CABIN CORE SYSTEM – A NEXT GENERATION PLATFORM FOR COMBINED ELECTRICAL POWER AND DATA SERVICES

Hartmut Hintze* [1, 2], Andreas Tolksdorf [2], Ralf God [1]

[1]Institute of Aircraft Cabin Systems, Hamburg University of Technology
Nesspriel 5, D-21129 Hamburg, Germany

[2]Airbus Operations GmbH, Department TBCEE41
Kreetslag 10, D-21129 Hamburg, Germany

Hartmut.Hintze@tu-harbung.de

Abstract

The primary goal of a new aircraft design is to satisfy customer needs and to cope with emerging technology trends. Moreover, the new design must support manufacturing needs and constraints, allowing for fast ramp-up and serial production. Cost efficiency and simple operation associated with flexibility in terms of customization are further important aspects to be considered in the design phase. All these main requirements lead to the following top performance objectives (TPOs): highest flexibility and performance with improved installation concepts, rapid processing in the final assembly line (FAL) and a minimization of weight. Regarding the aircraft cabin a focus lies in customization in conjunction with short lead times and weight reduction. These TPOs finally affect as well the cabin core system (CCS) which is the focal management platform for power supply, operation, control and monitoring of the cabin and for testing its systems. The directives for a future approach of a CCS design are presented and challenges arising from applicable aviation regulations are discussed in this paper.

1   INTRODUCTION

In recent years the amount of system functionalities within the aircraft cabin has grown enormously. In consequence cabin management systems have evolved into a complex digital network structure. Nowadays most of the linked systems are using individual cabin networks to fulfil their functional mission. This task-oriented evolution progressively increased the complexity of the CCS, its overall component weight and the amount of work involved in manufacturing and installing the CCS. Flexibility for customization and reconfiguration of the CCS decreased simultaneously.

It is quite obvious that a solution for a next generation platform has to reverse this trend by an advanced design concept. The challenge is to decrease the amount of individual networks and to diminish the system components by pursuing a higher

integration level without omitting existing aviation regulations. The advances in cabin management systems of business jets [1] can be considered to be a trend indicator and pacemaker for commercial aviation. It is clearly visible that connectivity for passenger owned devices is an emerging and important functional requirement which will bring value to the passenger. Additionally wireless interfaces are intensively discussed, because of the ease of reconfiguration. However reliability and network security issues remain and have to be resolved in the future.
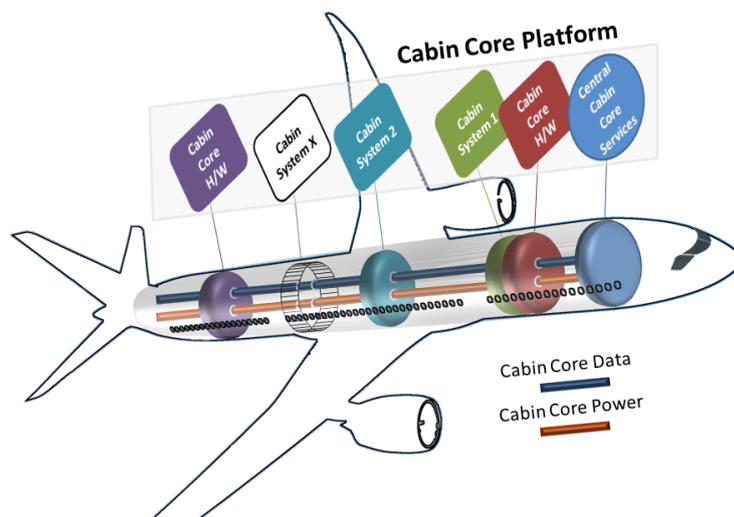

Figure 1 – High-level view of a CCS Platform with integrated data and power lines

An analysis of the task-oriented evolution of the CCS shows two major constants: a topology for cabin core power and another for cabin core data. Therefore our approach is based on an integration of both network topologies (Figure 1). A state-of-the-art cabin core power system is introduced in section 2. Its topology will be used as a baseline for the design of an advanced cabin core data architecture with the ultimate ambition to end up with an integrated next generation cabin core system platform. In section 3 the boundary conditions and regulations for a cabin core data network are given as background information. Based on these our approach of an advanced platform design is described. This approach considers concurrently the cabin power and cabin data requirements and presents a concept of the functional structure of a multi domain network node (MDNN) which is an essential building block of the next generation platform. In section 4 the proposed platform design is summarized and discussed with respect to viability, available technologies and TPOs.

2 CABIN CORE POWER

Within the A380 program the aircraft manufacturer Airbus established an innovative electrical distribution network concept for AC and DC power, which offers flexibility and supports various and customized electrical cabin loads [2] and has since been introduced into other A/C programs. The network concept (Figure 2) is strongly in line with the described TPOs and is based on solid state power controllers (SSPCs) which are located in secondary power distribution boxes (SPDBs). Each SPDB contains up to 15 SSPCs for AC and up to 8 SSPCs for DC switching.

The primary electrical power distribution center (PEPDC) in the avionics bay provides 115 VAC and 28 VDC to the secondary power distribution boxes (SPDBs) in order to supply cabin and cargo loads (up to 15 A) via the SPDBs and to protect the distribution network against failures. The SPDBs 1, 3, 5 and 7 supply loads of the cabin electrical side 1 and the SPDBs 2, 4, 6 and 8 supply loads of the cabin electrical side 2. SPDBs 1 to 6 are supplying cabin loads and SPDBs 7 and 8 cargo loads. The SPDBs are connected to the avionics data communication network (ADCN), which provides data communication links to the SPDBs, the PEPDC and to all related sub-systems. This data communication via the separated ADCN controls SSPCs in the SPDBs for power management and load shedding. It offers status reporting capability, system test, data loading and maintenance functions.
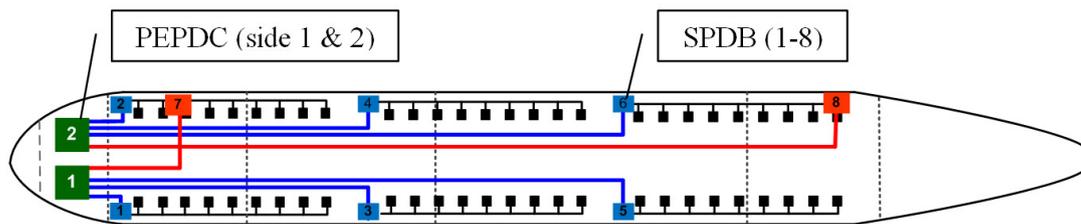

Figure 2 – Modern cabin power network with distribution boxes (SPDBs) containing solid state power controllers

Although in this example the ADCN architecture and power distribution architecture are not integrated by design, it proves again that power and data go along with each other, distribute at nodes and terminate in systems. Hence two fundamental questions have to be raised for future aircraft program developments: Could this type of approved power distribution architecture serve as base for a cabin data network backbone? And what would be the optimum amount of integrated power and data network nodes? These two questions have to be assessed against the given TPOs. For the power distribution network the second question was answered by an evaluation [3] which delivered an optimum of about six SPDBs per cabin side. Consistently the same evaluation should be performed for the cabin core data network. Finally the two results have to be put on top of each other to verify whether a new functional optimum for an envisaged network with combined power and data distribution nodes can be found. The subsequent sections will describe the prerequisites and challenges when designing cabin core data network which is combinable with the basically defined cabin core power network.

3   CABIN CORE DATA

In aviation system development the requirements are deriving from the intended functions of a system and commercial aspects coming from the customer. Both parts are additionally ruled by aviation regulations for the use of systems on board of an aircraft [4]. The aviation regulations imply general requirements for aircraft system integration and for interaction of the respected system with other aircraft systems. For a cabin core data system the aviation regulations consider system safety with related development assurance level (DAL) [5] and system security with related aircraft do-

main model [6] as the two most vital parts. Before describing the overall requirements of our next generation cabin core system platform the aircraft domain model and development assurance levels are briefly introduced.

3.1 Development Assurance Level (DAL)

The system development level is based upon the contribution of a system to potential failure conditions as determined by the system safety assessment process. The system development implies that the required level of effort varies with the failure condition category by showing compliance with certification requirements [5]. Based on a safety assessment process, the respective system development level definitions for an anomalous system behavior are:

DAL A: System failure resulting in a catastrophic failure condition for the aircraft.

DAL B: System failure resulting in a hazardous/severe-major failure condition for the aircraft.

DAL C: System failure resulting in a major failure condition for the aircraft.

DAL D: System failure resulting in a minor failure condition for the aircraft.

DAL E: System failure with no effect on aircraft operational capability or pilot workload. Once a system has been confirmed as level E by the certification authority, no further guidelines for the development are given for certification means.

To meet DAL A compliance for a system, which implies the highest level of reliability, requires the highest level for system design, documentation, system verification & validation and for the configuration management process. This fact has to be taken into account for the evaluation of a new cabin core design because it has to be assured that a lower system DAL would be clearly segregated from a higher system DAL to avoid negative impact. Today's most simple solution to this issue is the hardware segregation of the different DAL functions. Currently there are no DAL A systems defined within the cabin core system. An example for a DAL B system is the smoke detection function while the in-flight entertainment is defined as DAL E.

3.2 Aircraft Domain Model

Additionally to the DAL, which addresses primarily system safety aspects, for a cabin core data system the security aspect is significant as well. In modern passenger aircraft there is an increasing demand to provide integrated network capabilities for travellers, as well as for maintenance and other staff working aboard and around an aircraft. In consequence an additional cabin data network for commercial use has to be considered. Such type of network distinguishes drastically from a secured network with purely flight-relevant data which was originally developed to perform mission-critical tasks. The latter one is protected against intentional undesired and against unintended intrusions. However the arising needs for essential networking capabilities in parallel with commercially desired, but non-essential tasks led to an aircraft domain model which is grouping functionalities in consideration of system security aspects. Table 1 shows a contemporary domain reference model used for the aircraft data network design [6].

Table 1 – Aircraft Domain Model

Aicraft Control Domain ACD	Airline Information Services Domain AISD	Passenger Information & Entertainment Services Domain PIESD	Passenger-Owned Devices Domain PODD
Flight & Embedded Control Functions **Cabin Core Functions**	Administrative Functions **Cabin Operation** Flight Support **Cabin Maintenance**	Embedded IFE Functions **Passenger Device Interface** Flight Support Onboard Passenger connectivity	Usage of Passenger Notebooks Connection of Passenger Mobile Phones
Control of the Aircraft	**Operations of the Airline**	**Entertain the Passenger**	

In this domain model classification it is a prerequisite that a domain of higher priority has to secure itself against a domain with lower priority. The aircraft control domain (ACD) represents highest and the passenger owned devices domain (PODD) lowest priority. Higher priority is defined by more mission-critical, i.e. more essential functions in contrast to non-essential tasks. The situation becomes much more complex because the depicted aircraft domains have different interoperability characteristics and architectures. System security requirements exhibit a great challenge to the network domain interoperability. The subsequent definitions [6] describe the use and security level of the four domains in a descending priority order:

ACD – Aircraft Control Domain:

The ACD consists of systems and networks whose primary functions support the safe operation of the aircraft. The ACD is primarily focused on digital, and more specifically, internet protocol data networks. The justification for most of these systems is traceable to safety of flight. When these systems perform non-safety related functions, it should be demonstrated that there is no interference with safety related functions. The ACD may also provide services and connectivity between independent aircraft domains such as the AISD, the PIESD, the cabin distribution network and any connected off-board networks.

AISD – Airline Information Services Domain:

The AISD provides services and connectivity between independent aircraft domains such as avionics, in-flight entertainment, cabin distribution and any connected off-board networks. The AISD provides a security perimeter, incorporating network routing and security services between AISD and less critical domains and any connected wireless networks.

PIESD – Passenger Information and Entertainment Service Domain:

The PIESD is characterized by the need to provide passenger entertainment and network services. The PIESD is defined to include more than traditional IFE systems;

that is, any device or function of a device that provides services to passengers. It may contain multiple systems from different vendors that may or may not be interconnected to one another, and its borders may not necessarily follow physical device borders.

PODD – Passenger Owned Devices Domain:

The PODD is defined to include only those devices that passengers may bring on board. They may connect to the aircraft network or to one another. Its connectivity to the airplane network is defined to be provided by the PIESD.

An example will show why it is often difficult to clearly assign a function to a single domain: Cabin maintenance is a crossover function, which affects all domains. For operational reason, it is inefficient to separate this function from other domains. Therefore the main part of this predominantly airline information and service oriented function is hosted within the AISD and collects the respective data from the other domains by inter-domain communication. This shows that commercial domains (PIESD, PODD) and flight-relevant domains (ACD, AISD) are moving closer to each other. The challenge of system security is to protect the flight-relevant domains against intentional undesired and against unintended intrusions. Any new CCS design has to cope with this security requirement.

With respect to the high level requirements for system safety and system security arising from aviation regulations and other requirements deriving from intended system functions, the following section is describing an approach for a next generation cabin core system platform.

3.3 Design of a Next generation Cabin Core System platform

With reference to the given top performance objectives (TPOs), i.e. highest flexibility and performance with an improved installation concept, rapid processing in the final assembly line (FAL) and a minimization of weight, it seems to be manageable to define an optimal structure for a cabin core system (CCS) platform which fulfils these TPOs. Without having other conditions in mind a plausible layout (Figure 3) would consist of a single cabin backbone providing cabin core data and cabin core power via one network to each cabin system. The linkage of each system to the CCS could be achieved via network nodes (NNs) attaching the power supply, cabin systems and enabling bidirectional data communication within the CCS backbone itself and with the attached systems. This simple setup seems to comply with the given TPOs.
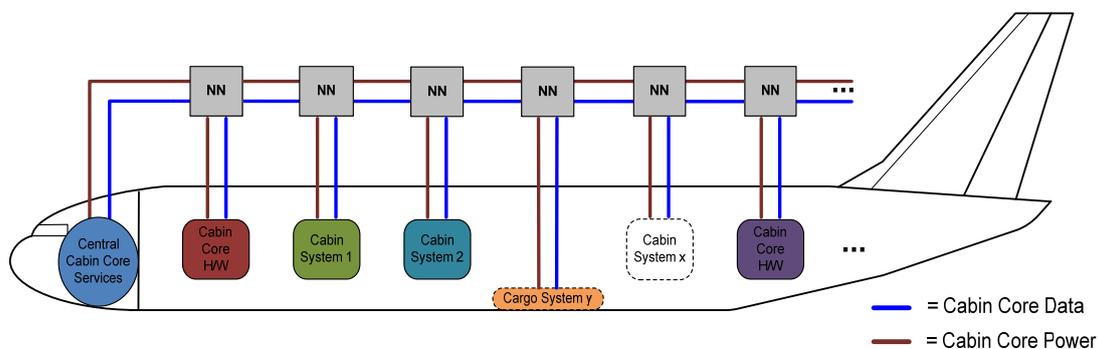

Figure 3 – Sketch of a cabin core system platform with parallel data and power network, focussing predominantly on top performance objectives

However, when adding aviation regulation affected functional requirements to the TPOs, this simple type of design is not able to fulfil essential conditions. Table 2 summarizes aviation regulation affected and other functional requirements for cabin core data and cabin core power.

Table 2 – Power and data network: High level requirements overview

	Power network	**Data network**
Aviation regulation affected functional requirements; cf. [4, 5]	Electrical power to all cabin and cargo systems as well as wing and tail systems either in AC (voltages: 230VAC or 115VAC) or in 270VDC (High Voltage DC = HVDC)	A full Cabin Backbone with the provision that all cabin and cargo systems can use the network to exchange data with other systems
	Protective function for Human Body Protection and Wiring Protection. This includes GFI protection, short-circuit and over-current clearance or Arc Fault Detection	Provide built-in redundancy to achieve high availability and to avoid single point of failures
	Current return support for CFRP-fuselage aircraft	Crew-friendly operation to reduce workload
Other functional requirements	Local AC/DC conversion to reduce wiring weight	Plug & play equipment to connect other system components without the need for physical device configuration or intervention
	Power management function to reduce wiring weight	Provide standardized interfaces to simplify the connections with the other systems
	Control function for remote system control	High quality PAX services to satisfy the passenger comfort
	Galley supply functions	Open, modular architecture to be prepared for future needs
	Supply function for medical equipment	Provide wireless information for dedicated applications
	Customizing functions	Future communication technologies
		Low maintenance effort to save time and costs
		Enhanced tools to relieve e.g. customizing
		Auto configuration without having manual intervention of the maintenance

The subsequent two examples demonstrate that aviation regulation requirements, representing system safety and system security, are challenging for a flexible, simple and lightweight design.

Figure 4 shows an example for indication by passenger lighted signs (PLS) in the cabin. Indication via PLS is classified as a DAL C function and it has to be ensured that every passenger in the cabin has clear visibility to the PLS at any time.
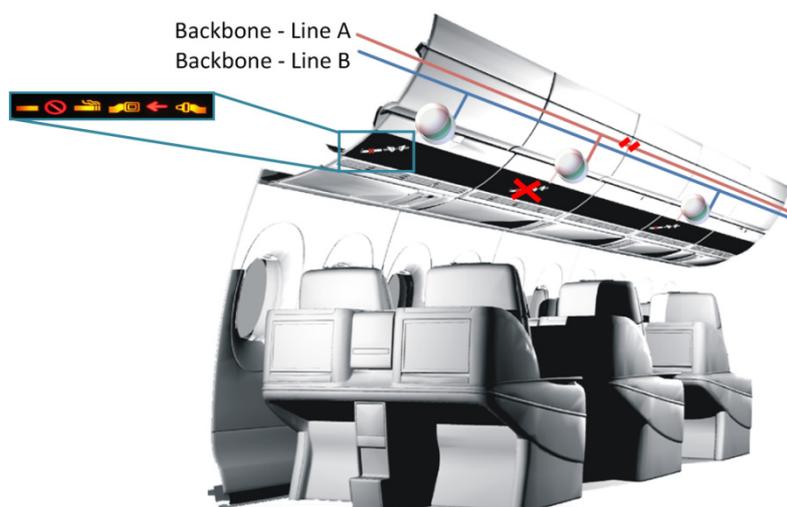
Figure 4 – Passenger lighted signs in the cabin require visibility for each passenger

Based on the aviation regulation requirement for high availability and avoidance of single point of failures within all aircraft programs the cabin backbone has two separated data lines A and B per side, where alternating every second PLS is connected to line A or B respectively. This type of design ensures, even in the case of one line being not available, that the airworthiness requirements are fulfilled. This is because of the next PLS supported by the other available line is still in good visibility and thus guarantees information transfer to the passenger. It is quite obvious that the installation of a dual line configuration on each side is contrary to the TPOs demand for easy installation and weight reduction. Hence, another solution is highly desirable.

This first example concerning the PLS was addressing a design dependency on an aviation regulation requirement for a system function which is located within the specific aircraft control domain (ACD) and which covers cabin core functions. In another example we are focusing again on the passenger seat environment. In parallel to the PLS the in-flight entertainment (IFE) should be available at a network node. Due to the fact that the IFE system is located in another domain (PIESD) a further challenge arises with respect to aircraft domain model compliance. Inter-domain communication and domain crossover functions can be necessary at a single network node and for network security reasons a domain of higher priority has still to secure itself against a domain with lower priority. Thus a network node in a single network has to cope with secure multi domain capabilities. The functional structure and requirements for such kind of a multi domain network node (MDNN) as a global interconnection point for various systems to the CCS platform will be discussed in the subsequent section.

Multi Domain Network Node (MDNN)

The proposal is to install multi domain network nodes (MDNNs) at different positions within the aircraft cabin to support data-connection of cabin and cargo systems from different domains via a standardized interface. At the MDNN power should be provided to the systems in parallel. Due to system security requirements described in

section 3.2, the aircraft domain model with its four separated domains (ACD, AISD, PIESD, PODD) has to be applied to the aircraft cabin network. Due to this fact, a multi domain approach for network nodes in the cabin necessitates novel and challenging system security and safety concepts. All conceivable combinations of cabin systems connected to a node should be covered. Figure 5 shows the functional structure of a proposed MDNN. The node is split into three parts: the cabin network interface, the local I/O interface and software applications and services within the node.
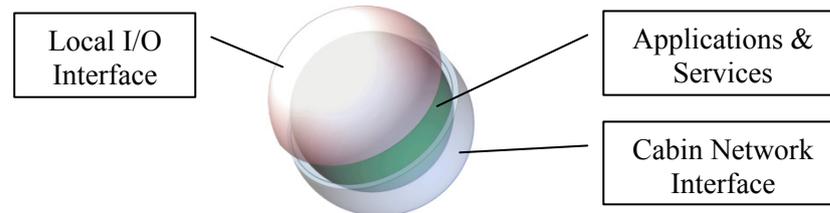

Figure 5 – Functional structure of the multi domain network node (MDNN)

The Cabin Network Interface of the MDNN

The Cabin Network Interface represents the linkage to the inner network backbone with wideband network functionality and covers data and power network requirements considering their DAL segregation, bandwidth and latency. Especially the DAL segregation for the power part represents a big challenge because every hardware based segregation will automatically affect the weight of the MDNN. The physical interface has to have a wideband capability like the today's Gbit network standard. Due to required cable length, weight aspects and physical segregation purpose, the fiber-optics seems to be an adequate technology. On the other hand the aircraft environment creates new challenges for the use of this technology. For example easy installation concepts and robust optical connectors are still an issue for research and development.

The Local I/O Interface of the MDNN

The Local I/O Interface deals with data conversion for multiple interfaces, e.g. like controller area network (CAN), low voltage differential signalling (LVDS) [7] and other interface types of connected cabin systems. These data standards have to be converted into the data format of the CCS platform. For bidirectional operation it provides data processing and transmission capabilities from the CCS to the connected systems as well. The long-term target should be the adaption of the existing various system interfaces to the ethernet standard. Additionally the local I/O interface should support system security by hardware design oriented security solutions like for example protocol data filtering and input buffer handling.

The applications & services of the MDNN

The applications & services cover all necessary software functions and services within the node to fulfill system security (e.g. by firewall functionality, data segregation and data encryption) and functional features for the network integration. Additionally network administration, real-time processing and prioritization of dataflow should be provided. Prioritized real time communication via the cabin core system platform is for instance needed during audio data distribution for passenger an-

nouncements and for cabin crew intercommunication, both classified as DAL C. With prioritized real time communication a synchronous transfer of audio and visual information can be guaranteed in this example.

Another important function of this applications and services part would be the realization of communication flow control combined with node security to contribute the multi domain approach. As shown before, the MDNN is defined as connection point serving communication for miscellaneous systems like in-flight entertainment and cabin core systems. All nodes are physically connected to a single cabin backbone. Systems within such a network may and may not be allowed to communicate to each other, based on their given tasks and domain model restrictions. A virtual domain structure based on a virtual local area network (VLAN) could fulfill this requirement. With VLAN groups of systems with a common set of requirements can be formed even if systems are not located at the same node. Network reconfiguration can be done through software instead of physically relocating devices. This facilitates network administration. Each group communicates in a logical network domain, regardless of the physical location of systems and the physical network structure. Figure 6 is showing an example of such a virtual domain structure based on VLAN. System 1 is allowed to communicate with its subsystem 1' and system 2 is allowed to talk to system 3 but is not allowed to communicate to system 1 neither 1'. All Systems are sharing the physical network, but the application and services level of the node is able to fulfill all required communication restrictions like isolation, 1 : 1 and 1 : n system communication.
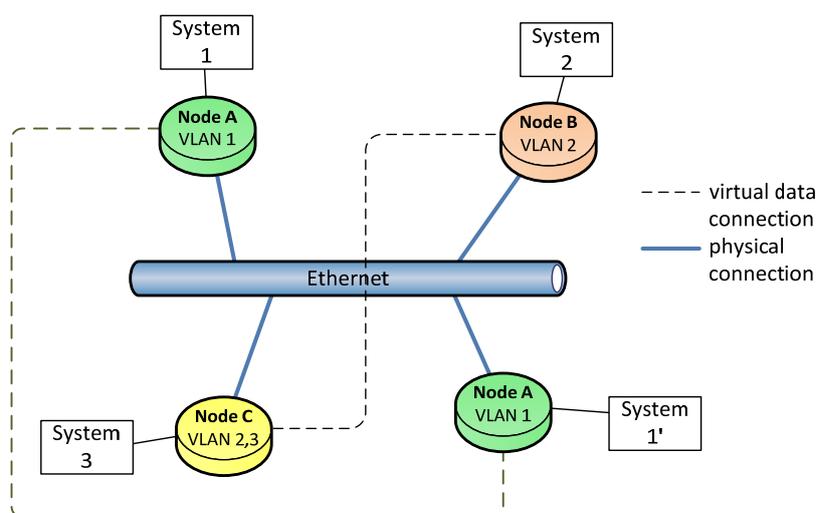

Figure 6 – Virtual domain structure of MDNN connections

4   SUMMARY AND DISCUSSION

In the aircraft cabin a constantly growing number of system functionalities led to a complex cabin core system (CCS) which is characterized by a staggered, task-oriented evolution. With increasing functional requirements the overall complexity of the system was in parallel enhanced by compulsory aviation standards given as aviation regulations or as requirements, respectively. A discontinuation of this trend

seems to be inevitable, because the currently achieved complex architecture of the CCS has become contradictive to the top performance objectives (TPOs) for aircraft manufacturing, which are highest flexibility and performance, improved installation concepts, speedy processing in the final assembly line and a minimization of weight.

An analysis of the historically evolved CCS shows a common denominator: all cabin systems have to be linked to a power and a data network. For the electrical power distribution network a novel concept was already introduced within the A380 aircraft program and is meanwhile proven to support aircraft manufacturing TPOs at excellent Airbus performance and quality standards. The power network is based on secondary power distribution boxes (SPDB) mounted along the aircraft cabin.

For the design of a next generation CCS platform the integration of power and data services seems to be viable. The basically defined cabin core power network architecture can serve as starting point. The necessary data network technologies and applications (e.g. example fiber optics, common network protocol and network security mechanism) are available for commercial use. It has to be proven that a transfer into an aircraft is possible with respect to aircraft regulations concerning system safety and system security. An integration of power and data services into physical network nodes affords a solution for a multi domain network node (MDNN) which is essential for the data part. A virtual domain structure based on virtual local area network (VLAN) technology is proposed to fulfill this need.

Altogether it is expected that the proposed platform concept with combined power and data services will contribute to reduce complexity of the CCS. Due to a higher integration level and the use of modern data network technologies the system is supposed to comply with TPOs in aircraft manufacturing. A detailed assessment of this platform concept with respect to aviation regulations, functional requirements and TPOs will be part of further investigations in a cooperation of university and aircraft manufacturer.

5   REFERENCES

[1]   B. Rosenberg, "Cabin Management Systems", Avionics Magazine, 26-30 (May 2010).

[2]   Ian Moir and Allan Seabridge, "Aircraft Systems – Mechanical, electrical and avionics subsystem integration", John Wiley & Sons, Third Edition – August 2008

[3]   J. Brombach, A. Lücken, D. Schulz, T. Schröter, "Strukturelle und funktionale Verbesserungen der elektrischen Energieverteilung moderner Verkehrsflugzeuge", proceedings of the DGLR 2010 annual conference.

[4]   In the United States the Federal Aviation Administration (FAA) and in Europe the European Aviation Safety Agency (EASA) are issuing and supervising regulations for aircraft system development.

[5]   Documents of SAE - Society of Automobile Engineers (ARP 4754 and 4761) and of RTCA – Radio Technical Commission for Aeronautics (DO-254 and 178B) provide guidance for the development of highly integrated or complex aircraft systems comprising hardware and software. These documents derive from the top level requirements given by FAA and EASA [4] in the Federal Aviation Regulations (FARs) or Certification Specifications (CSs) part 25 section 1309 (System Design and Analysis).

[6]   ARINC specification 664P5 „Aircraft Data Network – Network Domain Characteristics and interconnection", Network infrastructure and security workgroup.

[7]   CAN - ISO 11898 and ARINC 825; LVDS - ANSI/TIA/EIA-644-1995.