EMC, Weight Reduction, and Multi-Gigabit Call for Optical Harness

Electric and autonomous driving architectures are substantially pushing the challenges for wiring systems. Issues include electromagnetic interference, electromagnetic susceptibility, and weight reduction. On top of this, automotive applications, utilization, and safety requirements are boosting the necessary network speed tremendously. The new 48-volt electrical architecture in cars additionally pushes the envelope in terms of cross-domain isolation requirements. Copper links for communication rates above 100 Mb/s need heavy and expensive solutions to comply with the stringent OEM's EMC specs, resulting in high cost and very difficult engineering. Moreover, the weight of the ever-growing diameter of the required cables plays against the race for increased range in electrical powertrains.

Optical network technology overcomes these trends thanks to its inherent galvanic isolation, robustness, low cost, and low weight. Carmakers benefit from optical links for communications between the 48-volt and the 12-volt domains. For weight, an optical network will save more than 30 percent of the weight of the equivalent copper-based harness. Optical Ethernet provides 100 Mb/s and 1 Gb/s network solutions today, and multi-gigabit Ethernet is the significant upcoming breakthrough for in-vehicle networks. The standardization effort for optical multi-gigabit is already in progress within the IEEE as an amendment to the Ethernet standard 802.3.

Low Weight and Robustness

POF cables are the most reliable solution: plastic optical fiber can withstand harsh environments, vibrations, misalignments, dirtiness, humidity, wide temperature range, etc. In addition, POF allows fast dynamic bending, tight static bending, and immersion in liquid. Additionally, optical Ethernet generates very low noise and can operate in noisy environments, such as in RF electronic boards. With optical and copper in parallel, the optical network provides ASIL-D safety architecture ASIL-D = ASIL-B + ASIL-B.

Concerning weight, fiber optics also has a significant advantage. Plastic optical fiber reduces the weight by over 30 percent, compared to shielded twisted pair of copper wires (STP): POF weighs 10 g/m with 2 x 2.3 mm diameter. In comparison, JTP copper is at 13 g/m and STP copper sums up to 25 g/m with a diameter of 5 mm.

Electromagnetic Compatibility

Optical data networks, with their intrinsic Electromagnetic Compatibility (EMC), are the best technology choice for new powertrains that are either fully electrical or hybrid. POF communications have excellent performance in Electromagnetic Interference (EMI) and in Electromagnetic Susceptibility (EMS). POF is inherently immune to and robust against electromagnetic fields due to its native galvanic isolation. In numerous use cases, optical networking can be used to solve issues caused either by EMI/EMS or lack of galvanic isolation on copper-based networks in the powertrain of Hybrid Vehicles (HEV) and Electrical Vehicles (EV).

For their paper “Experimental investigation of communication quality degradation of 1000BASE-T1 by pulse disturbance,” Yusuke Yano, Tohlu Matsushima and Osami Wada of the Graduate School of Engineering, Kyoto University, have experimentally investigated the relationship between the communication quality of 1000BASE-T1 and the pulse width of the disturbance**.** The FER (frame error rate) increased by more than two orders of magnitude with a specific pulse width due to the common-mode reflection and the mode conversion. They concluded that the pulse disturbance with the steep change significantly degrades the communication quality.

The study “Susceptibility of 100Base-T1 Communication Lines to Coupled Fast Switching High-Voltage Pulses” (by S. Jeschke, J. Loos, M. Kleinen, O. Kurt, J. Baerenfaenger of EMC Test NRW GmbH, Dortmund, Germany; C. Hangmann, I. Wuellner of SIL System Integration Laboratory GmbH, Paderborn, Germany) examined the coupling effects between the high-voltage (HV) system and a 100Base-T1 two-wire Ethernet communication and the impact of pulse disturbances on the communications performance. With battery voltages of up to 850 V, together with faster switching times of the inverter, the disturbance potential of an HV system is most possibly high enough to have a performance degrading impact on the communication quality. The reduction of data rate due to capacitive coupling clamp (CCC) pulses with variable amplitude and bandlimited power (limited to 66.6 MHz) starts with 200V-amlitude pulses. Pulses larger than 400V reduce the data rate to 20 percent.

Noise Propagation in HEV/EV Powertrains

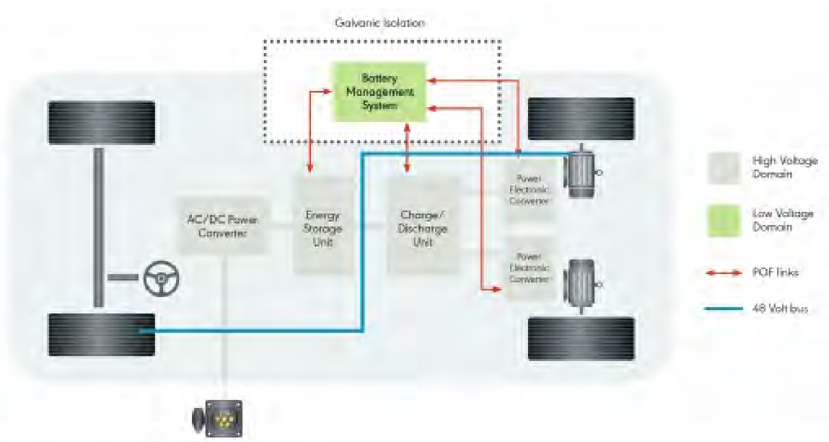
The powertrains of hybrid and electrical vehicles require multiple electronic control units (ECU) placed all around the car. These ECUs regulate and control the electrical flow of the energy between the batteries, converters, and motors/generators. The energy flow and conversion generates electrical noise, which will affect other areas of the car like the infotainment or navigation systems today and the autonomous control systems tomorrow. By optically connecting the ECUs, it is possible to confine each noise to the ECU that originates it, avoiding its propagation to all the other ECUs dispersed throughout the car. Trying to achieve a similar isolation with a copper-based network is very difficult and expensive, which translates into a longer engineering development cycle and a more expensive and complex ECU, which may in turn translate into lower reliability.

In their paper "Impact of HV Battery Cables' Emissions on the Signal Integrity of 2-Wire Ethernet Communication in Automotive Application," S. Jeschke, A.H. Razavi, J. Loos, and J. Baerenfaenger of EMC Test NRW GmbH, Dortmund, Germany, took a look at the coupling between the HV traction system and the 100Base-T1 communication. The inverter is operated at a voltage near its limit of 400 V. The voltage measured at the unpowered PHY terminals in time domain for the differential mode has peaks reaching 2 V. This demonstrates that UTP cable is prone to electromagnetic disturbances due to the EMC coupling between these high voltage (HV) traction systems and the communication channels.

Another study examined the "Impact of Highly Efficient Power Electronics on the EMC in Electric Vehicles With Autonomous Driving Functions" (by Dr.-Ing. Sebastian Jeschke, B.Sc. Jan Loos, M.Eng. Michael Kleinen, Dipl.-Ing. Marc Maarleveld, Dipl.-Ing. J. Baerenfaenger of EMC Test NRW GmbH, Dortmund, Germany). To increase the energy efficiency of electric vehicles, silicon carbide (SiC) and gallium nitride (GaN) semiconductors are used**.** These semiconductors are able to switch the battery voltage much faster (4 ns) compared to currently deployed Si semiconductors (120 ns)**.** Another method to enhance the efficiency is to increase the battery voltage, which reduces the current losses in the traction system. The paper demonstrates a significant increase in the electromagnetic emissions of the vehicle's high-voltage (HV) components due to these two methods**.**

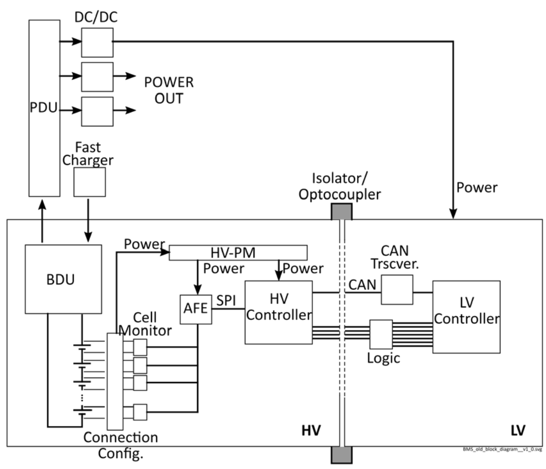
Isolation in Battery Management Systems

Propulsion batteries in EV or HEVs are grouped into clusters that are controlled by the Battery Management System (BMS). Although the amount of data moving back and forth between the clusters and the control module is not very high (typically below 100 Mb/s), the communication between the BMS control module and the individual clusters is crucial and needs to be very reliable. These BMS links are critical to avoid battery damage, and must be suitable in emergency situations like crashes or fires. Optical links between the BMS control module and the battery clusters are the best means to ensure the high reliability needed. Copper-based communications create parasitic loops, which, in the case of emergency events, may translate into dangerous conditions for the driver and occupants.

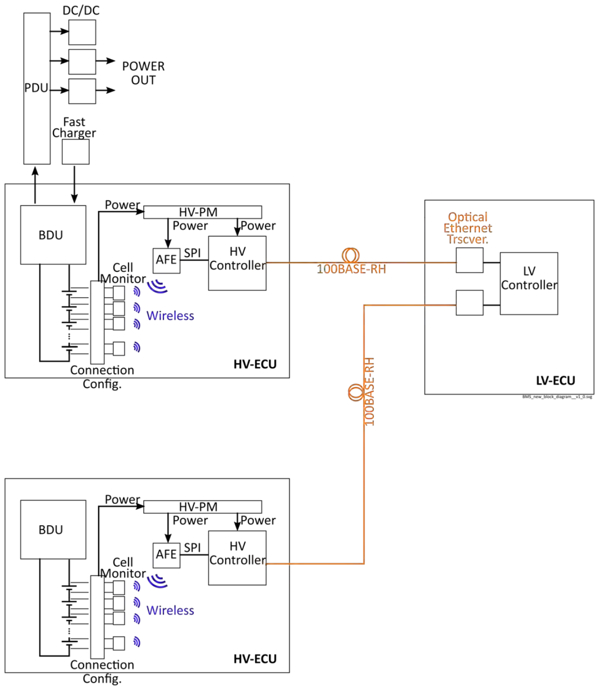


Fiber optics provide inherent galvanic isolation

For sensing the battery cells and monitoring, wireless communication is ideal in coexistence with optical Ethernet links to connect the HV and the LV ECUs.



Traditional BMS architecture



This new BMS architecture combines the advantages of both technologies.

For wireless monitoring, the benefits include link reliability as the links are short and are inside the HV enclosure. Periodic monitoring information is not critical as it is sampled continuously. In addition, wiring complexity is reduced. It also allows the installation of sensors in locations previously unsuitable for a wiring harness. Further, size, weight and cost are minimized.

The advantages of optical Ethernet instead of isolated CAN Bus comprise the superior EMC immunity in a very noisy environments as power electronics with high voltage with very low switching times. Safety is guaranteed by the inherent galvanic isolation. Engineering stays easy since battery packs may be distributed over larger areas of the vehicle. Ethernet is a standard solution. Integrating all ECUs in the same network along with other ECUs of the BMS system improves the system integration in the overall car architecture. Thus, cost effort is reduced.

48 Volts Jump-start Parasitic High Energy Pulse

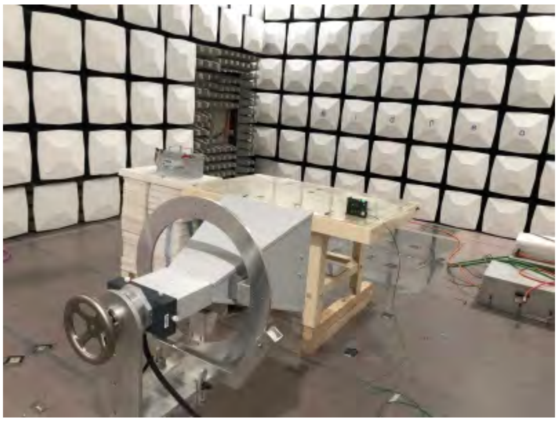
48-volt-based energy networks or mixed 12-48 volts topologies are and will keep being the mainstream of HEV and Plug-in Hybrid Electrical Vehicle (PHEV) powertrains. The electrical ground, which is connected to the vehicle chassis and is common to high and low voltage ECUs, creates problems on start-up events that continuously take place in such powertrains. For example, the infotainment system shares the electrical ground with the energy generation and control systems. The high return currents flowing through the chassis on start-up couple into the infotainment low-voltage system through the cable shielding, which is connected to the same electrical ground as other systems in the vehicle. Copper-cable shielding provides a parallel return path (alternative to the chassis) for the currents of the diverse ECUs. Due to this, currents higher than 8 amperes can be measured in the cable shielding during a typical jump start, as reported by a major European carmaker. If the communications link between the ECUs in the low-voltage systems like infotainment or ADAS is optical, then the native galvanic isolation will isolate them from the high voltage/high energy systems and their associated events, thus preserving their reliability.

Fault Protection in 48-/12-volt Systems

In mixed 48-/12-volt energy systems, 48 volts are reserved for "hungry" electrical modules like starters, alternators or battery modules, while 12 volts are dedicated for the more "delicate" electronic modules like Infotainment or ADAS processing units. Both domains share the same ground system, the car chassis. The ECU in the 48-volt domain is designed with electronic components sized for such voltages. These components are typically rated to withstand more than 70 volts. The 12-volt ECUs are designed with electronic components that support up to typically 60 volts. In case of an event like a loss of ground in a 48-volt ECU, and if there are non-galvanic isolated links between the 48-volt and the 12-volt domains, there will be an electrical path between both domains. This will expose the 12-volt ECUs and its components to voltages higher than the ones they were rated to support, causing failures or a reduction of its service life.

EMC Compliance

EMC qualification is one of the critical steps of a platform validation by Tier1 and OEMs. Copper links for communication rates above 100 Mb/s need sophisticated and expensive solutions to comply with the stringent OEM's EMC specs: high-quality shielding, controlled pair twisting, complex in-line connectors, etc. Optical ports can pass both EMI and EMS much more easily. This directly impacts the cost of the harness and the connectors, not to mention the engineering resources assigned to the development and debugging stages.



Optical ports can pass both EMI and EMS much more easily than copper.

Standardization and Compliance

IEEE 802.3™ Standard

As an amendment to the IEEE 802.3™ standard, IEEE Std 802.3bv™ for gigabit Ethernet over POF defines physical layer specifications and management parameters for automotive, industrial, and home networking applications utilizing POF. KDPOF technology entirely fulfills the preconditions of the new IEEE amendment, providing reliable and proven solutions for automotive applications. The KD1053 transceiver perfectly meets the requirements of carmakers by providing high connectivity with a flexible digital host interface, low latency, low jitter, and low linking time. The transceiver is optimized for low power and small footprint and transmits data at 1000/100 Mb/s on standard SI-POF, MC-POF, or PCS, according to 1000BASE-RH (IEEE 802.3bv).

ISO 21111

With the supplementary parts ISO 21111-3:2020 and ISO 21111-5:2020, the International Organization for Standardization (ISO) specifies further features for the reliable in-vehicle data transmission of 1 Gigabit per second over POF technology. ISO 21111-3:2020 specifies additional features to IEEE 802.3bv, such as wake-up and synchronized link sleep algorithms. It also contains a complete conformance test plan for IC providers that implement this standard. ISO 21111-5:2020 specifies requirements at the system level and a complete conformance and interoperability test plan for ECU providers that implement optical 1 Gb/s physical layer as specified in ISO 21111-3.

With the new ISO 21111 sections complementing the existing IEEE Std 802.3bv™, optical Gigabit connectivity is now entirely standardized. Based on these standards, KDPOF's optical technology allows a complete, compatible, and interoperating implementation for carmakers and Tier1s.

Reference Design

For compliant implementation of 1000BASE-H and 100BASE-H, KDPOF provides a reference design board. It serves as a guide for Tier1 of how to integrate the PHY in an ECU. In addition to solving components selection (clocks, PMIC, Cs, Rs, Ls, filters), the board establishes power distribution networks (decoupling, filtering, stability) and signal integrity. The board implements the wake-up

& sleep functionality according to ISO. Further features include PCB stack-up and layout, technology evaluation vehicle, and full temperature range.

Cost Reduction

As a plastic fiber with a large diameter, POF is more cost-effective to manufacture and install: installation is just easy plug and play; winding and clamping is similar to copper cables. Moreover, during the car assembly, the optical harness can be installed in the same process as the copper harness. POF has been present in vehicles for more than 10 years and is installed in millions of cars.

For further cost reduction, KDPOF is working on new integrated devices. The integrated Fiber Optic Transceiver (FOT) KD9351 is the first device for optical in-vehicle connectivity that incorporates the transceiver IC, optoelectronics, and optics. The integrated FOT is an optical port from 100 Mb/s to 1 Gb/s in one single component with reduced cost and footprint for automotive Ethernet connectivity. The decreased number of parts also reduces the effort in testing and qualification. Thus the overall expense is substantially reduced compared to STP. Further advantages are no margin stacking between links in the supply chain and supply chain simplification. Consequently, it offers competitive pricing for EMC critical or galvanic isolated critical links. The KD9351 offers a complete new FOT design. It reuses low-cost MEMs encapsulation and allows SMD reflow assembly with 8 by 7 mm LGA components. The FOT is fully shielded against electromagnetic radiation. Fiber connection is done with a very simple plastic connector placed on top. The temperature range, from -40 °C to +105 °C, conforms with harsh automotive environmental requirements. With a vibration class of V2, it withstands motor conditions. Additionally, the device endures water without sealing. EMC performance is excellent even with the ECU shield case removed, as shielding is integrated into the PCB component. The assembly of the FOT and the IC in the PCB is simplified. Optics implement Tx and Rx lenses.

Optical Multi-Gigabit

With technological leaps such as electrical vehicles, automated driving, and V2X interconnection rushing through, automotive applications, utilization, and safety requirements are boosting the necessary network speed tremendously. Consequently, in-vehicle networks are on the brink of speeds from one to multiple gigabits per second. Optical Multi-Gigabit Ethernet in the car is on the verge of standardization and implementation. With the approval of the IEEE 802.3 working group, a team of individuals affiliated with more than 15 key carmakers and components suppliers, including KDPOF, has started the standardization of an IEEE 802.3 Automotive Optical Multi-Gigabit Standard with strong support from the industry.

Demonstrating 50 Gb/s automotive Ethernet with datacom component leveraging

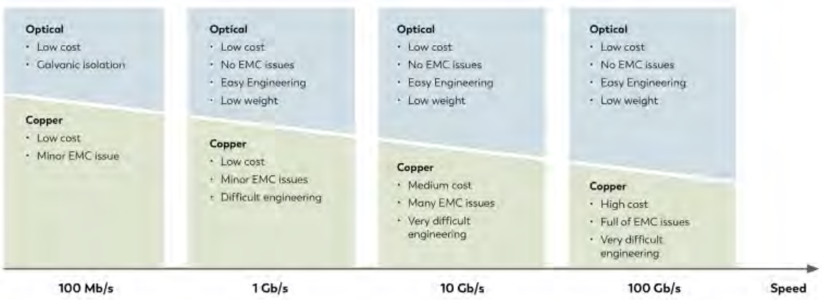
The working group, headed by Carlos Pardo, CEO of KDPOF, kicked off in the summer of 2019. The first prototypes are projected by the end of 2021. The study group is evaluating the creation of an IEEE Ethernet standard for the automotive industry, with speeds starting at 2.5 Gb/s and going up to 25 or 50 Gb/s. It will leverage the existing 10GBASE-SR, which is the current standard by IEEE for industrial use, to get a new technology that is suitable for the stringent automotive requirements.

The key development objectives for the new standard target outranging performance. The high speed will reach up to 50 Gb/s per line and will be scalable to 100 Gb/s with multiple lines. The temperatures range from -40 °C to 125 °C. Distances are 15 meters with 4 inline connectors for cars and 40 meters with 4 inline connectors for buses and trucks for 25 Gb/s. Meeting OEM reliability requirements, the failure rate is below 10 FIT (Failures In Time: 1 FIT equals 1 failure per 1,000 devices operating 1 million hours).

Complexity stays low with simple modulation. For fiber, the OM3 class is chosen since it is already extensively used by data centers and avionics. Only extensively used light sources will be selected. Two connector grades are defined in order to allow cost-effective implementations. Regarding topology, asymmetric up and down links have been considered from the beginning. The use of the Energy-Efficient-Ethernet (EEE) specification is an appropriate candidate to implement this feature. Cameras, displays, and further asymmetrical use cases have been included as test cases for standardization. An OAM side-channel will be available for dependability and link management. The absence of retransmissions means controlled latency for video distribution. Symmetric links will be added for backbone communications.

With cost-down and consistency in focus, optics, fibers, connectors, and electronics already developed for nGBASE-SR will be reused. Further specifications include 850 nm VCSEL, multimode OM3 fiber, PAM2 receivers, and connectors. Standardization work focuses on the automotive requirements: VCSEL reliability for the operation temperature range, connector development with quality grades, and an adaptive DSP to cope with the large parametric deviation of the VCSEL. Increasing the yield percentage results in cost reduction.

Outlook



Co-existence of optical and copper in automotive networking

The key advantages of the optical solution for specific applications using multi-gigabit speeds with in-vehicle connectivity are, among others, Electromagnetic Compatibility (EMC) thanks to the inherent galvanic isolation, low weight, and low cost. Relevant use cases from different carmakers in Europe and the USA incorporate the comprehensive features and benefits of optical network technology. Key leading optoelectronic, connector, and wire harness vendors worldwide are prepared and already provide a well-supplied and competitive market with all the new components needed for multi-gigabit in the car: Physical Layer (PHY), Fiber Optic Transceiver (FOT), fibers, connectors, and light sources. The technology will be scalable in order to enable even higher data rates in the future. By combining optimization in all areas of the new standard, the right balance of complexity and cost among all parts (CMOS IC, VCSEL, PD, ferrules, sleeves, cable, in-line connection technology, optics, and lenses, etc.) can be achieved in order to deliver the lowest cost, most reliable, and highly scalable solution to the automotive market.

Authors

César Esteban,
Applications & Support Manager of KDPOF

Juergen Schachtschneider,
Automotive Manager Central Europe & Greater China of KDPOF

Fabless semiconductor supplier KDPOF provides innovative high-speed optical networking for harsh environments. Making gigabit communications over fiber optics a reality, KDPOF technology supplies 1 Gb/s POF links for automotive, industrial, and home networks. Founded in 2010 in Madrid, Spain, KDPOF offers their cost-effective technology as either ASSP or IP (Intellectual Property) to be integrated in SoCs (System-on-Chips). The adaptive and efficient system works with a wide range of optoelectronics and low-cost large core optical fibers, thus delivering carmakers low risk, low cost and short time-to-market.

KDPOF Knowledge Development for POF, S.L.
Ronda de Poniente 14, 2ª Planta
ES-28760 Tres Cantos
E pr@kdpof.com
T +34 918043387
W kdpof.com