More Electric Aircraft Forum

Use of automotive data bus in avionics :

CAN and FlexRay

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ABSTRACT

This article describes the potential use in avionics for the FlexRay data bus which was initially developed for the automotive field. The goal is to discuss the same type of migration for the FlexRay as it happened for the CAN bus.
This article is published in the scope of the MOET European project which by the end of 2009 will bring the baseline for a more electrical aircraft.

INTRODUCTION

As aircrafts tend to be more electrical (flight control, air cabin system) they also become more electronic. The larger use of on-board microprocessors then leads to an increase of the data flow between systems. It forces aircraft manufacturers to carry out a permanent research work in order to validate the most recent data bus technologies. This validation in terms of safety and reliability is indeed compulsory to complete the certification phase with authorities (DGAC, EASA, FAA…). Other aspects must also be taken into account : the capability to maintain the technology over thirty years (devices, tools, supply) and the cost in development and manufacturing.

These requirements and especially the latter prevent starting from scratch to prefer migrating mature technologies from other domains to avionics.
Automotive provides similarities with avionics concerning reliability even if at a lower level.
Short development cycles in automotive are

The MOET project, coordinated by Airbus France, is co-funded by the European Commission within the Sixth Framework Programme
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based on longer technology cycles close to the aircraft industry.
In addition, the automotive mass-market provides a good evaluation of a technology and cost reduction.
Recent years have shown the use of automotive technology in aircrafts, among them : processors and communication busses.

Communication busses in avionics : CAN, AFDX, TTP, FlexRay

A good example is the CAN bus (Controller Area Network) available in 1987 and standardized in 1993 which was developed to simplify the communication network in a car.
First CAN busses were introduced in 2001 on the A340-600 for cabin application (smoke detector, air system,…) at a reduced bit rate (below 100kbits/s) towards its full capability.
The flexibility and the performances encountered led to its extensive use in A380 with more critical applications (electrical distribution, cockpit panels,…) with a large number of nodes (more than 500) dispatched over tens of busses. The bit rate then reached 1Mbit/s.
The latest airplanes currently under development (787, A400M, A350) use also largely the CAN bus.
The CAN bus seems definitively adopted in airplanes communication networks at least as a secondary bus inside systems.

However, its 1 Mbit/s bandwidth does not fit the need for the aircraft backbone which connects the different systems. In this area, a current bit rate of 100 Mbits/s is necessary and can be provided by the AFDX bus (Avionics Full DupleX) which includes advanced control mechanism for data routing.
Inside systems, the data throughput tends inevitably to increase as in any computerized system and a 1Mbit/s bandwidth will no longer be sufficient like in the electrical distribution system.
A strong need exists for a reliable and cost effective intermediate solution with a bit rate around 10 Mbits/s.
Two busses can currently boast such features :

- The TTP bus already on board the A380 (cabin air system) and the 787 (electrical power system)
- The FlexRay bus already embedded in several microprocessors but only used in the automotive field.

It was then an opportunity to study the FlexRay bus in the scope of the research European project MOET to assess its capabilities for a complete electrical power distribution system in an aircraft.
In addition, in the selected architecture, this "time-triggered" bus will be used in a mixed architecture along with CAN networks (Figure 1) to demonstrate the possibility of a hybrid architecture.

CAN overview

The CAN is specified by two main standards : ISO 11898 et ARINC825.
With a parallel access, it is well suited for bus or star topologies with a maximum bit rate of 1 Mbit/s (for a 40 meters length) and a sophisticated bus access grant mechanism ("Carrier Sense Multiple Access for Collision Detection with Arbitration on Message Priority"- CSMA/CD + AMP - Figure 2).
Each frame starts with a different header which is a combination of "dominant" and "recessive" electrical states. When two subscribers try to access the bus at the same time only one header can prevail. Low priority nodes listen to the bus to detect that their header is corrupted and try to retransmit later.
However, the flexibility of CAN which allows any node to transmit over the bus at any time ("event triggered") requires specific techniques to control the bus load and the transmitted data values at a specific time.
During the integration phase with different manufacturers products, this drawback can increase development costs.

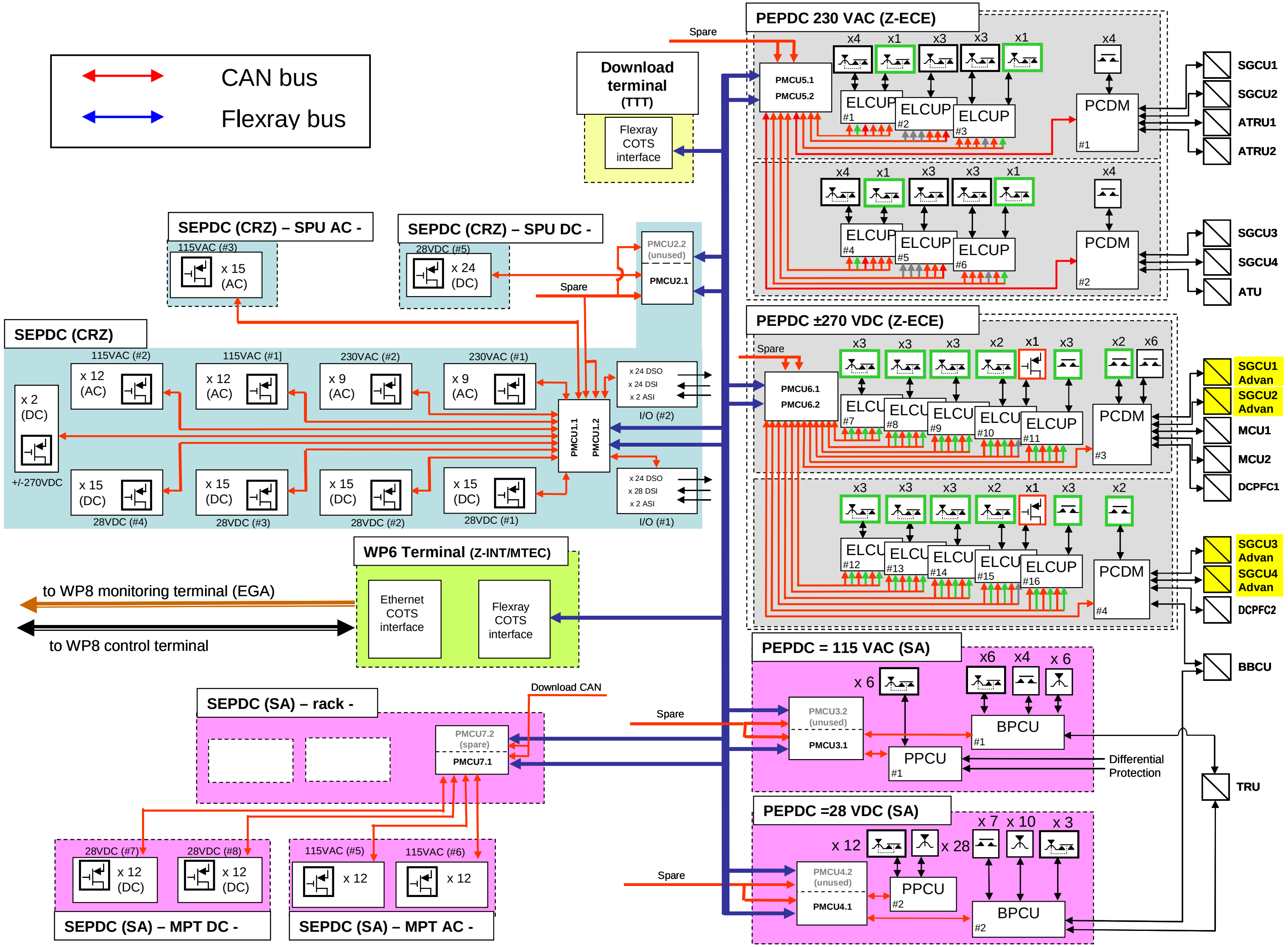

Figure 1 -- MOET Large aircraft communication architecture

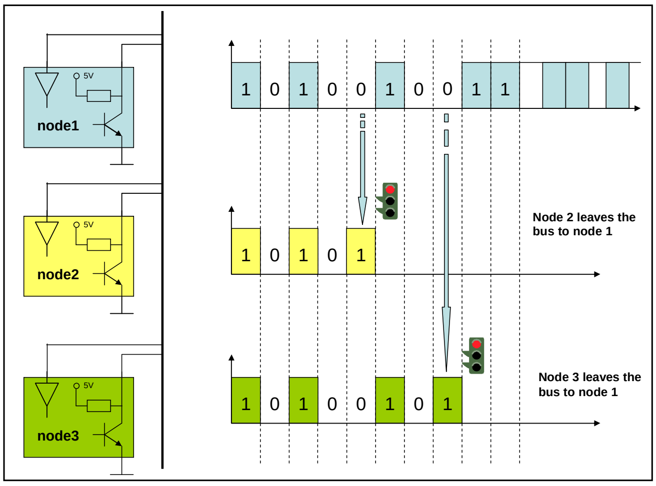

Figure 2 -- CAN bus arbitration

FlexRay overview

The FlexRay specification is maintained by the FlexRay consortium founded in 2000. Increasing demands for higher bandwidth, real-time capability and reliability were the driving forces behind the design of FlexRay. At present, FlexRay is used for high-speed data communication in automotive electronics networks (e.g. for vehicle stability and driver assistance functions) and considered as a candidate for consolidation of multiple CAN networks. FlexRay currently is not in use outside of the automotive industry and not applied in safety critical applications.

Protocol Operation

The communication pattern of FlexRay consists of a strict repetition of the communication cycle, including one static and optionally one dynamic segment. In the static segment, a predefined number of static slots with equal length is used for transmission of frames by statically assigned sending nodes. One node can transmit signals in one or multiple of these slots according to this static assignment, on either of the two channels supported by the FlexRay protocol controllers (Figure 3).

During start-up, a predefined subset of network nodes (“startup nodes”) establishes a global time base. This time base is then maintained for data communication by means of a complex distributed multi-master synchronization algorithm. Each node knows only its own sending slots and can receive data from any other slot. Each node is assigned a certain set of frame identifiers, which determine the slots in which a host can transmit data. Frame identifiers (frame ID) correspond to the slot number of the frame in which the frame is transmitted.
In the dynamic segment, the hosts get access to the bus through mini-slotting arbitration. Each node uses two slot counters, one for each channel, to keep track of the current frame ID count. At the beginning of each dynamic slot, a communication controller can initiate a frame transmission if it is configured with the corresponding frame ID. If transmission is initiated, the dynamic slot is observed by all communication controllers and the slot-counter is increased when the transmission is finished. If no frame is transmitted, the dynamic slot only lasts one mini-slot, with the slot-counter being increased immediately afterwards.

At the end of a round, the “Network Idle Time” (NIT), which is a short period without any transmission, is used to perform clock synchronization. After the NIT, the next communication cycle starts.

As the FlexRay communication cycle includes a static time division multiple access (TDMA) scheme, communication planning must be done at design time before being able to communicate on the bus. This can be done with the use of tools generating configurations for the communication controllers, either from a schedule produced by hand or using an automatic scheduler tool. The determinism brought by the TDMA scheme reduces dramatically integration costs thus overcompensating the extra design costs.

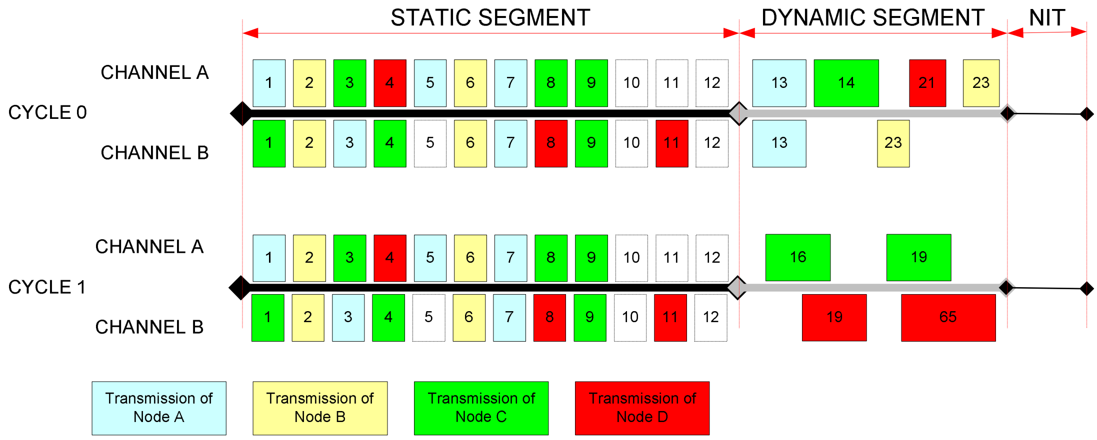

Figure 3 -- **Slot assignment in the FlexRay cluster. The communication cycle comprises a static and a dynamic segment. Mini-slotting is used in the dynamic segment for bus arbitration**

Technical Key Features

- ✓ FlexRay is a multi-master multi-cast protocol with statically configured communication cycles divided into a “static segment“ and a “dynamic segment“
- ✓ Bit rates specified for FlexRay: 2.5, 5, 10 Mbits/s
- ✓ Encoding: non-return to zero (NRZ), 2-bit BSS (byte start sequence) per transmitted byte
- ✓ Signal length: up to 254 bytes per frame (2-bit/byte overhead) with 5-byte header and 24-bit CRC
- ✓ Media access: distributed time division multiple access (TDMA) for the static part; mini-slotting for the dynamic part
- ✓ Large variety of applicable topologies : bus, star, mix of stars (up to 2) and busses, single- or dual-redundant channels
- ✓ Physical layer : twisted pair wiring, maximum cable length between any two nodes is 24 meters according to EPL specification (valid for critical configurations, longer cables may be possible for relaxed constraints).
- ✓ Number of nodes in one network: 2 - 22 nodes (limited by the standard EPL specification).
- ✓ Fault-tolerant global time base available to each participating node.
- ✓ Bus-guardian protecting transmission media from babbling idiot faults specified but not available as a component (no market requirement).

FlexRay advantages

- ✓ Maximum bit rate (10 Mbits/s) ten times greater than the one of CAN bus.
- ✓ True determinism (time, value) in the static segment of the communication cycle: highly predictable communication pattern.
- ✓ Pre-design scheduling creates a high degree of composability of system components and therefore reduced multi-partners integration effort.
- ✓ Global clock distribution makes the "time-triggered" network more robust to single node failure (no clock master).
- ✓ Possibility to optimize the use of the bandwidth with a bus load around 70% in the static segment.
- ✓ Dynamic segment offers flexibility for nodes that do not have to transmit data frequently or for sporadic non-critical data (e.g. diagnostics).
- ✓ The implementation of a time-triggered architecture allows the creation of an extremely predictable, deterministic system. The latency can be reliably reduced to the absolute minimum.
- ✓ In a dual-channel FlexRay configuration, the two channels can be used independently or redundantly or in a mixed fashion.
- ✓ Protocol supported by a large consortium with more than hundred companies (BMW, Bosch, Daimler, Freescale, NXP Semiconductors, Volkswagen, Fujitsu, Xilinx, Infineon, National Instrument, Vector Informatik, Ixxat, NEC, EADS Deutschland, TTTech….).
- ✓ Multi-sources devices and tools available.
- ✓ Mass market (automotive) available to decrease cost and demonstrate reliability

FlexRay disadvantages

- ✓ Dedicated tool and time required to perform network scheduling at the start of the design with adequate provisions for growth capability.
- ✓ Standard physical layer defined in the EPL specification is not DC-free: the NRZ encoding used by FlexRay is not DC-free, which inhibits the usage of transformer coupling often used for fieldbus networks in aerospace environments. A physical layer better suited for aerospace use would have to be defined.
- ✓ Maximum cable length between any two nodes is 24 meters and max 22 nodes in one network according to the standard EPL specification. Reducing the data rate to 5 Mbits/s or below might allow bigger cable length but this has to be carefully analysed. A physical layer better suited for aerospace use would have to be defined to overcome this issue. But this would reduce a lot the mass market advantage that FlexRay might have in the future.
- ✓ No acknowledgement mechanism built into the protocol – transmitting nodes do not have information about success or failure of the transmission. If needed, acknowledgment is implemented on higher (software) layers; compared with a protocol-level implementation (e.g. CAN bus) this increases system complexity, consumes additional bandwidth and reduces the overall efficiency.
- ✓ Inefficient bandwidth allocation: All transmissions in the static segment have equal size, which has a considerable impact on data efficiency when bus subscribers do not exchange the same amount of data. Selecting a large frame size creates bandwidth loss for nodes that need to send only a small amount of data.

Using a small frame size instead creates more overhead (8 bytes overhead per frame plus inter-frame gap). This disadvantage can be mitigated with clever architecture and communication planning at system level.

- ✓ The design of the FlexRay clock synchronization algorithm has limited propagation delay support, which leads to length restrictions of the bus media. The maximum tolerable propagation delay of 2.5 µs limits the use of signal repeaters or the performing of full signal reshaping.

FlexRay communication simulation in the MOET project environment

Flexray physical interface

Besides the FlexRay protocol itself, the FlexRay Consortium has specified a dedicated FlexRay physical layer [1]. Since FlexRay originally has been developed for automotive applications, the physical layer is customized to meet automotive requirements. The automotive market being strongly cost driven, the FlexRay physical layer is optimized to meet automotive EMI requirements even on cheap unshielded twisted pair wires. This is achieved by using low transmitter voltage levels and long rise and fall times for bit transmission. Furthermore, the physical layer is implemented as a ternary one, having the bit states “1”, “0” and “idle”. As a consequence, the signals are more susceptible to damping caused by cable losses, and the receiver thresholds are relatively high to distinguish between the three signal states. For short cable lengths, as they appear in automotive networks, this is not an issue. Aeronautic systems with cable lengths of 100 meters and above might encounter problems with this physical layer, especially in demanding topologies with many and/or long stub lines. To maintain generality of the specification, the FlexRay Consortium recommends not exceeding a maximum cable length of 24 meters. With this boundary condition, point-to-point, passive bus and passive star topologies should be working robustly without having to assess signal integrity in detail.

Running FlexRay on topologies that exceed the recommendations of the specification requires taking a closer look on signal integrity. The FlexRay topology (Figure 4) of the MOET large aircraft system has an overall cable length of 26.3 meters. Together with the relatively long and inhomogeneous stubs, this is a challenging topology for FlexRay. The selected approach to validate signal integrity on the MOET large aircraft topology is based on simulations and measurements on a physical layer test bench with a setup close to the real system implementation in terms of topology, cable types and the FlexRay interface inside the nodes. Central elements of the simulation model are the FlexRay transceivers and transmission line models to model cable (type WX26) and PCB traces. Both have been individually developed and parameterized for the MOET system. The simulation model of a MOET FlexRay node is depicted in Figure 5.

Signal integrity criteria derived from the protocol and physical layer specification are applied to measured and simulated transmission of test pulses for every combination of sending and receiving node. It has to be ensured that symmetric and asymmetric delays of the signal transitions stay inside the valid ranges. The voltage levels at the receivers have to exceed the maximum receiver thresholds with some safety margin. Furthermore, the signal transitions have to be sufficiently fast to avoid faulty detections of the “idle” state. The evaluation revealed no critical points related to signal integrity on the MOET large aircraft FlexRay topology. Robust FlexRay communication should therefore be possible with a gross data rate of 10 Mbits/s even on this challenging aeronautic topology.

Other analyses [2] have shown that FlexRay can also be run on an aeronautic topology with an overall cable length of 90 m, if the data rate is reduced to 5 Mbits/s.

Thus, it can be inferred from these results that the physical layer of FlexRay generally is not an obstacle to use FlexRay in aeronautic systems. Ensuring the compliance with the FlexRay signal integrity criteria, FlexRay can safely be run on harnesses that exceed the recommendations of the specification in terms of topology and cable lengths.

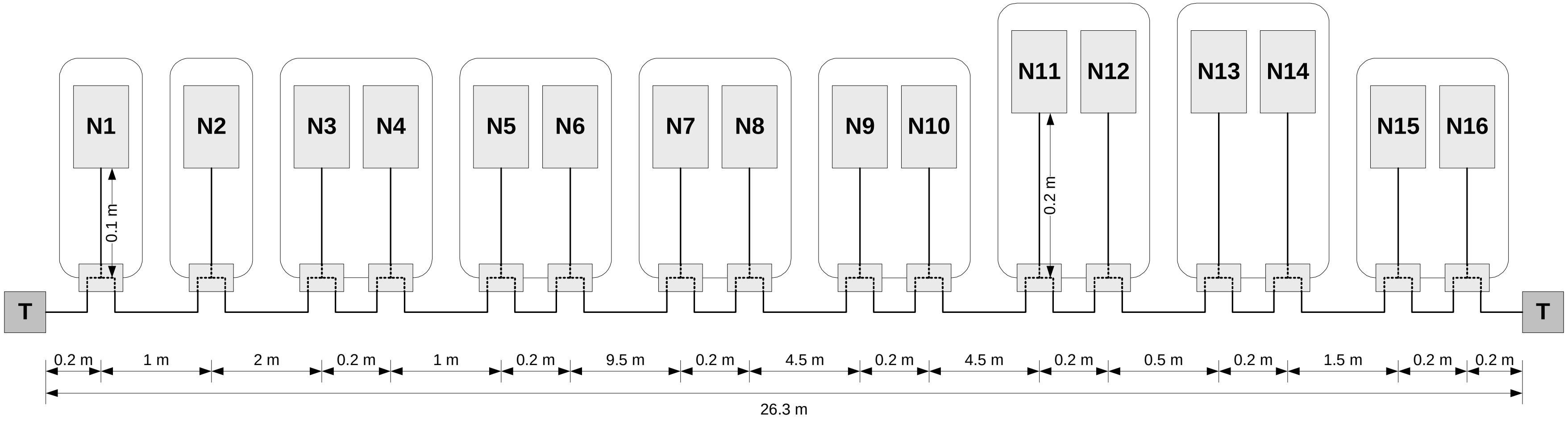

Figure 4 -- MOET Large aircraft FlexRay topology

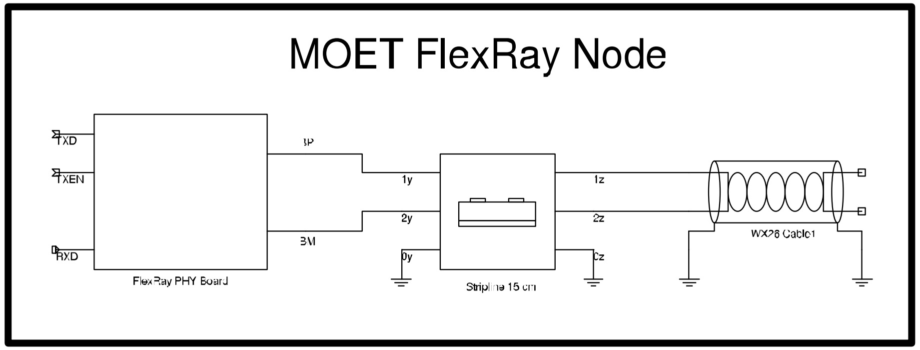

Figure 5 -- Simulation model of MOET FlexRay node

FlexRay/CAN data flow :

The combination of FlexRay and CAN protocols in the same communication architecture in aerospace applications presents an interesting area of investigation due to the different nature of these protocols (time-triggered vs event-triggered). According to the MOET software interface requirement, each CAN datalink (DL) communicates with Master/Slave type communication, where communication is initiated by the Power Modules Communication Unit (PMCU) in a half duplex fashion. Each DL communicates at a data rate of 500 Kbits/s. During communication, different types of frames can be transferred between nodes, e.g. Data Frame, Remote Frame, Error Frame, Overload Frame. Each CAN frame contains 128 usable bits and 29 stuffing bits giving a total of 157 bits without inter-frame bits. Based upon this the frame timing and minimum interframe timing are respectively 157bits /500000=314µs and Ti min=3/500000=6µs. The latency of CAN depends on the bit rate, the priority of the message, and load on the bus.

FlexRay / CAN Interface Simulation Setup :

In this experiment, the logical control unit was connected to all six subscribers located on six independent data links. The control unit could be connected to all six subscribers through a gateway. Figure 6 shows the implementation in simulation setup.
In Figure 6, the gateway node is shown by by . In this case, the logic control unit is implemented in a gateway which connects six DL, means six separate CAN channels. The control unit can send/receive messages to/from any subscriber located on any DL through the gateway.

Creation of nodes in Simulation Setup :

In Figure 6, the FlexRay main controller which is the ‘WP6 control and monitoring terminal’ is connected via FlexRay. CAPL_PMCU_SSPC_CAN1 and CAPL_PMCU_SSPC_CAN2 are the gateway nodes to send messages to the slaves present on the CAN channel.

Subscribers	Latency in Multipoint communication on FlexRay (µS)
Subscriber 1	52
Subscriber 2	104
Subscriber 3	156
Subscriber 4	208
Subscriber 5	260
Subscriber 6	312

Table 1 -- Latency in the Flexray network

For the FlexRay, the timeslot during which a message from a particular subscriber was transmitted, could be pre-determined, making it particularly attractive for safety critical systems where reactions to faults need to be configured more accurately.

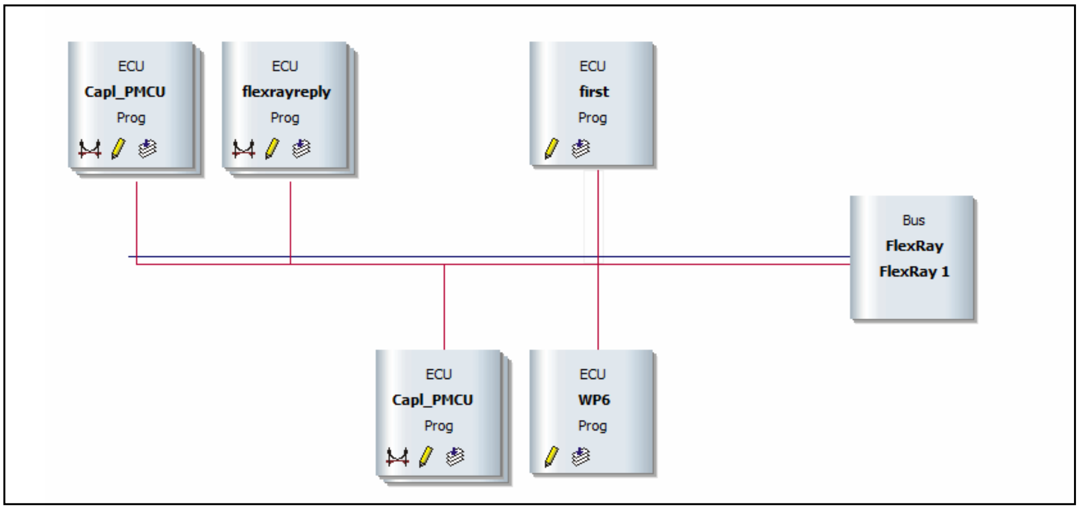

Figure 6 -- FlexRay Network

The future of the Flexray bus in the avionic field

It took around 8 years to migrate the CAN from automotive to avionics.
If the technology was easy to use in the development phase, the integration and certification stages were more complex especially for the latter considering the avionics requirements.
However, the feedbacks from the automotive wide use were bringing confidence.
Can we expect the same roadmap for the Flexray ?

An advantage of FlexRay seems to be its use in a high production volume market. The expectation is to get cheaper FlexRay components, embedded softwares and tools. FlexRay controllers are today available as integrated modules in embedded multipurpose CPUs (system-on-chip) from various suppliers (e.g. Freescale, Infineon, NEC). Moreover several suppliers exist already for automotive middleware components according to the AUTOSAR specification.

However, financial constraints and market pressures contributed to delay the expected adoption of FlexRay in automotive systems. Today, only premium car makers which differentiate on new technology take advantage of it for some assistance functions. Originally, the FlexRay requirements included safety critical real-time networking in advanced vehicle functions, but the claim for suitability of FlexRay for safety related functions has not been fully substantiated yet. At present, FlexRay is primarily used as a high-speed network and viewed as a powerful replacement for the CAN bus. It is not clear how current and future variants of FlexRay will address safety requirements.

Moreover, consortium and certification issues should be carefully considered as well. For the moment, the FlexRay consortium has indicated that its only field of interest is the automotive industry. Apart from current licensing terms (FlexRay use for production limited to the automotive industry), this can also impede certification and qualification of components for aerospace use. Finally, available middleware products are currently optimized for automotive use and do not offer aerospace qualification or standards compatibility.

CONCLUSION

The communication networks are at stake in the avionic field where the number of electronic equipments are always more complex and require an increasing flow of data to be exchanged.

To answer this need, field busses like the FlexRay bring the adequate solution for on-board systems (electrical power distribution, fuel system, …) even if for the moment some features of the bus need to be tuned to fit avionics requirements.

Can we imagine in few years that the FlexRay like the CAN bus will also be widely used in aircrafts?

The onus is on firms which will decide to invest in the costly process of certification with the necessary collaboration of the FlexRay consortium.

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GE aviation, Microtech International, Alenia Aeronautica.

DEFINITIONS, ACRONYMS, ABBREVIATIONS

AFDX	Avionics Full DupleX switched ethernet
CAN	Controller Area Network
EPL	Electrical Physical Layer : the electrical connection to the bus media
PMCU	*Power Modules Communication Unit : a gateway communication board developed by Zodiac Aerospace in the MOET project to interface CAN and Flexray networks*