DATA BUS

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Version 1.0.a

Introduction

Data bus are standardized communication channels through which information is exchanged.

Based on the direction of the information flow they are classified into:

- *Simplex*: one-way channel
- *Half-duplex*: channel with multidirectional but not simultaneous transmission
- *Full-duplex*: channel with simultaneous but only bidirectional transmission

Network topology

A network is made up of a set of terminals, the avionics equipments, and of connections that unite them, the wiring.

The connections can be physical or logical.

Network architectures are divided into:

- *Point-point*: where communication can only take place between physically connected nodes.Therefore there is an increase in the weight and in the volume of the wiring as the number of nodes grows.
- *Multipoint*: it consists of a single transmission line, the bus, shared by several nodes. The number of interconnections and the network weight decrease while the nodes complexity grows.

Bus efficiency

For an efficient use of the transmission line there is the need for:

- Control strategy
- Allocation techniques
- Access techniques

The bus capacity coincides with the bandwidth if the signal is analog, with the number of bits per second if it's digital.

Typical capacities of aeronautical buses are included between 12.5 Kbit/sec and 100 Mbit/sec (on copper). Higher speeds are only achievable with optical fiber.

Allocation techniques: multiplexing

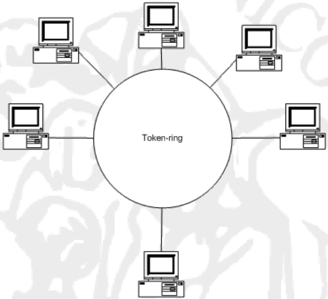
Three allocation techniques can be distinguished:

- *Frequency Division Multiplexing*: the line bandwidth is divided into many channels. In this way it's possible to transmit several signals simultaneously on the same mean.
- *Time Division Multiplexing*: each node has been assigned with a precise time interval within which it can transmit, exploiting the full bus capacity.
- *Code Division Multiplexing*: everyone transmits simultaneously, at the same frequency, continuously, but not disturbing the others thanks to different PNR codes. It's used by Global Positioning System (GPS).

Access techniques

Access techniques are methods through which nodes are allowed to use the bus, such as:

- *Polling*: a node, called master, queries the others asking if they want to transmit. The bus access order can change, depending on the importance of the message.
- *Token Passing*: it's typical of ring networks. Each node receives the Token, the right to use the bus, in turn and in an arranged order.



These two techniques avoid collisions, in fact they are called non-contentious, but with a reduction in the network efficiency.

Access techniques

There are also contentious techniques, that exploit collisions as a mean for bus management. One of those is the *Carrier Sense Multiple Access with Collision Detection (CSMA-CD)*.

Carrier Sense means the nodes are able to sense that the bus is already busy and therefore not to transmit.

Collision Detection instead, means the nodes are capable to detect the collision between messages, due to a very high energy level on the bus.

Access techniques: deterministic or stochastic?

Non-contentious techniques satisfy a fundamental requirement for air communications: the determinism of the transmission. There is the certainty that each node is able to transmit and update its data within a maximum time.

In the CSMA-CD technique instead, there isn't a prearranged transmission order, nor the guarantee of a maximum waiting time after which it's possible to retransmit. This is called stochastic approach and it's unacceptable on on-board buses.

Error minimization

Common strategies used so that the number of errors per bits transmitted is sufficiently low, are:

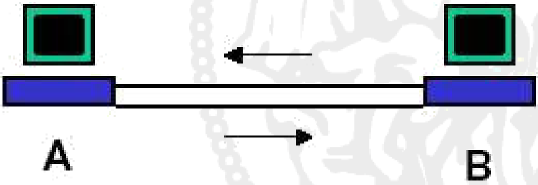
- Differential coding
- Cable shielding
- Parity check
- Twisted pair

For reliability reasons each connection must also be doubled.

Differential coding

It is a feature that all data buses and all cable transmission systems have in common (Ethernet,Universal Serial Bus (USB),High Definition Multimedia Interface (HDMI)).

Differential coding is essential because it removes common mode disturbances from the line, such as electromagnetic interferences.



ARINC-429

Introduction and historical notes

Aeronautical Radio Inc. (ARINC) is one of the main used data buses in civil aviation, conceived by *Airlines Electronic Engineering Committee (AEEC)*, in order to find a shareable language of communication.

In years, more versions of *ARINC* have been created. Among them, some of the most relevant are:

- *ARINC 419*
- *ARINC 429*
- *ARINC 629*

ARINC 429's official name is *Mark 33 Digital Information Transfer System*. It was published in 1977 and became one of the most widespread, even nowadays.

Structure

ARINC 429 adopts a simplex open loop model for data transmission, which includes:

- *Source* Line Replaceable Unit (LRU)
- *Sink* LRUs

This type of model gives the system the name of *shout* or *broadcast bus*.

Information exchange

In *ARINC 429*, the same data are continuously transferred at a chosen time distance between two consecutive transmissions.

That is advantageous: if some information goes lost, the same data will be given by the following transmission.

Odd parity indication is used to detect eventual errors.

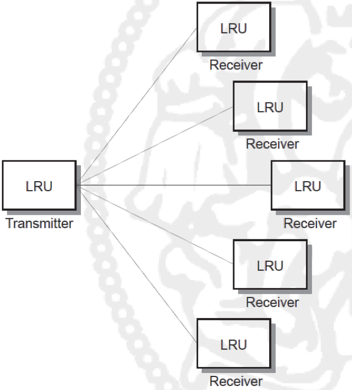
Information exchange

In each *ARINC 429* bus:

- There is a single transmitter and up to 20 receivers
- Data can travel at low speed (12.5-14.5 kHz) or high speed (100 kHz)
- Information can be sent in one direction only
- LRUs are not marked by addresses

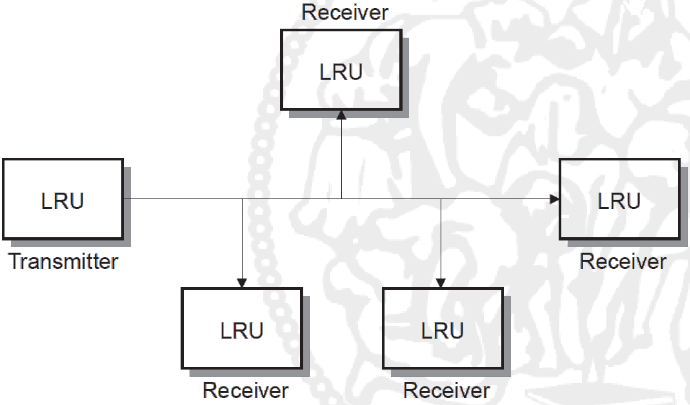
Star topology

- Advantage: in case of failure information loss is contained
- Critical aspect: large number of wires

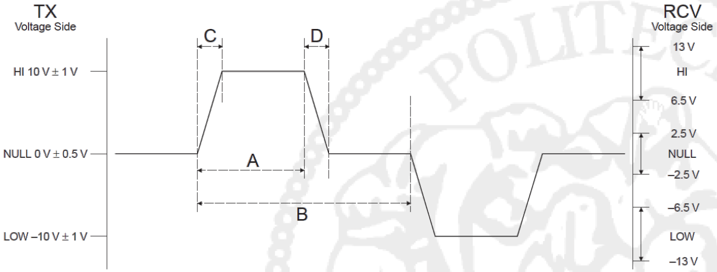


Drop topology

- Advantage: shorter line connection
- Critical aspect: more loss of information in case of failure



Waveform



- Impulses can be transmitted at 3 different levels: *hi*, *null*, *low*.
- B represents the bit time, characterized by an impulse in its first half and a null level in the second one. This transmission technique is called *return to zero*.

Differential coding in ARINC

In *ARINC 429* differential coding is used to eliminate disturbances effects.

What happens is that:

- Strong disturbances can make the receiver detect the signal in a different level with respect to the original one
- Two wires A and B are used and differential coding rule is imposed
- Signals are sent to the wires and the receiver computes their difference
- If the disturbance distributes equally on the two wires, its effects are eliminated

Example of differential coding in ARINC

The transmitter imposes a hi level signal (10V) and the presence of a magnetic disturbance induces a -20V tension. The receiver then will detect a low level (-10V).

Two wires are used:

- Wire A: hi signal at +5V, low signal at -5V
- Wire B: hi signal at -5V, low signal at +5V

The measures of tensions will be (5-20)V = -15V for wire A and (-5-20)V = -25V for wire B. The receiver will execute the operation A-B and a signal of (-15+25)V = 10V will be then obtained. In this way the disturbances effects are eliminated.

Word

P	SSM		Most Significant Data									DATA - 19 bits					Least Significant Data					SDI		8-Bit Octal Label							
32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
MSB															32-Bit ARINC 429 Word																LSB

The transmitted information is a sequence of 32 bits, called *Word*. During transmission, different words are separated by a 4 bits distance.

The bits are organized to divide a single word into 5 parts:

- Label (first 8 bits), to identify the payload
- Source Destination Identification (SDI)
- Data
- Sign/Status Matrix (SSM)
- Parity odd (last bit), for the integrity check

Equipment ID

The *Equipment ID*:

- Is an additional way to identify the payload
- Is a code, used to overcome label's limitation
- Is known a priori (not transmitted), once the transmitting source is known
- Works together with the label to uniquely identify the payload

SDI and SSM

SDI is used if more identical implants are installed. Its functions are:

- To identify the source
- To direct the information to the determined sink

The function of SSM is to report:

- Hardware equipment condition (fault/normal)
- Operational mode (functional test)
- Word's content validity (verified/not computed)

Indication of invalid data can compare and it includes two categories: no computed data and failure warning.

Data integrity and Error containment

In data buses it is very important to guarantee data integrity. In order to do that and to make sure the error is sufficiently small, *ARINC 429* uses:

- Shielded cables
- Differential coding
- Twisted pair
- Parity check

MIL-STD-1553B

Introduction and historical notes

MIL-STD-1553 is a military standard published by the United States Department of Defense (DoD) that defines the mechanical, electrical and functional characteristics of a serial data bus.

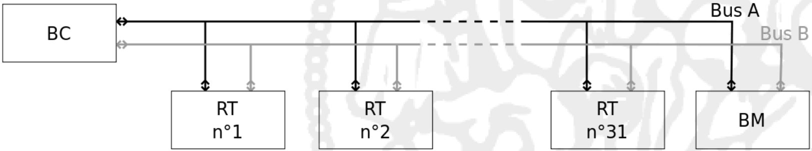
MIL-STD-1553 was first published as a U.S. Air Force standard in 1973, and first was used on the F-16 Falcon fighter aircraft. *MIL-STD-1553B*, which superseded the earlier 1975 specification MIL-STD-1553A, was published in 1978. MIL-STD-1553C is the last revision made in February 2018.

The purpose of the standard is to define the requirements for a digital command response time division multiplexing data bus.

System architecture

There are three types of equipment connected to the bus:

- *Bus Controller (BC)*, to initiate all message communication over the bus
- *Remote Terminal (RT)*, to provide an interface between the data bus and an attached subsystem
- *Bus Monitor (BM)*, to monitor and record bus transactions

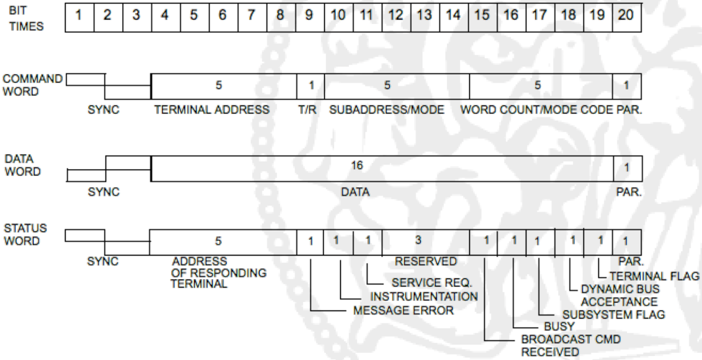


The standard defines the presence of two buses (A and B) to ensure redundancy, but only one bus is active at any time.

Messages transmitted

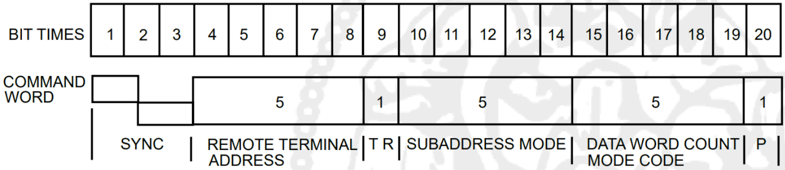
Messages consist of one or more 16-bit words, to which the sync waveform and parity bit are added, for a total of 20 bit.

Three types of word formats were selected to operate the information transfer system.



Command word

The *Command Word* format is used to control and manage the information transfer system.



Two basic additions were made to the command word by 1553B: these include the broadcast mode and the identification of the optional mode codes.

Data word

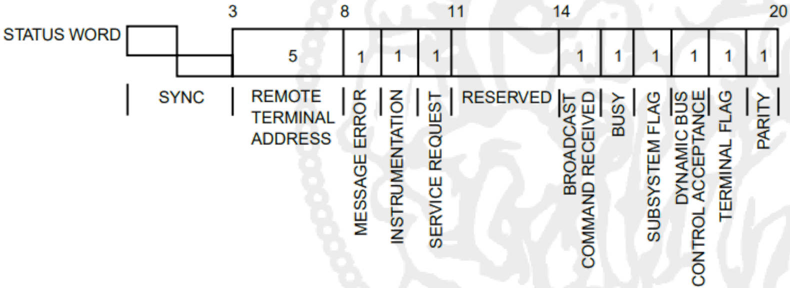
Data Words are used to transmit parameter data, which is the goal of the information transfer system.

Data words are distinguished from command and status words by the inverted three bit sync pattern.

Status word

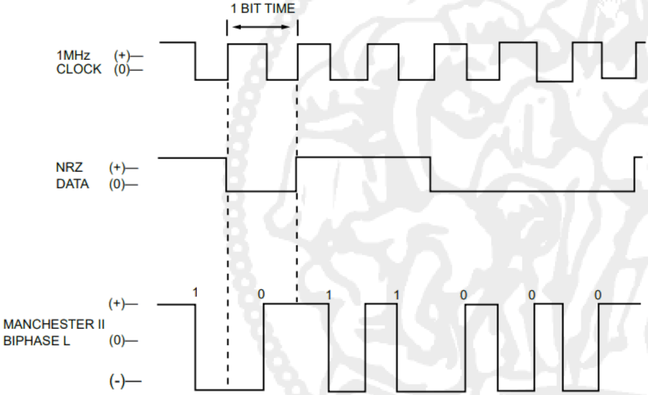
The *Status Word* is divided into the following fields:

- Sync
- Terminal address
- Status field
- Parity (P)



Bit coding

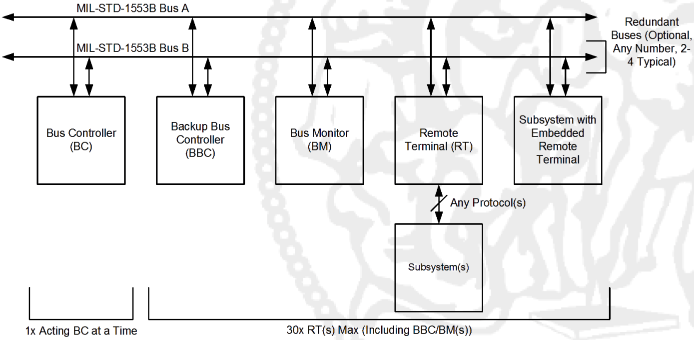
The signal shall be transferred over the data bus in serial digital pulse code modulation form. The data code shall be *Manchester II biphase level*.



Management of anomalies

In addition to the parity bit, other systems are used to ensure redundancy and management of malfunctions:

- *Redundant Buses*
- *Backup Bus Controller*
- *Bus Monitor*



AFDX

AFDX/ARINC 664

Avionics Full Duplex Switched Ethernet (AFDX)

Background

Introduced by Airbus with the A-380 program, its aim was to overcome the limits of previous data buses generations.

It's getting more and more common because of its versatility and is nowadays the standard for new airliners.

Features

The features of AFDX data bus are the following:

- It's based on commercial Ethernet with provisions
- Full-duplex technology
- It works at 100 Mbit/sec (with 10 Mbit/sec provision)
- Supports both copper and fiber optic
- 3 types of network elements: end systems, switches, links

Why Ethernet?

It was based on Ethernet technology because it grants:

- World wide experience coming from consumer electronics
- High reliability
- Possibility to manage a very high number of LRUs preserving performance
- No need for a node controller

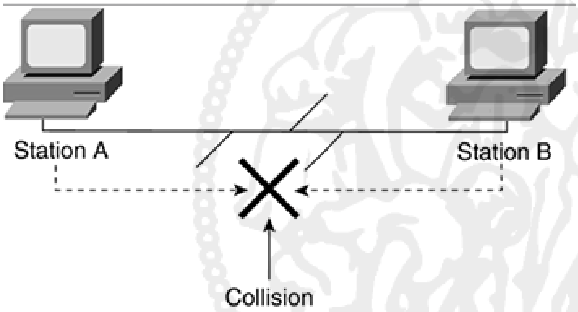
Why AFDX and not standard Ethernet?

The original Ethernet protocol cannot be used in aerospace because of the following issues:

- *LACK OF DETERMINISTIC TIMING*: there is no way in Ethernet to determine a maximum time in which we have the certainty that a communication has been completed
- *LACK OF REDUNDANCY*: Ethernet protocol does not take into account the possibility to have multiple links for the same communication

Lack of deterministic timing in Ethernet: CSMA-CD

CSMA-CD is a protocol (implemented in Ethernet) meant to solve transmission conflicts in networks without a node controller.



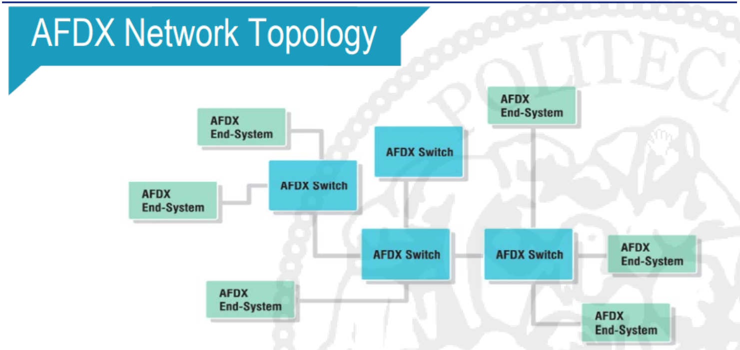
Lack of deterministic timing in Ethernet: CSMA-CD

CSMA-CD implements the following features:

- Each node can transmit when is needed;
- A carrier sense analysis is carried out before starting the transmission: if no other node is transmitting the communication begins. Otherwise, if the band is already occupied, a randomic timer starts and a new carrier sense analysis is performed: this loop continues until the node is allowed to transmit.

This protocol is not compatible with aerospace needs: the randomic timer system does not grant determinism in time. Since it's potentially catastrophic during flight, a different solution is needed.

AFDX Network Topology



There are two types of elements:

- *End System*: device whose applications access the network components to send or receive data from the network;
- *Switch*: device which performs traffic policing and filtering, and forwards packets towards their destination End-Systems.

AFDX Network topology: features

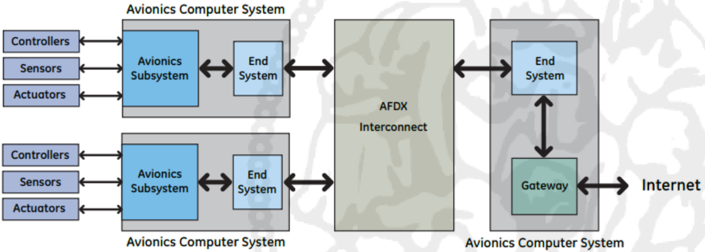
AFDX networks are characterized by the following features:

- each cable is connected to two devices only;
- each end system is directly connected to a switch;
- switches are connected to each other;
- both cables and switches are made redundant, in order to not compromise transmission of data when one single element of the network fails.

In particular, switches memorize messages sent by end-systems, classify them in order of priority and enroute these same consequently (highest priority messages are the first to be sent).

AFDX Network

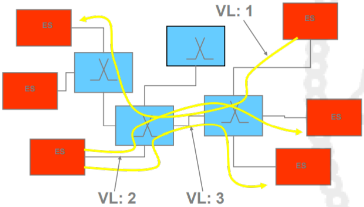
This structure grants both determinism and redundancy.

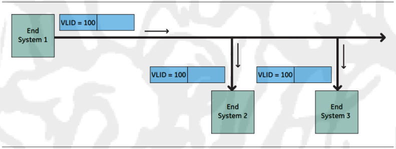


Virtual link

End Systems are not directly connected with each other but are separated by switches: as a consequence, End Systems have to exchange frames through *Virtual Links (VLs)*.

Each Virtual Link (VL) defines a unidirectional connection from one source End System to one or more destination End Systems.





Virtual link

Virtual link is not a physical connection, but a logic one. This kind of communication is made possible by switches, that guide messages from source to destination.

AFDX networks can handle 2^{16} (65536) different VLs, while each End System 128.

End Systems perform Traffic shaping and Integrity Checking on each VL.

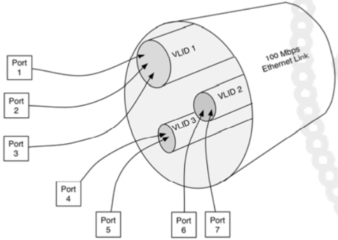
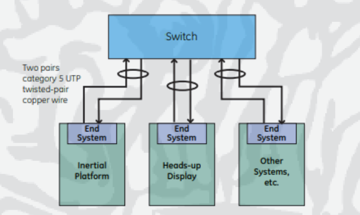
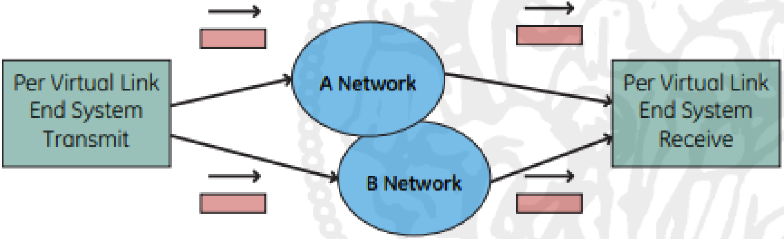


Figure 19. Three Virtual Links Carried by a Physical Link



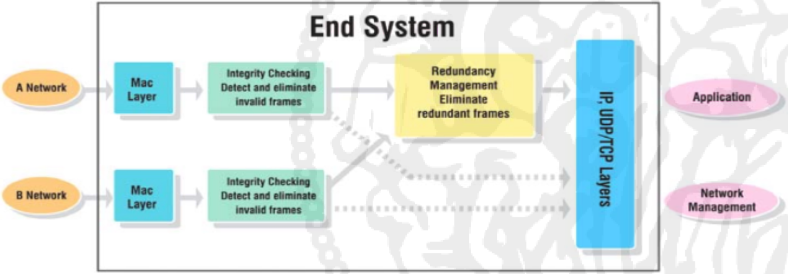
Redundancy management

- Ports, Links and Switches are duplicated for redundancy;
- Frames are concurrently transmitted over both networks;
- The Receiving End System uses the first frame to come;



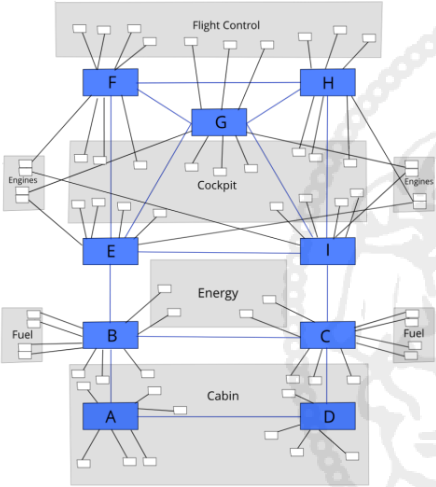
Integrity checking

- Integrity checking is done per VL and per Network (both physical and logical check);
- Checking is based on Sequence Number and Maximum Consecutive Frame Lost (MFCL);
- All Invalid Frames are discarded;



Integrity Checking and Redundancy

Example: Airbus A-380



- Two independent AFDX Networks;
- 9 switches for each network;
- Several rings (including the one using all 9 switches);
- Within the rings, it is possible to form cyclic dependencies;
- End Systems inside a cluster are always at most 2 switches from each other;

Credit where credit is due

The present material has been prepared as part of the contribution to the *Flipped Class-innovative didactic* initiative during academic year 2021/2022 by the following students:

- Marco Cicalini
- Davide Foroni
- Anna Riva
- Samuela Scurati

List of Acronyms

AEEC	Airlines Electronic Engineering Committee
AFDX	Avionics Full Duplex Switched Ethernet
ARINC	Aeronautical Radio Inc.
BC	Bus Controller
BM	Bus Monitor
CSMA-CD	Carrier Sense Multiple Access with Collision Detection
DoD	Department of Defense
GPS	Global Positioning System
HDMI	High Definition Multimedia Interface
LRU	Line Replaceable Unit
MFCL	Maximum Consecutive Frame Lost
RT	Remote Terminal
SDI	Source Destination Identification
SSM	Sign/Status Matrix
USB	Universal Serial Bus
VL	Virtual Link