networks - Amendment 25: Enhancements for Scheduled Traffic," IEEE, IEEE 802.1Qbv, 2015.

35. IEEE, "802.1Qbu - Frame Preemption," 2015, http://www.ieee802.org/1/pages/802.1bu.html, accessed Oct. 29, 2019.

36. IEEE, "802.1Qat - Stream Reservation Protocol," 2010, http://www.ieee802.org/1/pages/802.1at.html, accessed Oct. 2, 2020.

37. IEEE, "802.1Qci - Per-Stream Filtering and Policing," 2017, https://1.ieee802.org/tsn/802-1qci/, accessed Oct. 29, 2019].

38. IEEE, "802.1CB - Frame Replication and Elimination for Reliability," 2017, https://1.ieee802.org/tsn/802-1cb/, accessed Oct. 29, 2019.

39. IEEE, "802.1Qca - Path Control and Reservation," 2016, http://www.ieee802.org/1/pages/802.1ca.html, accessed Oct. 29, 2019.

40. Arthur Marris, R.S. and Dhingra, S., "Improve Reliability and Redundancy of Automotive Ethernet through Open Standards," 2016, https://ip.cadence.com/uploads/1114/cdnwpd-automotive-reliability-and-redundancy-pdf, accessed Sept. 30, 2020.

41. Lian, F.-L., Moyne, J., and Tilbury, D., "Network Design Consideration for Distributed Control Systems," *IEEE Transactions on Control Systems Technology* 10(2):297-307, 2002, doi:10.1109/87.987076.

Contact Information

Victor Bandur, Ph.D.
(289) 674-0250 ext. 59096
bandurvp@mcmaster.ca

Definitions, Abbreviations, and Acronyms

ADC - analog-to-digital converter
ASIL - Automotive Safety Integrity Level
BMS - Battery Management System
CAN - Controller Area Network
CAN FD - Controller Area Network Flexible Data-Rate
CRC - Cyclic Redundancy Check
DAC - digital-to-analog converter
DCU - domain control unit
DEEP - Domain Controlled E/E Powertrain
E/E - electrical and/or electronic
ECU - Electronic Control Unit
FCA - Fiat Chrysler Automobiles N.V.
HV - high voltage
I/O - Input/Output
I^2C - Inter-Integrated Circuit
LIN - Local Interconnect Network
OEM - Original Equipment Manufacturer
OS - operating system
PDC - Powertrain Domain Controller
PWM - pulse-width modulation
QoS - Quality of Service
RAM - random access memory
SDK - Software Development Kit
SPI - Serial Peripheral Interconnect
SRP - Stream Reservation Protocol
TDMA - Time Division Multiple Access
TSN - Time Sensitive Networking
VM - virtual machine

ISSN 0148-7191