The Potential of CAN FD Technology to Impact Upon FlexRay

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Abstract - CAN FD has been introduced as a way of improving the data throughput and integrity of CAN bus systems. FlexRay is the emerging technology for automotive high speed control networking. The adoption of a faster network such as FlexRay has the ability to reduce the weight of the vehicle electrical architecture by replacing a number of lower speed networks with a single faster network. This in turn reduces the number of gateway ECUs, wiring and connectors, and reduces system complexity.

By increasing the data throughput CAN FD has the potential for car manufacturers to delay the adoption of a faster network such as FlexRay by breathing new life into existing CAN architectures.

In this paper the features of CAN FD and FlexRay are compared in terms of the cost of implementation, data throughput and protocol complexity. A conclusion is made on the impact of CAN FD on FlexRay technology.

Introduction

CAN FD has been introduced as an enhancement to the CAN protocol by providing improved bandwidth [1]. The FlexRay protocol has enjoyed some adoption in high-end cars as a high speed network. The aim of this paper is to look at the potential impact of CAN FD on FlexRay technology by comparing some key aspects of these technologies. Therefore this paper has an automotive perspective.

The key features of CAN FD and FlexRay are compared at a top level. Then some analysis is carried out on the potential bandwidth of both technologies and a comparison between the two is made. Finally CAN FD and FlexRay are compared in terms of cost and application to automotive high integrity systems.

High-Speed Networking Benefits

FlexRay has become a successful technology for high speed automotive control networks. It was originally aimed at providing features for X-by-wire systems. However the biggest benefit has been on a system design perspective in which a higher speed network such as FlexRay can provide a number of benefits.
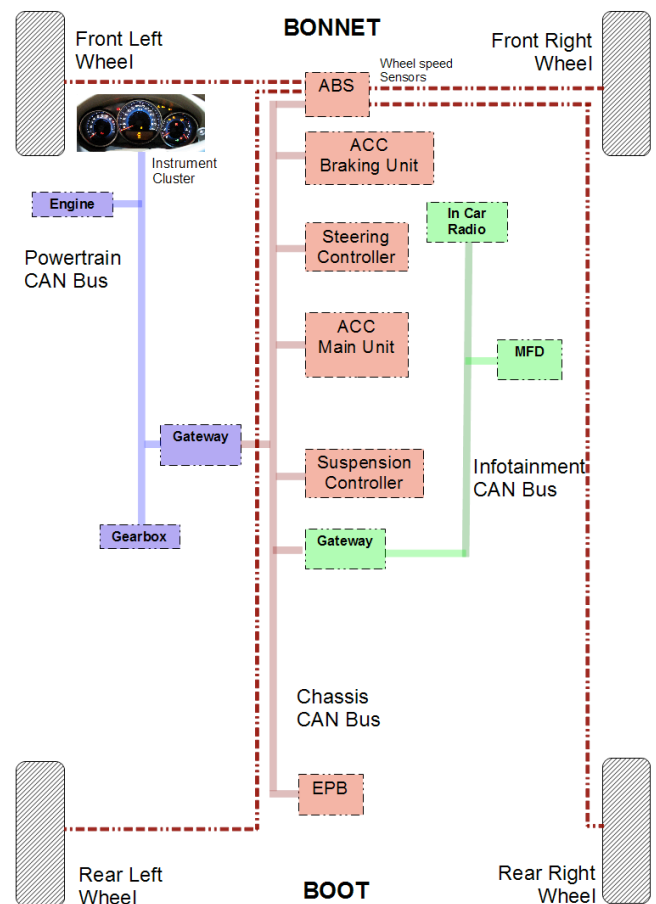
Figure 1: Example complicated architecture that can be simplified using a high-speed networking technology

Firstly a single faster network can replace several lower speed networks. This in turn reduces the number of gateway Electronic Control Units (ECUs), reduces the amount of wiring in the vehicle due to the reduction in the number of networks which therefore reduces the weight of the electrical system. Secondly the deletion of one or more networks reduces the control system complexity and less effort needs to be taken to decide on how to partition a network and how to transport a signal which may need to exist on several CAN buses [2]. For example in figure 1 there are three CAN buses each of which must use the wheel speed signals. In this example these signals originate on the chassis CAN bus but would also be used on the powertrain CAN bus by the engine and gearbox controllers and be processed in the instrument cluster to display vehicle speed. It would most likely also be used on the Infotainment bus for the in-car radio for speed adaptive volume control.

Summary of Known FlexRay Adoption

The FlexRay consortium was launched in 2000 to develop the FlexRay specifications and market. It consisted of core members BMW, DaimlerChrysler, Freescale (previously called Motorola), Philips Semiconductors, Robert Bosch and Decomsys. The first draft of the FlexRay protocol was introduced in 2001. The aim of FlexRay is to complement CAN in higher bandwidth and integrity applications and is now at revision 3.01. This particular revision has been announced for inclusion in the latest BMW X5 chassis control system [2].

FlexRay has established a significant advance on CAN technology by increasing bit rate, providing synchronisation between nodes so that a time triggered bus access methodology is achieved and providing a backup data channel for dual mode redundancy.

Since 2005 FlexRay has enjoyed some adoption in some high-end automotive such as several BMW platforms and also extended into the Audi A8 initially before extending into other Audi and Bentley vehicles. Since the BMW group own the luxury brand Rolls Royce adoption into these platforms is likely. Wider adoption in the automotive industry is currently unclear. A number of research projects for FlexRay have taken place in aerospace and robotic control applications.

The implementation of FlexRay for chassis control in a production BMW was described by Berwanger et al in 2005 [2]. Although the nodal costs of FlexRay are higher, an interesting reason for choosing FlexRay stated by Berwanger et al is that it can reduce system costs when compared to a CAN implementation. This is counter-intuitive when nodal costing is considered. However, it is argued that cost savings can be enjoyed by replacing several CAN buses. This in turn reduces wiring, connectors, gateway ECUs and all of this reduces system partitioning effort. They also stated that reducing the number of CAN sub-buses, cables and redundant sensors meant that, holistically, the implementation of FlexRay is roughly the same as for CAN. They also estimate that integration of the FlexRay controller into the microcontroller and using a lower cost transceiver will save approximately three and one Euros respectively per ECU. However, no real data has been presented to support these arguments and also it is not clear whether this considers the impact of adopting a new and sophisticated technology such as FlexRay.

Motivation for CAN FD

FlexRay is a way of providing more bandwidth and as previously described has already been adopted on a small number of high-end vehicles. However there is at least one use case in which FlexRay is not the best solution. FlexRay is not an efficient protocol for ECU flashing. This is because the protocol would require that an ECU undergoing a flashing operation must wait for appropriate spare time in the communication schedule to be able to handle flash data. Traditional CAN connected via the OBD is very slow as it runs at 500 Kbit/s and FlexRay can be fast running at 10Mbit/s but is not flexible

enough due to its time-triggered communication. Therefore CAN FD has been proposed initially to at least close the gap between CAN (max. 1 MBit/s) and FlexRay (10 MBit/s) for ECU flashing type applications.

Another motivation for CAN FD is the high effort for migration for an automotive OEM and its suppliers to move to a faster technology such as FlexRay or Ethernet. Hardware, software and staff expertise costs would be significant and therefore adoption of CAN FD for other automotive networking use cases is a possibility because it is only an evolution of the traditional and well-known CAN technology.

To help keep the comparison consistent between the three technologies it was assumed that the DLC was 8 bytes. The comparison is shown in Figure 2SEQ which shows maximum data throughput in bytes per second versus the bit rate in the data phase. Overlaid on this diagram is CAN at 500 Kbit/s and FlexRay at 2.5Mbit/s. FlexRay has three possible bit rates that are used; 10 Mbit/s which with a data payload of 8 bytes will result in a data throughput of 625000 bytes/s, 5 Mbit/s which with a data payload of 8 bytes will result in a data throughput of 312500 bytes/s and 2.5 Mbit/s with a data payload of 8 bytes results in a data throughput of 156250 bytes/s.

Table 1 Comparison of key features of CAN, CAN FD and FlexRay

	CAN	CAN FD	FlexRay v3.0.1
Message IDs	11 or 29 bit		11 bit
Data Payload	8 bytes	64 bytes	254 bytes
Bit rate	1 Mbit/s	AP: 1Mbit/s, DP: 8Mbit/s	2.5, 5 or 10 Mbit/s
CRC	15 bit	17 bit (16 bytes) 21 bit (64 bytes)	15 bit header CRC 24 bit trailer CRC
No. Channels	1	1	2 (A and B)
Network Access	CSMA-CD NDBA or Time Triggered	CSMA-CD NDBA or Time Triggered	Time Triggered
Chip Support	Most micros	Bosch, Freescale, NXP, ST	Many 16 / 32-bit micros
AUTOSAR Support	Yes	v4.1.1 CAN FD 8 bytes v4.2.1 CAN FD 64 bytes	Yes

CAN-FD Bandwidth Potential

A study was carried out to help understand more about the potential of CAN FD when compared to FlexRay. As a reference traditional CAN is included assuming that it is running at 500Kbit/s due to the fact that the majority of passenger cars do not exceed this speed in their fastest CAN buses. In this study it was assumed that 100% bus utilisation could be achieved by using a pseudo-deterministic CAN bus scheduling technique [5] [6] or a deterministic CAN strategy such as Time-Triggered CAN (TTCAN) [7].

In SEQ Figure 2 CAN FD is shown with an Arbitration Phase of 500Kbit/s and 1Mbit/s which sit below and above FlexRay at 2.5 Mbit/s. Therefore CAN FD is equivalent to low-end FlexRay.
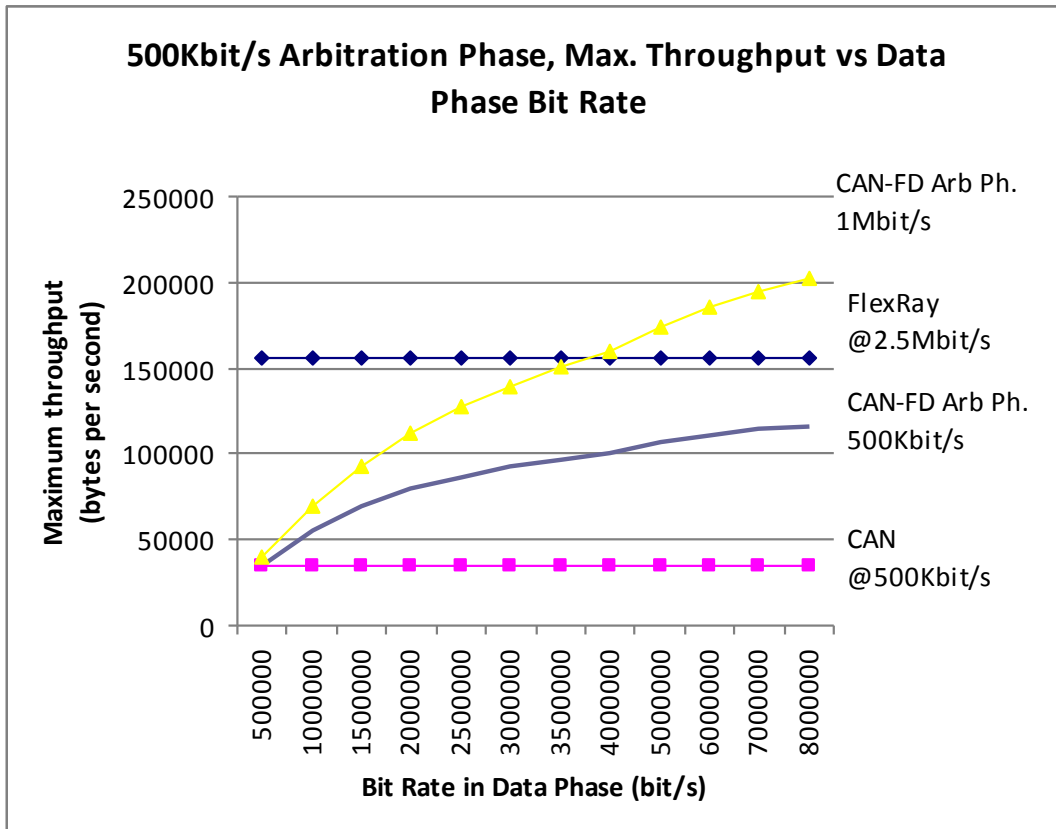
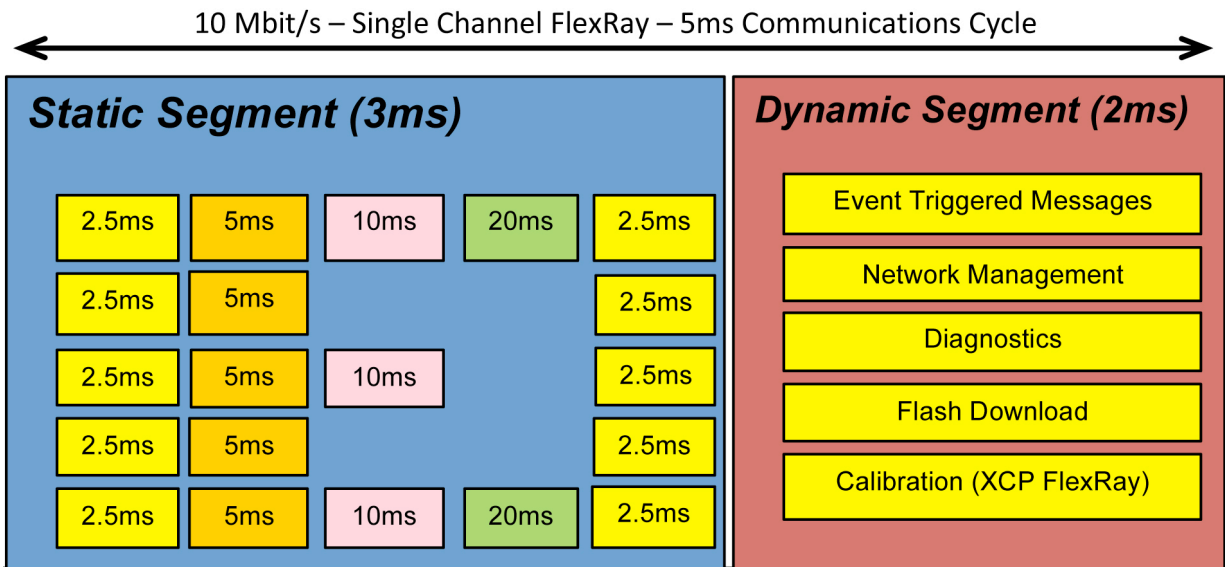Figure 2: Example complicated architecture that can be simplified using a high-speed

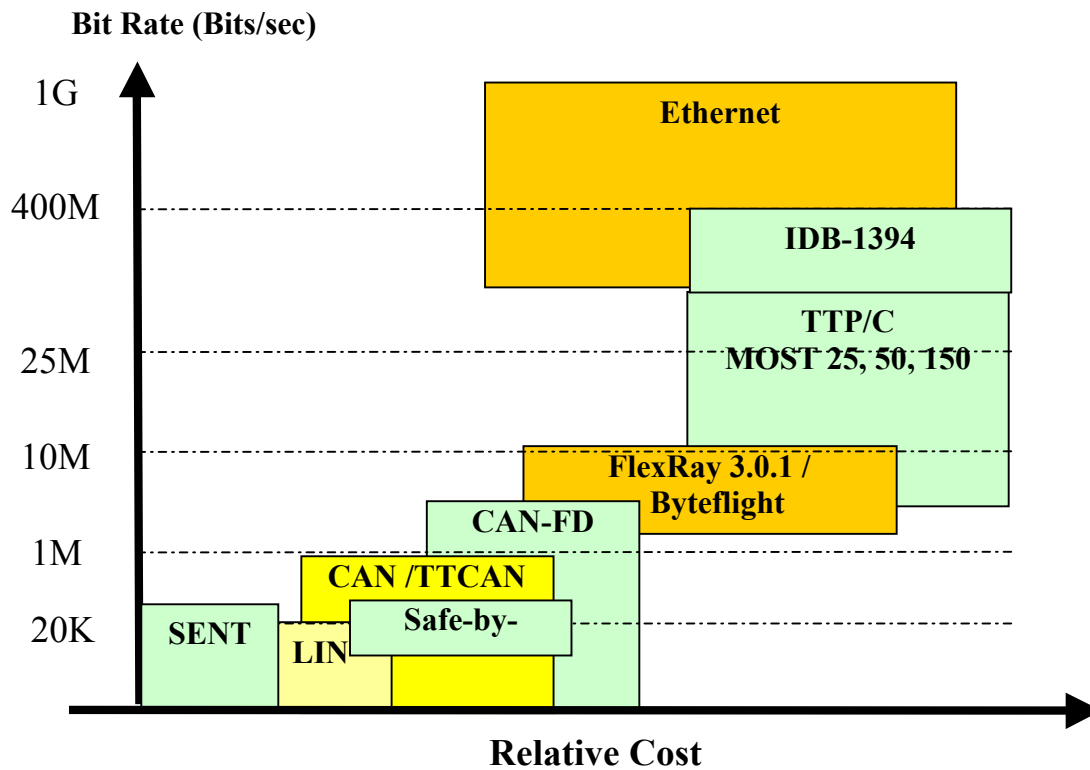Figure 3: Summary of BWM X5 communications schedule

Figure 4: Current and emerging communications technologies versus price versus bandwidth (based on Figure 1 of LIN specification package Revision 1.2 page 2 [8])

Real-Time Control Cycles

FlexRay has a time-triggered communications schedule, each row of the communications schedule has a Static Segment and a Dynamic Segment. The static segment is fixed and messages designed to be transmitted there will always be whilst in the dynamic segment there is the possibility to only send a FlexRay message from an ECU if it has some new information to report. There are always 64 rows to the FlexRay communications schedule. An example of FlexRay communications schedule which summarises the use in the BMW X5 vehicle is shown in Figure 3SEQ. It can be seen that the communications cycle is 5ms long and messages are multiplexed within this schedule depending upon the transmission period required. It can be seen for this example that the required cycle times vary from 2.5ms to 20ms. These cycle times would not be too challenging with CAN FD as a single message could be less than 100μs and at the same time transport a lot of data.

The other interesting point to notice about this example of FlexRay communications is that the Dynamic Segment is used for flash download, diagnostics and calibration and certainly one of the cited motivations for CAN FD is for flash download in production and whilst vehicle is in service. As the Dynamic Segment is 2ms out of a total 5ms communications cycle, then 60 % of the bandwidth cannot be used for flash download, diagnostics and calibration.

Cost Comparison

Previous studies have looked at how features of microcontrollers impact upon the cost. In general things like memory capability and number of gates are aspects that can influence the cost of a microcontroller. With this in mind the datasheets of a number of Robert Bosch IP cores were studied and their features are compared in in Table 2. From Table 2 it can be seen that FlexRay requires a larger number of gates for its implementation and more message RAM in its ERay controller than the other cores.

The C_CAN and D_CAN cores have lower message RAM and number of gates. CAN FD sits in between CAN and FlexRay in its gate and RAM requirements.

Gates, RAM Comparison – Bosch IP

Figure 3 shows a comparison between the relative nodal costs of protocol implementation versus its bandwidth for the main automotive relevant protocols. This figure is based on Figure 1 of LIN specification package Revision 1.2 page 2, but has been updated based on other information already presented in this report to include the current and emerging protocols in the automotive industry in terms of network technology costs. Since CAN is the de-facto automotive standard, CAN is used as the relative cost of unity and is therefore the reference protocol in the figure.

Table 2: CAN IP core feature comparison

Name	Protocol	Gates	Message RAM (Bytes)
ERay	FlexRay	110000	8448
C_CAN	CAN	14500	544
D_CAN	CAN	18200	564
M_CAN	CAN/ CAN-FD	30700	4750
M_TTCAN	CAN/ TTCAN /CAN-FD	47700	5250

A LIN node is expected to be cheaper to implement than CAN as a result of a number of cost saving features of the protocol such as the use of a single wire for the transmission of data (instead of the twisted pair used for CAN), the ability that LIN slave devices can use cheaper RC oscillators (instead of crystal oscillators that are a necessity for all interoperable CAN devices) and the physical layer is simpler and therefore cheaper in its standard form.

The SENT protocol is a unidirectional point to point technology that is slightly faster than LIN (28 KHz) but also reported to be cheaper to implement.

TTCAN has been assumed to be similar pricing to CAN since it uses the same silicon. FlexRay in its current revision v3.0.1, is expected to be significantly more expensive than CAN, mainly due to a greater RAM requirement in the FlexRay controller. There is a spread in the cost domain for FlexRay due to the variety of network architectures that could be used, for example bus and star configurations are possible. Some configurations are lower cost, whilst others are of higher cost. There is contradictory information in the literature concerning FlexRay being a higher cost protocol [8]. In the year 2006, the BMW X5 became the first production car to implement FlexRay within its chassis control system. Although the nodal costs of FlexRay are higher, an interesting reason for choosing FlexRay is that it can replace several CAN buses, thus reducing wiring, connectors, gateways and system partitioning effort (Berwanger et al; 2005). TTP/C has been implemented on faster systems than FlexRay and is slightly more expensive.

It should be noted that Figure 4 does not capture the holistic costs and misses a lot of key information. It does not show data throughput for each network technology which does tend to be but does not necessarily have to be directly related to bit rate. The received wisdom that LIN is the low cost technology, CAN is the medium cost technology and FlexRay is an expensive technology is too much of a simplification. The general trend is that the higher the bandwidth, the higher the cost of nodal implementation. In practice many other factors must be considered such as cost of training employees and buying tools, the architecture employed itself and warranty costs.

Impact on Automotive Integrity

ISO26262 is the new standard providing guidelines on how automotive electronic systems should be delivered to provide an appropriate level of safety.

Systems are rated by Automotive Safety Integrity Level (ASIL) from A to D with ASIL-D being the most safety critical.

ASIL-D requires a Probabilistic Metric for random Hardware Failures (PMHF) of $<10^{-8}$ h^{-1}. It has been reported that traditional CAN does suffer from undetected double bit errors with a certain probability of this occurring [4]. This can mean that under certain circumstances traditional CAN does not satisfy the failure rate requirements due to the probability of such undetected bit errors. This of course does depend upon the Bit Error Rate (BER) of the transmission medium. It has also been reported that BER of an automotive CAN bus may change significantly over the life of the vehicle such that failures become unacceptable for ISO 26262.

FlexRay has been designed specifically with safety in mind and CAN FD has been designed with improved CRC handling and therefore it would be interesting to see how the two compare. Unfortunately this has been beyond the scope of this current study reported in this paper.

Future Automotive Electronic Architecture

Modern vehicles already have a large number of different network technologies within their electrical architectures such as CAN, LIN, MOST and FlexRay. Ethernet is now being considered for some non-critical high bandwidth applications and also in some safety critical applications. It is extremely likely that due to the cost sensitive nature of the automotive industry that there will always be a mixture of network technologies used in the vehicle and their sophistication will be due the bandwidth requirements of the applications on the vehicle. Figure 5 shows a possible network technology mix and hierarchical architecture comprising of many established and emerging technologies appropriate to the different applications in the vehicle.
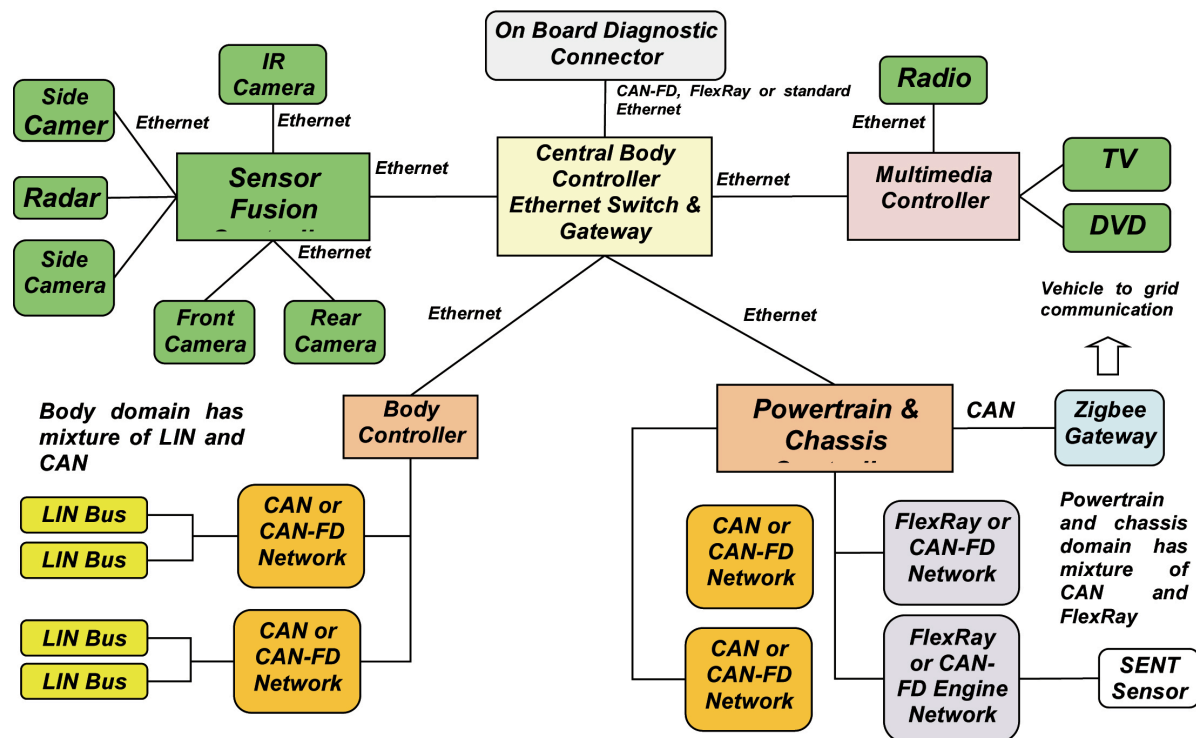

Figure 5: Future Automotive Network Technology Mix

Conclusion

This paper has compared some of the key features and performance metrics associated with CAN, CAN-FD and FlexRay. In particular data throughput, cost of implementation and application to automotive electronic integrity systems were compared. Finally a possible automotive network hierarchy of the future was looked at.

It is concluded that both CAN-FD and FlexRay are likely to be a part of the automotive network technology mix of the future. CAN-FD has the potential to provide the same data throughput as three to four traditional CAN buses. It also has the potential to provide a similar data throughput to low-end FlexRay (e.g. FlexRay running at 2.5Mbit/s). FlexRay is a faster network technology with some safety features built in but its widespread adoption is not yet guaranteed. Currently only a few automotive OEMs have adopted FlexRay and this could be in part due to the risk of a new technology, higher cost of tool and personnel training. CAN-FD has the potential to threaten FlexRay adoption for lower-end application and could be used to extend the life of older CAN based platforms and architectures. Interest in Ethernet and TT-Ethernet is growing for higher-speed applications and therefore there is a threat to FlexRay from different sides of the bandwidth spectrum and could delay or even halt its adoption. However it is possible that FlexRay has carved out its niche enough to survive. CAN-FD is likely to generically become known as CAN as it gets absorbed into a new part of the ISO11898 specification.

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References

[1] Hartwich F; "*CAN with flexible data-rate*", Proceedings of the 13th iCC 2012 at Hambach Castle (Germany)

[2] Berwanger J, Schedl A and Peller M (2005); "BMW – First Series Cars with FlexRay in 2006"; Automotive Electronics Systems, Special Edition FlexRay, Page 6 to 8, Hanser Publishing.

[3] Quigley, C., Jones, R. Peter, McMurran, R. and Faithfull, P. (2012) *Microcontroller memory capability assessment and variant selection for reducing the cost of mechatronics.* International Journal of Vehicle Design, Vol. 60 (No. 3/4). p. 248. ISSN 0143-3369

[4] Tran, E; "Multi-Bit Error Vulnerabilities in the Controller Area Network Protocol", Carnegie Mellon University, Pittsburgh, PA, May 1999

[5] M. Grenier, L. Havet, N. Navet, "Pushing the limits of CAN - Scheduling frames with offsets provides a major performance boost", Proc. of the 4th European Congress Embedded Real Time Software (ERTS 2008), Toulouse, France, January 29 - February 1, 2008

[6] Tindell K and Burns A (1994); "Guaranteeing message latencies on CAN", Proceedings of the 1st International CAN Conference.

[7] Führer T, Müller B., Dieterle W., Hartwich F., Hugel R., Walther M., Robert Bosch GmbH; "TTCAN Time Triggered Communication on CAN", Proceedings 7th International CAN Conference; 2000.

[8] LIN Specification Package, Revision 1.2, 17th November 2000, The LIN Consortium (www.lin-subbus.org).