POF Backbone and Camera Link for Ethernet Automotive Networks

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1 Introduction

The exponential growth of infotainment (information + entertainment) devices within the car, along with the proliferation of ADAS (Advanced Driver Assistance Systems) has created a demand for a more efficient way to interconnect devices within the automobile. With advantages over other technologies, Ethernet is an ideal technology for automotive networks.

Plastic Optical Fiber (POF), a well-known transmission media within the automotive space, now offers Gigabit capabilities that make it the perfect solution for the backbone of future Ethernet automotive networks, as well as for point-to-point links like those required in camera applications.

2 Ethernet Automotive Networks

The automobile is rapidly becoming an extension of the home. Infotainment systems are increasingly becoming default equipment in new cars with connectivity to nearby devices and other cars, the web and the automotive infrastructure becoming the future de-facto standard for car equipment.

Likewise, with driver assistance being the path to "Vision Zero" for automotive safety where traffic accident deaths are eliminated because the car and infrastructure are designed to achieve this goal regardless of the driver's mistakes or intentions, ADAS will join other passive and active systems as part of the standard car equipment.

These feature-rich infotainment and driver assistance systems will substantially increase the demand for communication bandwidth, while also increasing the complexity of car networks. Because more complex car networks affect reliability and maintainability, the increase in infotainment and driver assistance systems have led to the need for a new networking solution, beyond today´s approach of point-to-point links or ring topologies, that provide no communication between automotive domains.

2.1 Ethernet Offers Scalability and Flexibility

The CAN (Controller Area Network) bus, a communication protocol that has dominated E/E Architecture for the last three decades, cannot fulfill all the needs of future automotive architectures. Ethernet, on the other hand, provides both scalability and flexibility for next-generation in-vehicle networking architectures.

Scalability, a key feature for most automotive OEMs, enables the use of a platform approach for multiple car lines. This scalability is supported through the use of network technolo-

Ethernet provides both scalability and flexibility for next-generation in-vehicle networking architectures.

gy that allows the customization of each vehicle.

Flexibility also is a key feature as it allows the car OEM to offer several car customizations to the user without any change to the network. The network configuration will adapt itself to the specific set of accessories with which the car is equipped. Car manufacturers will not need to configure the network for each model version.

2.2 Ethernet for Lower and Upper Communications Layers

Ethernet may be used as the lower communication layers in the standardized IP Diagnostics interface, as specified in ISO 13400 (Diagnostic communication over Internet Protocol (DoIP)), which will be adopted by most worldwide automotive OEMs. This interface, which is based on the same IP protocol used for the Internet, simplifies the diagnostics of systems around the automobile. As a lower layer technology, Ethernet interfaces smoothly with IP, which is one reason for its current proliferation on Internet-connected networks.

Ethernet also enables a seamless connection with other upper layer protocols that, for example, facilitate the synchronization of audio and video or the secure transmission of timely information. Very important for infotainment networks, audio and video synchronization (AVB protocols stacks, IEEE 802.1 Qav, 802.1 AS, 1722) is needed to ensure that the video and audio are in sync for the different screens and speakers around the car.

Likewise, timely information provided by Precision Timing protocol stacks (IEEE 1588v2 and 1722) is very important, especially for ADAS, to ensure that the information reaches its destination without delay as required by the safety application.

2.3 Ethernet Backbones for Hierarchical Architectures

All the major automakers agree on the advantages of segregating the different functional domains within the car. Within this new paradigm, the car will comprise a number of different domains working together and sharing information. Examples of domains are power train, body, transmission, and safety systems.

Within each domain, the type of connectivity used will be based on the functions that need to be performed and the domain requirements. Typical intra-domain networks will be based on FlexRay, MOST, Ethernet (first generation to be based on BroadR-Reach), CAN or LIN.

To meet the new requirements of a hierarchical architecture, a broadband network will be needed to communicate with all the domains in a reliable way. Ethernet seems to be the best choice as of today; however, the most appropriate PHY layer for Gigabit-speed is still under discussion. One optical PHY based on POF will deliver the needed bandwidth of one Gbps, which fulfills all the requirements of current and next-generation systems while at the same time delivering the advantages of lower cost and weight.

The centralized architecture in use today is shown in Figure 1. In this architecture, a single Central Gateway (CGW) provides CAN connections (solid green), LIN connections (grey), FlexRay connections (dashed green) and MOST connections (dotted green).

In the distributed backbone architecture, vehicle subsystems are grouped into domains that can have a single network technology, like CAN or Ethernet, or a mixture of technologies.

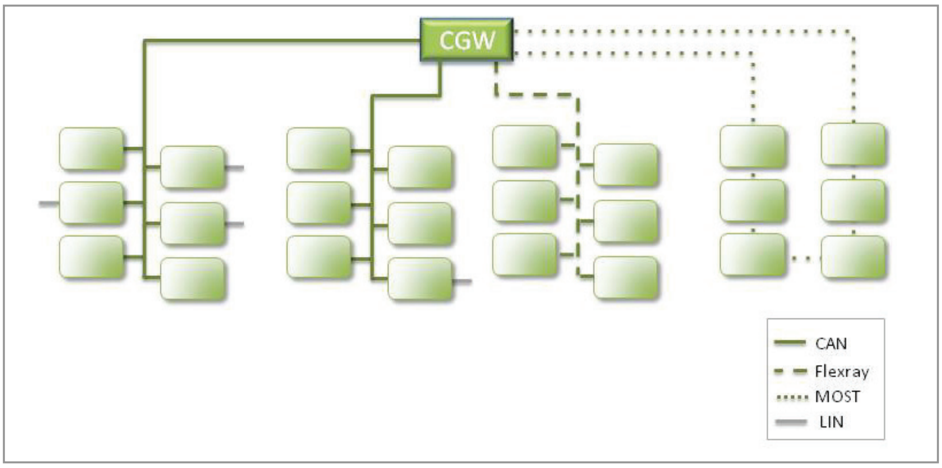

Figure 1. Centralized architecture.

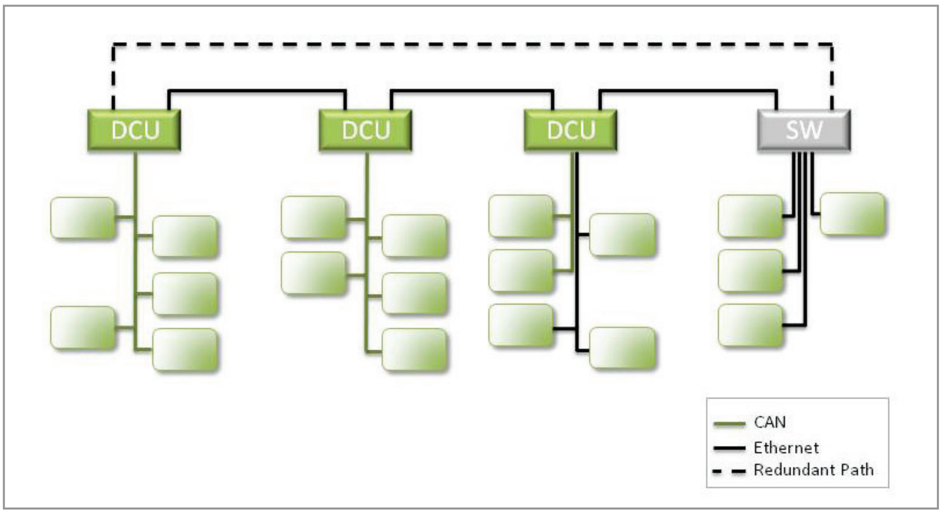

Figure 2. Daisy-chain backbone with optional redundant path.

With this new domain-based architecture, the need arises for a backbone that connects all the Domain Control Units (DCU) and switches of each domain with each other. While there are several backbone architectures, the most compelling is the daisy-chain backbone with an optional redundant path (shown in Figure 2).

As the single backbone connects all the domains, its size should accommodate the data required to be moved between each domain. Future projections show that a one Gbps backbone will be needed to meet the data requirements of all the ADAS and Infotainment systems, along with current existing domains within the car.

3 Unique Challenges of the Automotive Environment

The physical layer of the network technology used for the automotive network must meet the unique challenges of the automotive environment, without significantly driving up costs. The final cost of the system not only depends on the performance itself, but on the performance within the automotive environmental conditions, which, in most cases will increase the final cost.

POF is the ideal backbone for automotive networks.

Challenges for automotive networks include:

- **Vibration**
  The network technology must be able to withstand the vibrations that are inherent in the automobile due to continuous movement. Vibrations affect all mechanical parts and are especially damaging to electrical connections, while imposing severe restrictions to cables and connectors.
- **Temperature**
  Different temperature ranges are specified for each car domain, depending on the location of the network. The maximum temperature for most automotive domains is 105°C.
- **Weight**
  The weight of the medium used for the network is very important as it directly impacts fuel consumption/costs not to mention the associated carbon dioxide emissions.
- **Cost Predictability**
  Physical layers based on copper are subject to unpredictable pricing as copper prices have significantly increased over the last ten years. The inability to predict costs is a negative factor affecting copper-based solutions.
- **Electromagnetic Compatibility (EMC)**
  Electromagnetic emissions and susceptibility is a significant challenge for an automotive network. Electrical-based communications, like copper, used for physical layers are especially susceptible to EMI (Electromagnetic Interference).
- **Length**
  The typical length of an automotive network is about five meters, with some networks extending up to 15 meters. Any communications technologies used in an automotive network must be able to cover these lengths with enough signal-to-noise ratio margin.

3.1 POF Backbones for Automotive Networks

POF is the ideal backbone for automotive networks. As an optical medium, POF does not have the typical limitations of electrical-based physical layers, such as EMI, weight and cost predictability. In comparison to other optical solutions based on silica fibers, POF—which is well known in the automotive market due to the MOST and FlexRay protocols—is much easier to handle and less expensive to install and maintain. Finally, due to KDPOF technology, which is specified by VDE and ETSI, POF can overcome the current optoelectronics limitation to reach the one Gbps performance required by the stringent automotive standards.

In meeting the unique challenges of the automotive environment, POF offers several advantages over copper-based solutions and even silica fibers:

- **Vibration**
  As POF is an optical technology that does not use electrical contacts, it avoids electrical noise induced by vibrations. The large core diameter (1mm) of POF also makes it robust enough to protect against vibration-induced noise.
- **Temperature**
  POF is a polymer material that is more sensitive to temperature than copper or silica fibers. However, POF solutions for the most common high temperature ranges in the automotive environment (105°C) enable the use of POF in all the target car domains. Moreover, while the optical transceiver currently has an upper temperature limit of 95°C, the newest AVAGO transceiver for

Gigabit POF links is aiming for temperatures of up to 105°C.

- **Weight**
  POF is much lighter than copper, weighing one sixth of a UTP class 5 copper cable. The reduced weight of POF, scaled to the overall communication wiring mesh required within the car, adds up to a substantial weight advantage over copper.

- **Cost Predictability**
  Polymer is a material not dependent on the extreme swings of commodity market prices. On the contrary, copper is subject to extreme pricing fluctuations, more than quadrupling in the past decade. As shown in Figure 3, in 2002 copper traded for less than USD$1.00 per pound, and in 2012 sold for just under USD$4.00 per pound.

Figure 3. *Copper Price Trend: 1989 to 2012*
(Source: InfoMine)

- **EMC**
  System designers prefer optical solutions like POF which are immune to electrical noise, which translates into an increased noise margin and simpler system solutions. System testing is simplified with the benefits of lower development costs and shorter time to market.

- **Length**
  Gigabit POF technology is able to extend the typical automotive 15 meter target up to 40 meters and a combination of in-line connectors, thus opening new applications for buses and trucks at the same time keeping the stringent noise margins of the shorter car targets.

3.2 POF for Lower-Speed Links

Although POF technology supports a bandwidth of up to 1 Gbps, it can be used with existing 100 Mbps systems. That means that POF not only will meet the needs of future automotive network applications that require gigabit backbones in cars, but the technology also is ideal for current lower-speed communication buses within cars.

Two key examples of POF in lower-speed applications include hybrid or electric power trains, and buses/trucks. With a heavily demanding environment in terms of EMC, hybrid or electric power trains are ideal environments for electrically-immune solution like POF. With weight a key factor affecting due to the use of a large battery in these environments, the low weight of POF provides a distinct advantage over other technologies.

With larger sized buses and trucks, lower-speed POF-based solutions can extend the network reach over 40 meters up to more than 100 meters, thus opening new applications for buses and trucks.

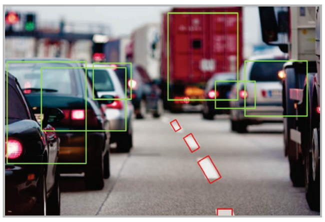

Figure 4. Object detection in ADAS.

4 Ethernet for Camera Applications

The current trend in the automotive market is toward more cameras inside the car with safety-related imaging applications becoming a standard in today's vehicles. According to the consulting firm TSR, the percentage of integrated vehicle cameras using CMOS sensors has increased from around 20 percent in 2008 to more than 70 percent in 2013.

The development of vehicular electronic vision systems for the automotive market is a growing field, driven in particular by customer demand to increase the safety of vehicles both for drivers and for other road users, including vulnerable road users, such as pedestrians. Automotive camera systems are designed to display areas around the vehicle to the driver, typically covering the vehicle blind spots.

Key automotive markets like Europe, Japan and North America are in the process of introducing legislation to aid in the prevention of fatalities of vulnerable road users, with emphasis on the use of vision systems. This trend is driving the quick adoption of ADAS (as shown in Figure 4) using cameras by carmakers around the world. Once only available in high-end cars, these new safety systems are quickly being introduced to lower priced once production costs allow significant price reductions.

It is expected that by 2017 cars will not be able to achieve the desired five-star NCAP (New Car Assessment Program) rating without ADAS. Therefore, leading car manufacturers are going to include at least one ADAS system as standard equipment by that time. With the substantial growth of ADAS systems (as shown in Figure 5), there is a need for an efficient technology to interconnect all the cameras, ECUs (Electronic Control Units) and HMIs (Human Machine Interfaces) in an automotive network.

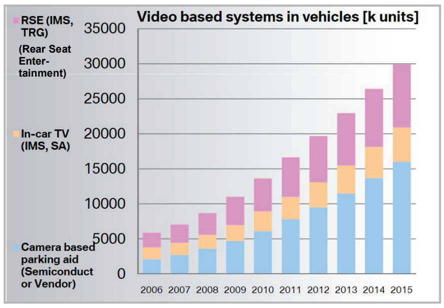

Figure 5. Growth of video-based systems in vehicles. (Source: IMS, Strategy Analytics (SA), Gartner, ABI Research, div. Semiconductor Vendor)

As an example, a vehicle typically has a minimum of five blind spots that would require several vision cameras to provide area safety scanning, as shown in the Figure 6. The five blind spots (shaded) in a standard left-hand drive car are shown in this figure. The sizes of the blind spots are dependent on the design of the car and the viewing angle of the mirrors.

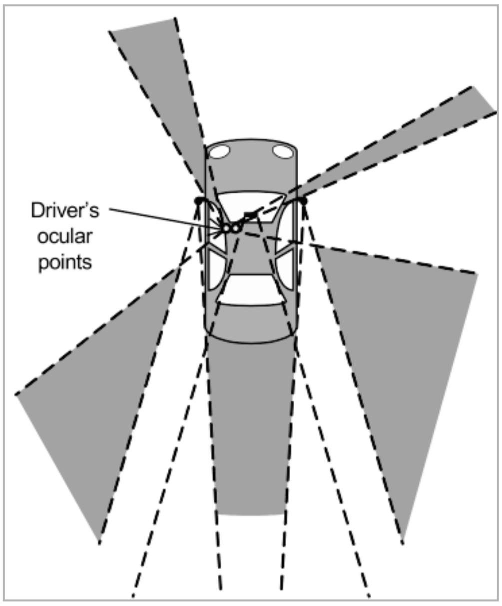

Figure 6. Five blind spots typically found in most cars. (Source: ISVCS 2008 July 22 - 24, 2008, Dublin, Ireland.)

Figure 7. Example of "360 View System".

Several car makers have already released or plan to release to market the "360 View Systems," which employ at least four cameras that provide a composite image of the surroundings of the car, as shown in Figure 7.

5 Interconnection Alternatives

While there is no single standard interface for automotive cameras, Dedicated Serial Links are the most common interfaces for cameras.

The interface between the camera and the Image Processing Unit (IPU) or display determines the way different cameras of the same system can be interconnected. For example, LVDS is an interface that only allows a point-to-point connection between the camera and the IPU or display.

If a system consists of several cameras interconnected with an IPU, the only allowed topology would be a direct connection between each camera and the central unit. When the car has several ADAS and each ADAS consists of several interconnected cameras, this direct connection topology translates into an unacceptable number and length of wires, connectors and interfaces.

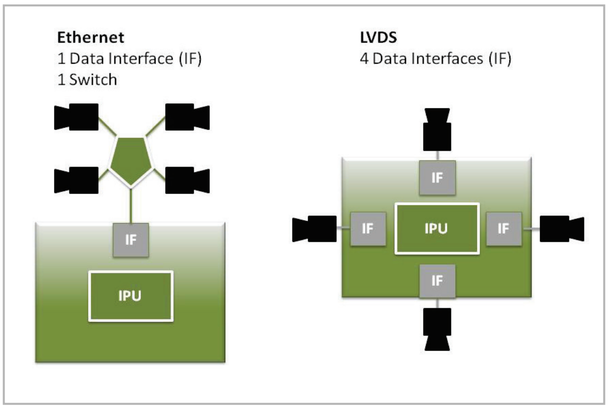

Figure 8. Comparison between Ethernet and LVDS on the connection of four cameras with their Image Processing Unit (IPU).

If Ethernet is used as the camera interface in place of an LVDS dedicated link, for example, the network can be simplified. Although a point-to-point interface like LVDS, Ethernet is a packet-switched network with a much simpler network topology that can grow or shrink without the need to reconfigure the hardware or software components of the system. The simplified layout of Ethernet in comparison to LVDS is show in Figure 8.

Predictability of data arrival time is the advantage of the dedicated direct connection at bit level between the source and data sync. Because there is no packet switching in the direct link, there are no unpredictable delays. Ethernet is able to achieve this predictability when upper layer protocols like AVB (Audio Video Bridging) are used. This implies more computer complexity.

In summary, there is a trade-off between direct, simple connections and Ethernet-based connections. For a simple one-camera system, a direct connection is the best option. However, when complex ADAS are used, the Ethernet interface and topology is the optimum technology.

5.1 POF as the PHY for Each Alternative

One alternative for the physical layer that interconnects cameras and IPUs or displays in ADAS is to use one Gbps POF technology from KDPOF along with Avago optoelectronic transceivers (shown in Figure 9) implemented inside the Small Form Factor connector system from Yazaki (shown in Figure 10).

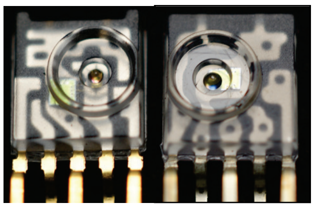

Figure 9. Avago fiber optic transceiver (FOT) pair.

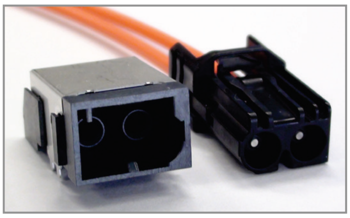

Figure 10. *Yazaki Small Form Factor connector system.*

KDPOF ASSPs (Applications Specific Standard Products) can interface either with direct data links like DVP or through native Ethernet ports like RGMII or SGMII. This means that either LVDS-type or Ethernet-based ADAS can be easily built around KDPOF products.

5.2 POF Advantages over Copper-Based Systems

Figure 11 shows a practical example of KDPOF Gbps POF technology on an ADAS application. The prototype shown in Figure 11 is an implementation of two cameras working in stereoscopic mode connected via POF to an IPU. The display shows the image with shape recognition and depth calculation, which can serve as the input to a driving support function like collision warning, pedestrian detection or smart cruise control. The approximated binary stream is 960 Mbps with each camera capturing images at 1280 x 800 pixels and 30 fps.

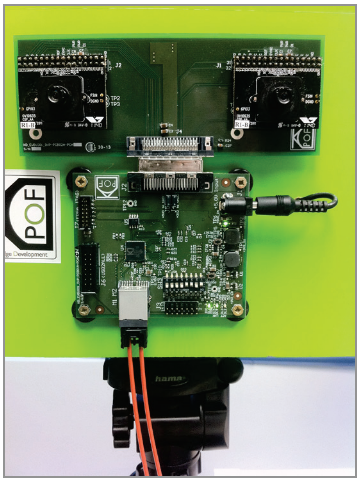

Figure 11. *Two automotive cameras connected in a stereoscopic configuration. The interface board sends 1 Gbps data through POF to the IPU.*

The camera start up configuration can be done in two ways. In the first option, based on duplex POF, one fiber serves as the upstream link and the other as the downstream link. A second option uses simplex POF to transport the image data to the IPU, with a parallel simple and low-cost LIN-type copper pair serving as the channel over which the start-up configuration is sent to the camera. This parallel channel also could be used to remotely power the camera thus saving an extra pair of cables. Both of these options are shown in Figure 12.

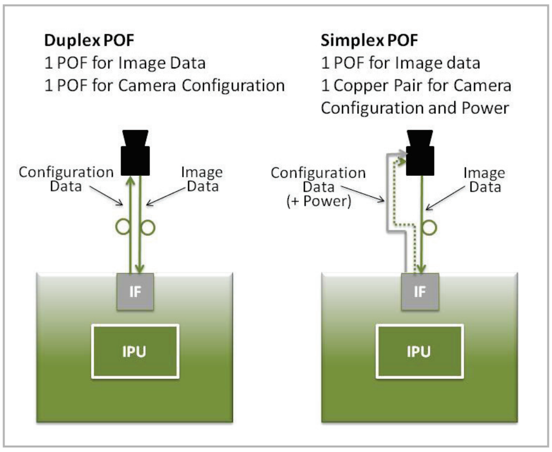

Figure 12. *Alternatives for Ethernet POF camera control.*

6 Conclusion

With the growing demand for infotainment networks and ADAS, the need to migrate to a new backbone topology is growing. The advantages of Ethernet and the significant benefits of the KDPOF 1 Gbps Plastic Optical Fiber (POF) ASSP, the Avago optical transceiver and the Yazaki Small Form Factor optical connector, combine to provide a solution that is both scalable and flexible to meet the ever-changing demands of the automotive network.