

Standardization of CAN networks for airborne use through ARINC 825

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The demands on the availability of data in the cabin and cockpit have been increasing in recent years. Right there is the application of new field bus systems. These must be suitable for the harsh environment in aircraft and therefore shown to be sufficiently robust. In the area of network based aircraft systems, the CAN-bus has emerged as a future technology. Through standardization, industrialization of that technology is now ahead for the aviation industry. In the Technical Working Group ARINC 825, industry partners of the aircraft industry, led by the two largest aircraft manufacturers Airbus and Boeing, developed a standard that will change the interconnection of systems in aircraft further. The standard describes guidelines and "best practice" to be observed by the system developers and the aircraft manufacturer for seamless integration into the aircraft and smooth interaction of the equipment.

1. Architecture of airborne systems

Conventional system architectures were based on electronic units, making use of dedicated connections and interface types.

Today's technology provides well-designed network standards which fulfill the data integrity and performance requirements of flight safety critical systems at reasonable effort. The use of these low-cost avionics networks enables the creation of state-of-the-art systems for commercial aircraft.

These network based systems offer a significant weight reduction, lower development cost and substantial procurement and maintenance savings compared to traditional avionics system architectures. This is mainly achieved by use of an avionics network backbone which serves as a shared resource for the communication between modules. The use of a network significantly reduces wiring (Figure 1), allows

standardization of the network interface and relieves the application developers from spending excessive amounts of time on developing interfaces to other modules. Network based systems provide a unified network hardware/software interface which is used for all Line Replaceable Units (LRU) regardless of their specific task and level of functional centralization or decentralization. Taking advantage of standardized hardware/software components, upgrades and changes are both easier and less expensive to accomplish. Development and maintenance of modules is therefore easier than with previous specific architectures, resulting in direct cost savings.

By its nature, a network based system also supports functional centralization and decentralization. Several functions can be combined in one LRU, sharing the internal hardware resources and reducing the overall unit count. Alternatively, a single complex function may be spread between several LRUs communi-

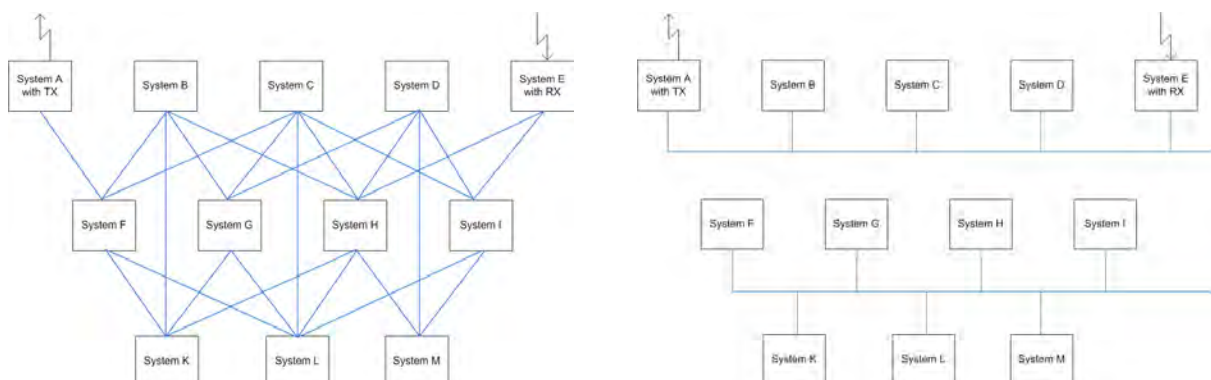


Figure 1: Conventional system architecture compared to network based system architecture

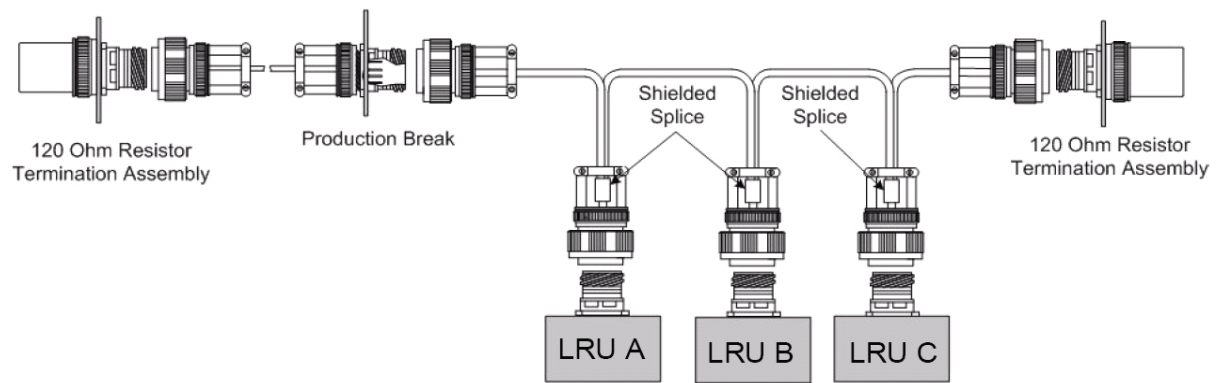


Figure 2: Typical CAN installation in aircraft

cating with each other. With new aircraft having more software-based functions, and computers becoming more powerful, adding new features or functions during the aircraft life cycle can be accomplished more easily. The flexibility of network based avionics also permits functions to be reconfigured on other modules, if the module that supported them is detected as being faulty, increasing the overall availability of the on board avionics. To support fault detection and isolation, dedicated network communication layer allows the control of built-in test functions and collection of the corresponding results for continuous integrity monitoring.

Another important aspect for avionic systems is interoperability. Equipment and systems exchange information and automatically interpret it meaningfully and accurately in order to produce useful results as specified. The effort to ensure interoperability increases with the number of interfaces necessary to exchange the information. For traditional avionics system architectures, interoperability has always been a challenge and often difficult to achieve. In network based systems, the number of interfaces may be substantially reduced by choosing the appropriate system architecture. Interoperability there is ensured by means of a network hardware interface specification and a common information exchange reference model covering standardized data formats and sign conventions.

2. Controller Area Network (CAN)

A candidate for a network that combines adequate functionality and low cost due to high production volumes is the Controller Area Network (CAN), developed by Bosch as an automotive data bus in 1983 [1].

CAN offers significant advantages for reliable data communication in mission and safety critical applications making it attractive for aviation.

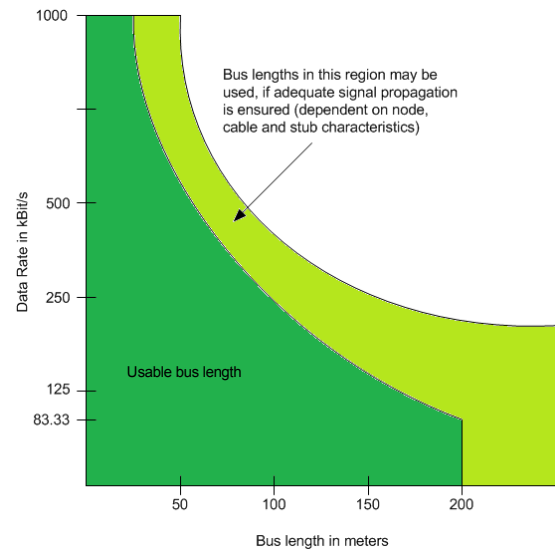


Figure 3: CAN data rate versus bus length

The following paragraphs describe the most prominent attributes of CAN, which were made part of ARINC 825 to meet the needs of aviation industry.

Installation of CAN in aircraft is easy and robust, which distinguishes it from other networks. Various bus interconnection methods like daisy-chaining or bundle splice are possible if properly done (see Figure 2). CAN may be used with shielded or unshielded cables and with a variety of connectors, including affordable Sub-D types.

With respect to the electrical properties of CAN, the data rate is a function of the network length as shown in Figure 3. For shorter bus lengths, the maximum data rate of 1Mbit/s can be used. The $\pm 2.5V$ differential transmission ensures a high common mode rejection and a high level of electromagnetic immunity (EMI).

The number of nodes that may be attached to a CAN network segment depends on the minimum load resistance a CAN bus transceiver is able to drive.

In aviation, the long life cycle and specific operating environment of avionics systems has to be considered. To ensure adequate performance margin over the design life cycle, a certain amount of “capability de-rating” is usually applied. Table 1 represents successful systems experience based on the typical aircraft operating environment.

CAN Data Rate (kBit/s)	Number of CAN Nodes (Typical Maximum)
1000	30
500	35
250	40
125	50
83.33	60

Table 1: Relation of maximum number of CAN nodes and data rate

CAN is a broadcast bus using an object-oriented approach for data transmission. CAN data frames (see Figure 4) have a payload size between zero and eight bytes and are preceded by a CAN Identifier. This CAN identifier serves a dual purpose:

First, it determines the priority of the data frame transmitted by the identifier, where the identifier with the lowest numerical value receives the highest priority. The priority has a direct impact on the order of transmitted messages, in case where several modules are attempting to transmit on the bus at the same time.

Second, the CAN identifier uniquely identifies the data frame so the data payload can be processed correctly in the receiving nodes. CAN supports two versions of identifiers with different lengths (11 bit and 29 bit), referred to as

“standard” and “extended” identifiers. Both types may coexist on the same bus and do not interfere with each other (ARINC 825 exclusively uses the 29 bit identifier because of the bigger address space).

CAN uses a sophisticated error detection and handling protocol, consisting of a 15-bit Cyclic Redundancy Check (CRC), frame structure, data acknowledge checking and bus signal monitoring. Any node on the network which detects an error during data transmission or reception immediately sends an error flag. This error flag destroys the current (faulty) message and causes the transmitting station to abort the transmission. All nodes then disregard the current message and check to see if they were the cause of the error.

A node that identifies itself as the cause of the error increments an internal error counter; A node who’s internal error counter has exceeded the limit withdraws from the bus and does not participate in further bus activities until re-attached by software. These measures minimize the risk for a single node taking down the entire bus. The CAN error detection and handling mechanisms provide an extremely low probability of undetected CAN bus data corruption ($\sim 4,7 \cdot 10^{-11}$ per message transmission according to Bosch literature).

3. The ARINC 825 Standard

With an increasing number of CAN networks in avionics, a standard interface was required to foster interoperability and reusability of modules and systems. The ARINC 825 Technical Working Group developed an industry standard that will change the interconnection of systems in aircraft further [2]. The first ARINC 825 specification was published in November 2007. Supplement 2 was published in May 2011.

The standard describes the necessary precautions to be observed by the developers of the

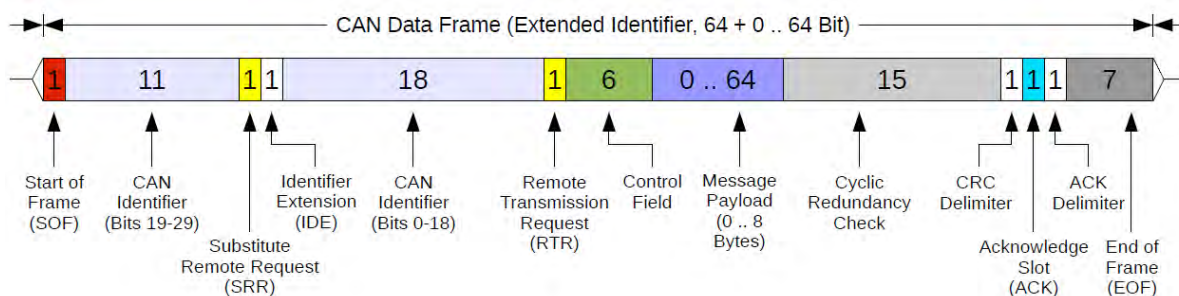


Figure 4: CAN data frame structure

system as well as by the aircraft manufacturer for the integration into the aircraft. In addition, the ARINC 825 standard describes in many places "best practice" that simplifies the smooth interaction of equipment.

Further ARINC specifications are based completely on ARINC 825 or use significant parts, like ARINC 826 (software dataload) and ARINC 812 (Galley Insert Communication).

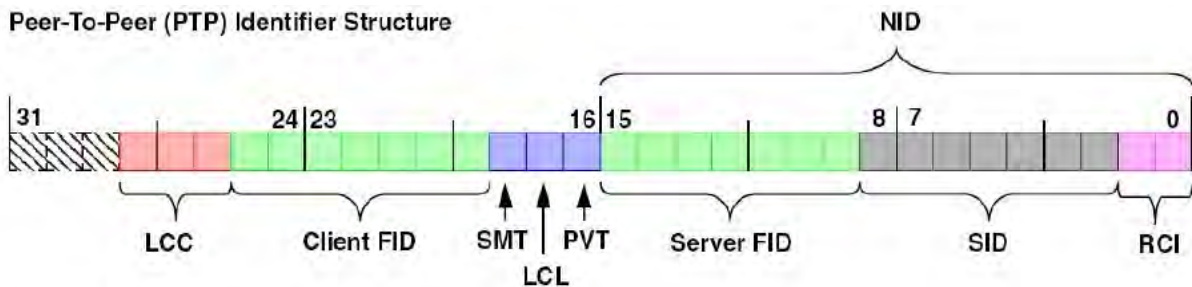
Flight safety or mission critical systems are required to demonstrate predictability under all conditions. ARINC 825 therefore has the following features:

- **Democratic Network:** No master/slave relationship is required for normal operation. Every node on the bus has the same rights for participation in the bus traffic.
- **Identifier Assignment:** ARINC 825 offers an identifier structure which accommodates predefined Logical Communication Channels (LCC), Function Identifiers (FID), Data Object Codes (DOC) and other fields for node addressing and data flow control
- **Emergency Event Signaling Mechanism:** Information about failures detected by built-in-test functions is transmitted by the affected node.

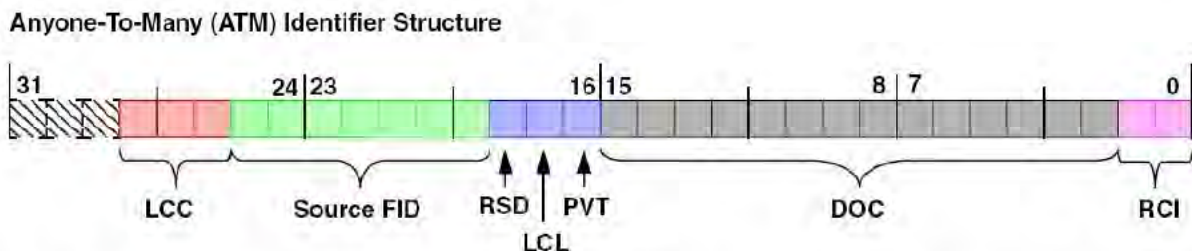
- **Node Service Mechanism:** Addressing of specific nodes for integrity monitoring, data download, time synchronization or interrogation using connection-oriented and connectionless services is supported.
- **Openness to Extensions:** All definitions are extendable to provide flexibility for future enhancements and requirements of specific applications.
- **Free Availability:** No royalties apply for use of ARINC 825

CAN is a multi-drop network using broadcast communication, also referred to as anyone-to-many (ATM). The advantage of ATM communication is that it creates inherent data consistency between all nodes in the network as they all participate to the network health. Both periodic and aperiodic data transmission during normal operation is possible. The shortcoming of CAN is that there is no inherent peer-to-peer (PTP) communication mechanism which means that CAN nodes cannot be addressed individually without further protocol enhancements. ARINC 825 provides these enhancements.

Peer-To-Peer (PTP) Identifier Structure



Anyone-To-Many (ATM) Identifier Structure



Field	Description
LCC	Logical Communication Channel
FID	Aircraft Function ID
RSD	Reserved
SMT	Service Message Type
LCL	Local Bus Only

Field	Description
PVT	Private Data
SID	Server ID
RCI	Redundancy Channel ID
NID	Node ID
DOC	Data Object Code

Figure 5: PTP and ATM Identifier structure

Channel Number	Channel Acronym	Communication Type	Description	LCC Bits	Message Priority
0	EEC	ATM	Exception Event Channel	000	Highest
1			Reserved	001	↓
2	NOC	ATM	Normal Operation Channel	010	
3			Reserved	011	
4	NSC	PTP	Node Service Channel	100	
5	UDC	ATM/PTP	User-defined Channel	101	
6	TMC	PTP	Test and Maintenance Channel	110	
7	FMC	ATM/PTP	CAN Base Frame Migration Channel	111	

Table 2: Logical communication channels

ATM communication avoids overhead and makes effective use of available bandwidth. Nevertheless, to relieve receiving nodes from the task of processing data that they do not need, hardware acceptance filtering within the CAN controller may be used to block incoming messages not referenced by the affected node from being passed upward into layers implemented in software, thereby saving precious CPU time.

PTP communication allows client/server type interactions between all nodes in the network and is necessary to request certain actions from a specific node. The idea behind this concept is that any node in the network may be a client for one task and a server for another task at the same time. By this concept, functions may be distributed over the network, unleashing the real power of distributed systems. PTP communication distinguishes between connectionless (no response transmitted) and connection-oriented (handshake type) communication, similar to UDP/IP and TCP/IP with Ethernet.

Using both ATM and PTP communications at the same time requires multiple network layers supporting different functions while isolating them from each other. In order to provide these multiple network layers, the three most significant bits of the extended (29 Bit) CAN identifier are used to specify the ARINC 825 Logical Communication Channels (LCC) (Figure 5).

By utilizing user-defined LCCs, the system designer is given a high level of freedom to make use of the network according to the designer’s needs (Table 2).

The CAN identifier bit range assigned to LCCs has an impact on message prioritization and bus arbitration. Consequently, the communication channels are prioritized according to their importance.

A predefined identifier distribution list makes sure that all aircraft functions are tagged unambiguously.

The standard calls these predefined parameters Function Identifier (FID) as in Table 3.

FID	Function
0	Multicast Function Code
1	Reserved for Future Growth
4	Flight State
5	Reserved for System Integrator
10	Flight Controls
17	Fire Protection
.....
...	...
102	Central Maintenance System
103	Cargo and Accessory Compartments
...	...
123	Galley Inserts (ARINC 812)
124	Reserved for Future Growth
125	Periodic Health Status Message (PHSM)
126	Reserved for ARINC 826 Target
127	Temporary Test & Maintenance

Table 3: Function Code List

Equipment Type Descriptions can be found in Air Transport Association Specification 2200 “Information Standards for Aviation Maintenance Specification” (so-called ATA chapters).

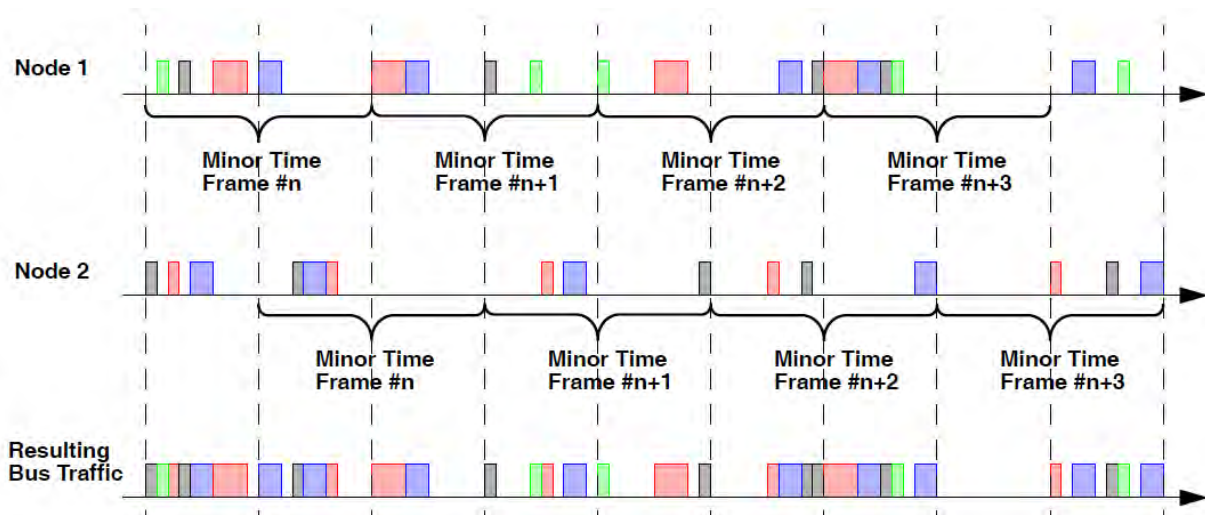


Figure 6: Predictable bus traffic at 50% bus load based on time triggered bus scheduling

ARINC 825 ensures interoperability through well-defined data formats and sign conventions known to all nodes in the network in order to interpret received data correctly and transmit properly calculated and formatted data. Consequently, the ARINC 825 standard defines data types, sign conventions and engineering units. The data formats are predefined in a Unit Type List.

The complete set of parameters, which was defined application specific by the system designer is summarized in a so called "Profile".

As the majority of the embedded systems use processors with Big Endian CPU architectures, ARINC 825 uses Big Endian representation exclusively. According to the Big Endian definition, the most significant bit (MSB) of any datum is arranged leftmost and transmitted first.

An essential characteristic of all systems critical to flight safety is that their behavior can be precisely defined, analyzed and tested to meet formal certification requirements. This characteristic is often misinterpreted as microsecond-level timing "determinism" but is in fact predictability. The degree of precision required for timing is specific to each application and has to be quantified by system analysis. The ultimate target to be reached, however, is that it can be demonstrated to certification authorities that a safety critical system based on ARINC 825 behaves predictably under all circumstances. Nodes transmitting high priority messages at a high rate can potentially consume an excessive amount of bandwidth, block out other nodes too often and cause unpredictable transmission delays. Such a scenario would also generate substantial jitter in the data transmission and must be entirely avoided. A suitable bandwidth management concept on the system level is therefore always necessary to ensure that the bus load is within certain limits and evenly balanced over time.

Using ARINC 825, the required predictability can be achieved. ARINC 825 sets forth a concept of managing the available bandwidth for one-to-many and peer-to-peer communication called "time triggered bus scheduling". This concept is based on a limitation on the number of CAN messages that any node in the network may transmit within a "minor time frame" so that no single message is delayed beyond a tolerable limit.

The minor time frame is defined during the initial system design. The maximum number of

messages transmitted within one minor time frame may differ from node to node and contain growth potential if granted by system design. The concept takes advantage of the fact that not all messages in a given system have to be transmitted at the rate defined by the minor time frame interval. Specifying multiples of the minor time frame transmission interval and associated "transmission slots" accommodates a substantially larger number of parameters to be transmitted in time.

Transmission Slot Group	Transmission Interval	Maximum Number of Parameters per Transmission Slot	Number of Transmission Slots (equalling 100% bus load)
A	15ms (66.6Hz)	1	100
B	30ms (33.3Hz)	2	200
C	60ms (16.6Hz)	4	400
D	120ms (8.3Hz)	8	800
E	240ms (4.2Hz)	16	1600
F	480ms (2.1Hz)	32	3200
G	1000ms (1.0Hz)	66.6	6666

Table 4: Relation of multiples of minor time frames and transmission slots

The corresponding relationship, based on a typical ARINC 825 network with 1Mbit/s data rate and standard CAN identifiers is shown in Table 4. If all ARINC 825 messages in the network use the maximum payload of 8 bytes (worst-case assumption), the length of each message is 64bits + 64bits = 128bits. To compute the maximum bus capacity, the inter frame space (3bits) and an average number of 19 stuff bits must be added, resulting in a total data frame length of 128bits + 3bits + 19bits = 150bits (see also Figure 4). At 1Mbit/s data rate, such a message takes 150µs to transmit. The bus capacity for this example is therefore 6.666 messages per second which means that either 100 parameters transmitted every 15ms or 6.666 parameters transmitted once a second would generate 100% bus load. In reality, a combination of parameters in the various transmission slot groups from Table 4 will be used.

Every node in the network must adhere to its transmission schedule at all times when generating network traffic. However it is neither required nor prohibited that nodes in the network synchronize to other nodes concerning their message transmission order or transmission times. The time triggered bus scheduling

concept is one method to make ARINC 825 networks behave predictable.

Error situations may lead to non-predictable behavior if the bandwidth is consumed by error frames resulting from faults of the network or the nodes attached to it. Therefore, it is recommended to limit the bandwidth usage to 50% of the maximum bandwidth limiting the potential for unpredictability. While the time triggered bus scheduling concept requires margins and does not optimize network bandwidth usage, it provides a safe and straightforward approach to build certifiable (predictable) systems. Figure 6 shows the transmission schedule example of an ARINC 825 network with two nodes transmitting their messages asynchronously, in alternating order and at random times within their minor time frames (worst case scenario). This example utilizes 50% of the maximum bandwidth.

4. Timing Model

The ARINC 825 standard introduces a timing model underlining its importance for busload considerations by the system designer. Tools applying such model were still under development while ARINC 825 was written. The available tools did not reflect the required limiting factors. Future investigations are necessary in order to ease the design process.

5. Application Example: Smoke Detection System

The system architecture of the Airbus A318 Smoke Detection System differed significantly from former developments. Airbus selected CAN as system bus (Figure 7).

The concept later was reused and adapted for the Airbus A380 [3]. The design-principles of airborne systems using CAN were elaborated at that time, i.e. the electrical harness was designed respecting the known limits of signal propagation in the aircraft environment (see Figures 2 and 3).

The communication protocol was defined including the principles of message prioritization and parameter oriented data exchange.

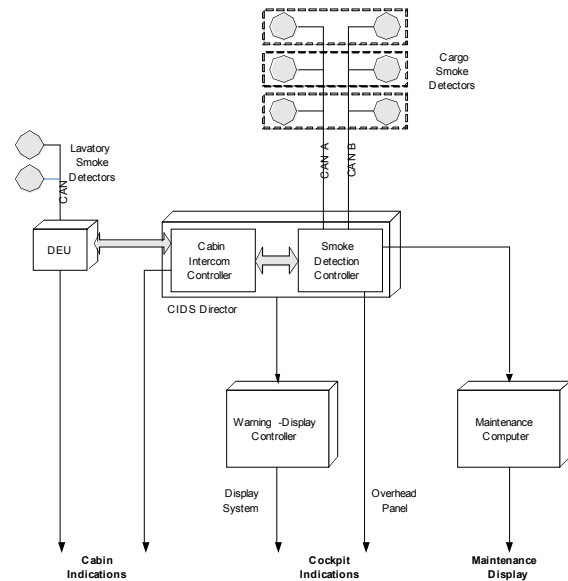


Figure 7: Smoke Detection System using an open standard CAN bus to interface detectors

The system prove its robustness during lab tests and through in-service-experience with several thousand flight hours.

The experience gained during this development was valuable for system development on the Airbus A350 and was also used as input for the ARINC 825 standard.

6. Conclusion

Driven by the large aircraft manufacturers, reliable avionics networks like CAN are widely used on all new commercial airliners today. A fast growing number of business and commuter airplanes also make use of this technology.

CAN has proven to be robust enough for the harsh environment in aircraft.

Industrialization of systems based on avionics networks is fostered by the ARINC 825 standard. Using this standard, designers can specify open systems that can easily be monitored, repaired, or augmented unlike proprietary systems linked to a single manufacturer. Together with the fast evolving computer technology, this enables definition of new architectures for avionic systems.

Application of ARINC 825 reduces wiring and connection panel complexity and thereby offers significant weight and cost benefits.

Manufacturers can use the ARINC 825 to leverage third party sensors and actuators into their own system using standard ARINC 825 identifiers.

Modern commercial airliners use CAN extensively for numerous systems of all criticality levels. The combination of CAN and the ARINC 825 standard provides a network for mission and safety critical applications in aviation.

7. References

- [1] ISO11898 AMENDMENT 1 “Road vehicles – Interchange of digital information-Controller are network (CAN) for high-speed communication”
- [2] ARINC 825 Specification
- [3] Schmid, C.: SID 2616DD100 “ATA26 CAN Application Layer Protocol”, Issue 2.
- [4] Knüppel, R.; Schmid, C.; “Smoke Detectors interfaced by a safety critical aircraft based CAN-Bus Network”, 11th iCC, Stockholm
- [5] Stock, M.: Stock Flight Systems. CANaerospace, 2006
- [6] Stock, M.: ARINC Specification 825 - The General Standardization of CAN for Airborne Use, CAN Newsletter 12/2009.

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