Avionics Primer for ~~Hackers~~

Security Researchers

Nicholas Childs

Avionics Primer for ~~Hackers~~ Security Researchers

Nicholas Childs TSgt, USAF

B-1 Weapon Systems Controller

Bomber/Special Integrated Communication/Navigation/Mission Systems Craftsman
OAS?

github.com/boxswapper
Twitter/Instagram @Boxswapper
Email boxswappers@gmail.com

Avionics Primer for ~~Hackers~~ Security Researchers

Why?

Things are broken, Avionics bus systems were designed for use not for security, Like most legacy systems, the addition of new technologies has introduced vulnerabilities.

I need your help..or

WE'RE ALL GONNA DIE!!!

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Viewers Like you…

Mariah Kenny @_mi5t_

MetaCTF Dungeon Master, TCAS hobbyist

Chris Kubecka @SecEvangelism

APPSec CA “More than Turbulance” https://www.youtube.com/watch?v=l2sv7jiUY7E

Olivia Stella @OliviaCurls

Airplane Mode Cybersecurity @ 30K Ft https://oliviastella.com/

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```
C:\Users\1256369778>whoami
- 18 years experience in communication navigation systems
- Aeronautical Engineering Degree
- Mechanical repair and servicing experience with 737, L10-11, DC-10, 747
-Proficient with multiple airframe avionics systems; C-17,C-5,C-141,KC-
135,B-1
- 5 years experience Active Directory Administrator on DoD network
- Multiple cybersecurity certifications (all expired) ☹
- FCC Radiotelephone Operator License with Radar Endorsement
```

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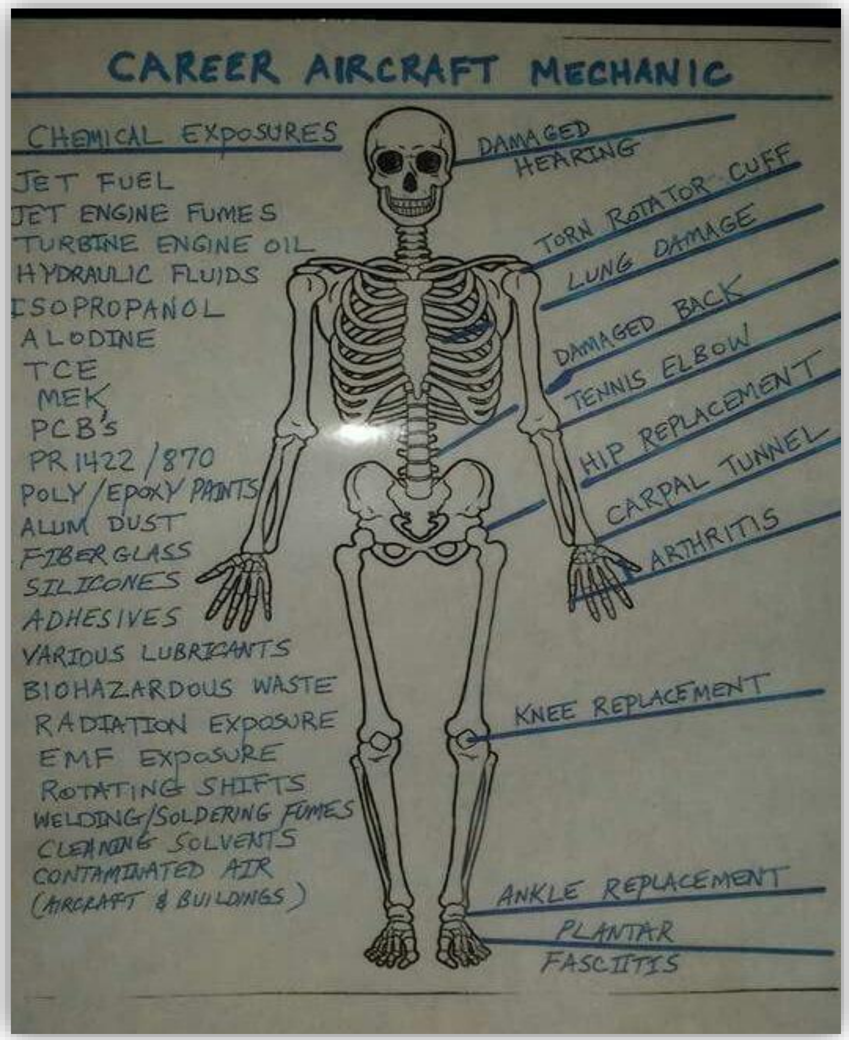
Maintainers have our own problems

EVERY AIRCRAFT MAINTENANCE TEAM
DOES 99% OF THE WORK
HAS NO IDEA WHAT'S GOING ON THE WHOLE TIME
SAYS HE'S GOING TO HELP BUT HE'S NOT
DISAPPEAR AT THE VERY BEGINNING AND DOESN'T SHOW UP AGAIN TIL THE VERY END



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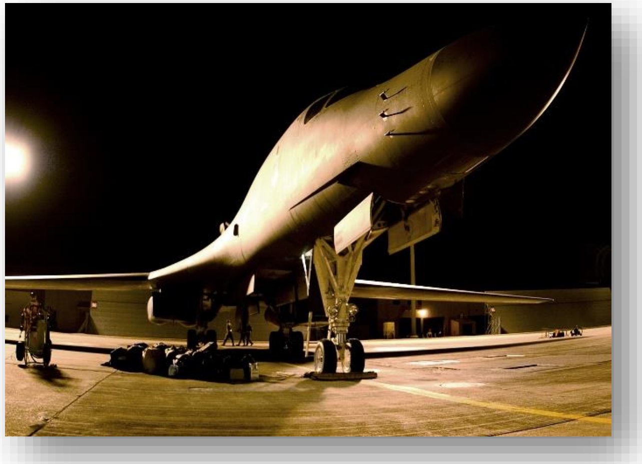
(Origin Story)What problems did the BUS solve?

Communication along BUS systems

A few networks you should know about

Attack vectors sorry no POC



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What problems does the BUS solve?

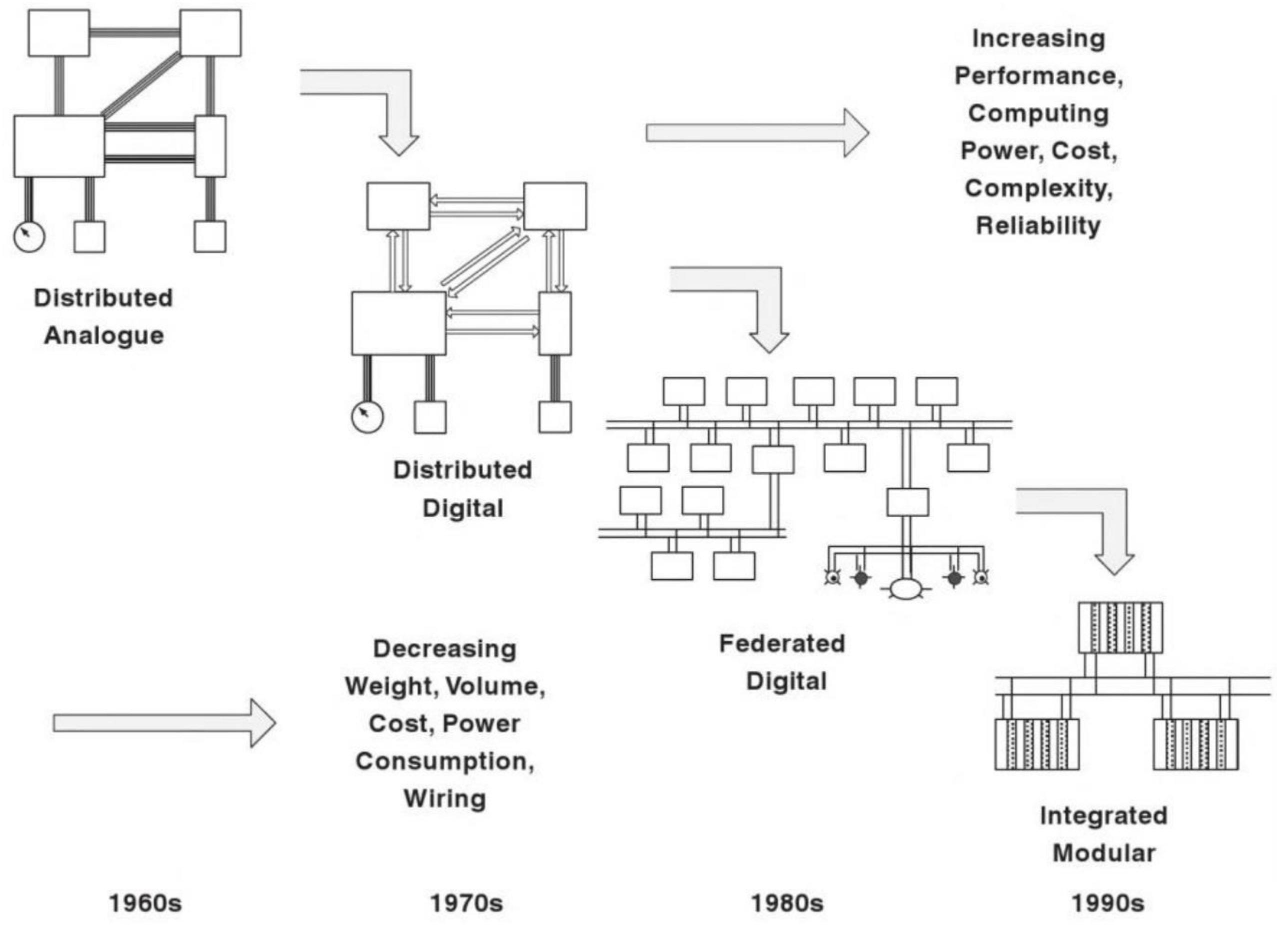

Figure 5.11 Evolution of avionics architectures.

Design and Development of Aircraft Systems Ref (a)

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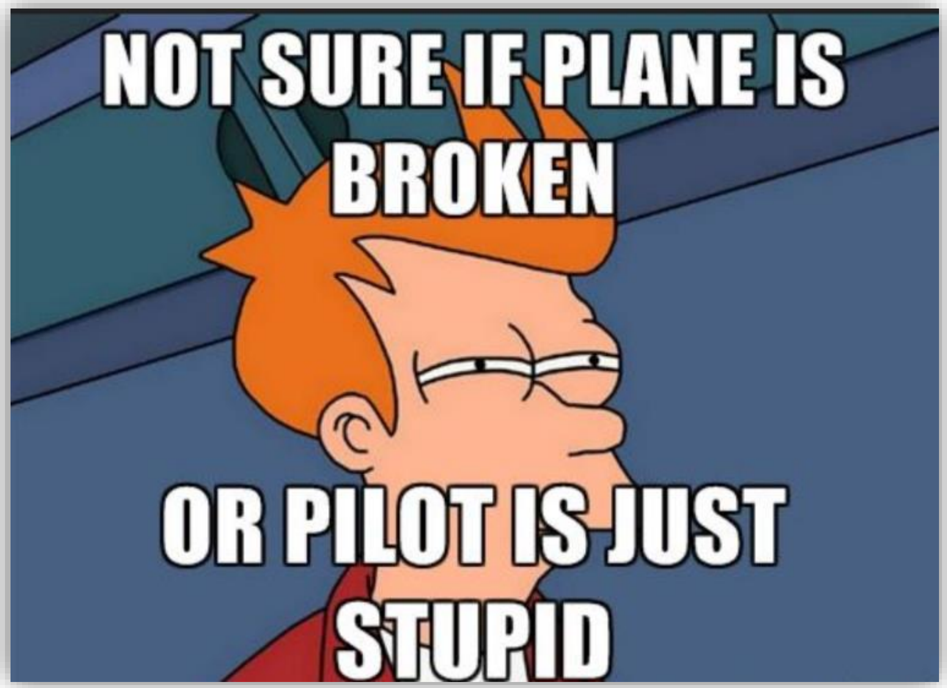
What problems does the C/N BUS solve?

The MIL-STD-1553

-1973 To help with weight reduction, simplicity, standardization, and flexibility.

-First used in the F-16 Fighter.



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Legacy Control and Navigation

C-141 Starlifter Cockpit
At Airshow McChord AFB

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Modern Control and Navigation

C-5M Super Galaxy Cockpit

Paris- LeBourget
©Jonathan Zaniger

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Generic 1553 bus system

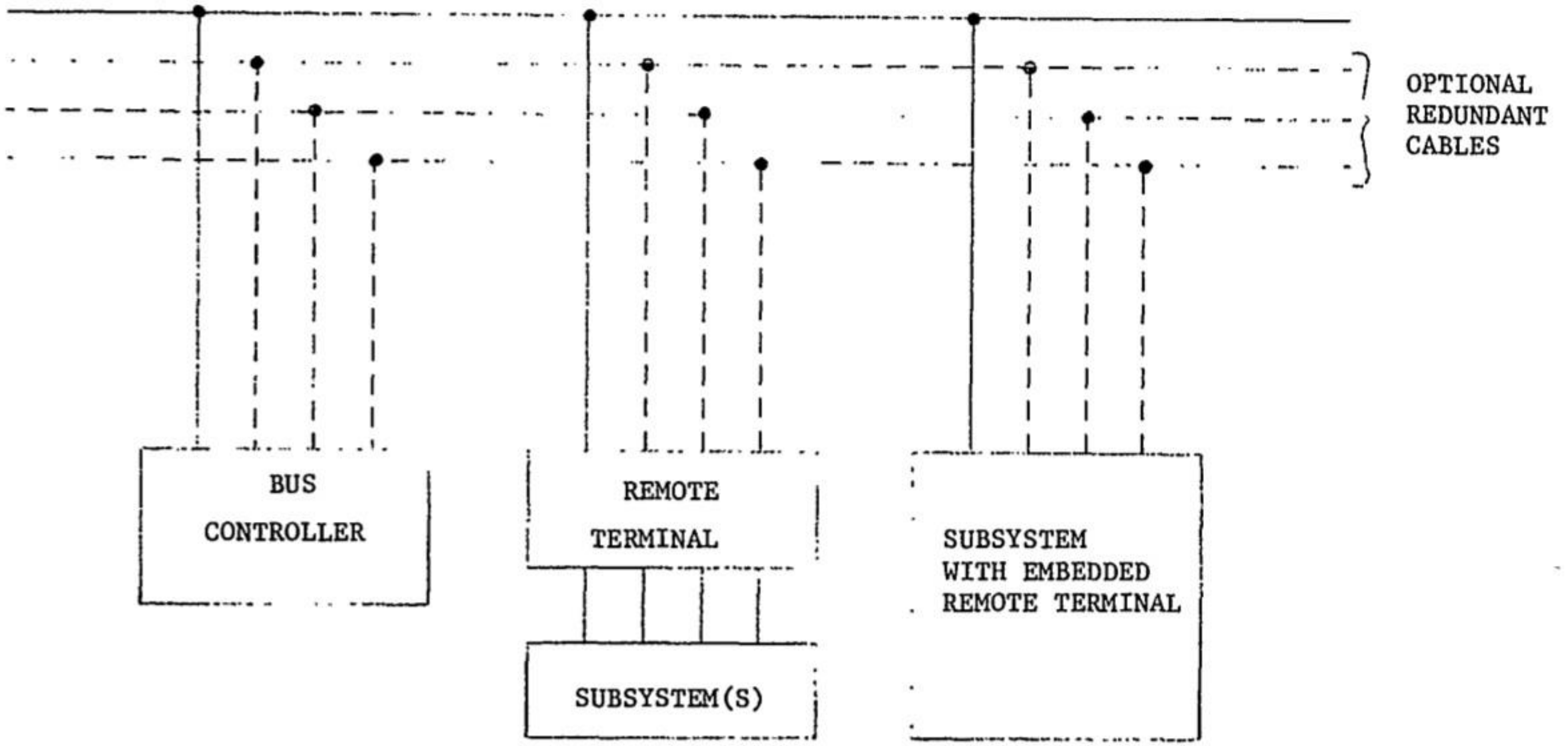

FIGURE 1. Sample multiplex data bus architecture.

MIL-STD-1553b Data bus Standard Ref(b)

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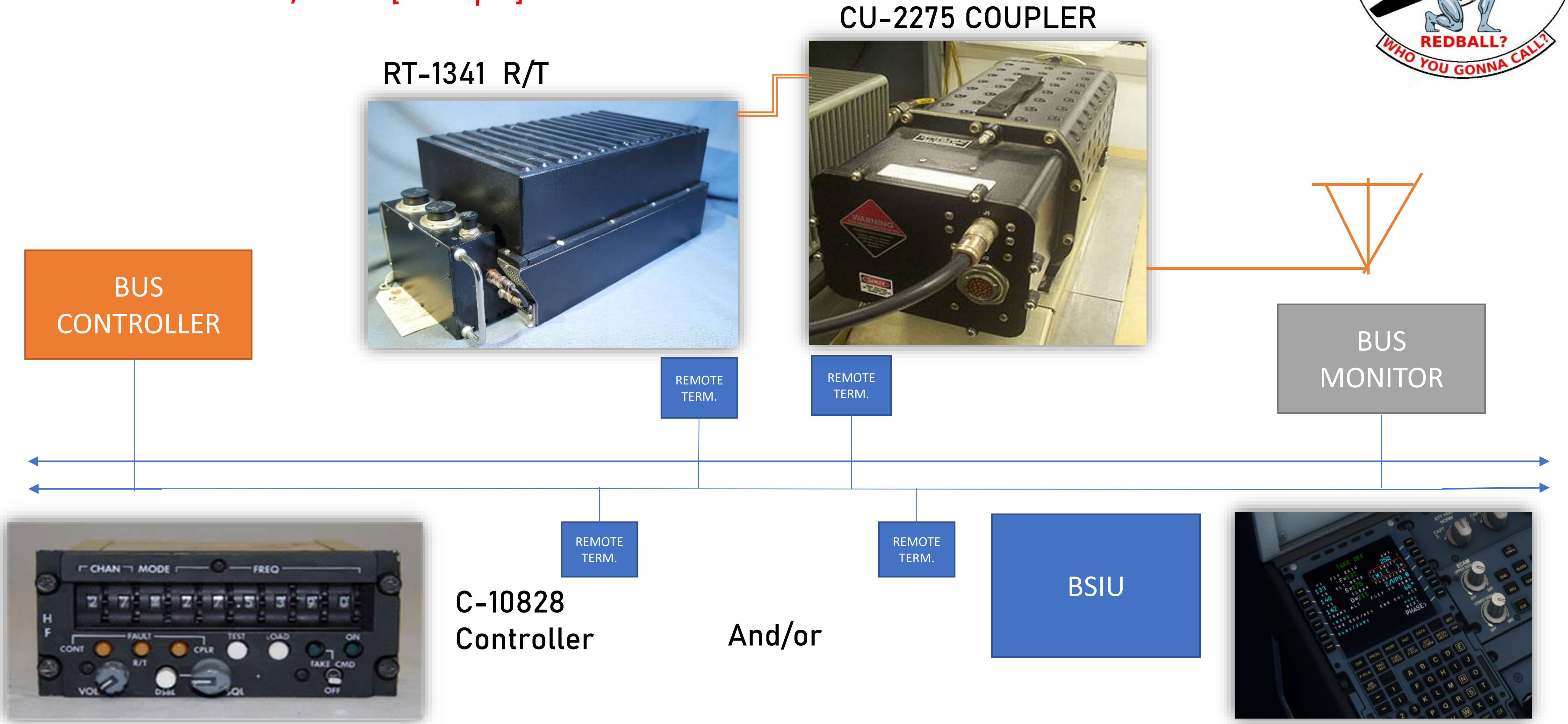
REDBALL?
WHO YOU GONNA CALL?

HF radio on the C/N bus [example]



CU-2275 COUPLER

RT-1341 R/T

BUS CONTROLLER

REMOTE TERM.

REMOTE TERM.

BUS MONITOR

REMOTE TERM.

REMOTE TERM.

BSIU

C-10828
Controller

And/or

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B-1b CITS

B-1b Offensive Officer Position
Dyess AFB
c/o Defense.gov

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Commercial Aviation Bus system

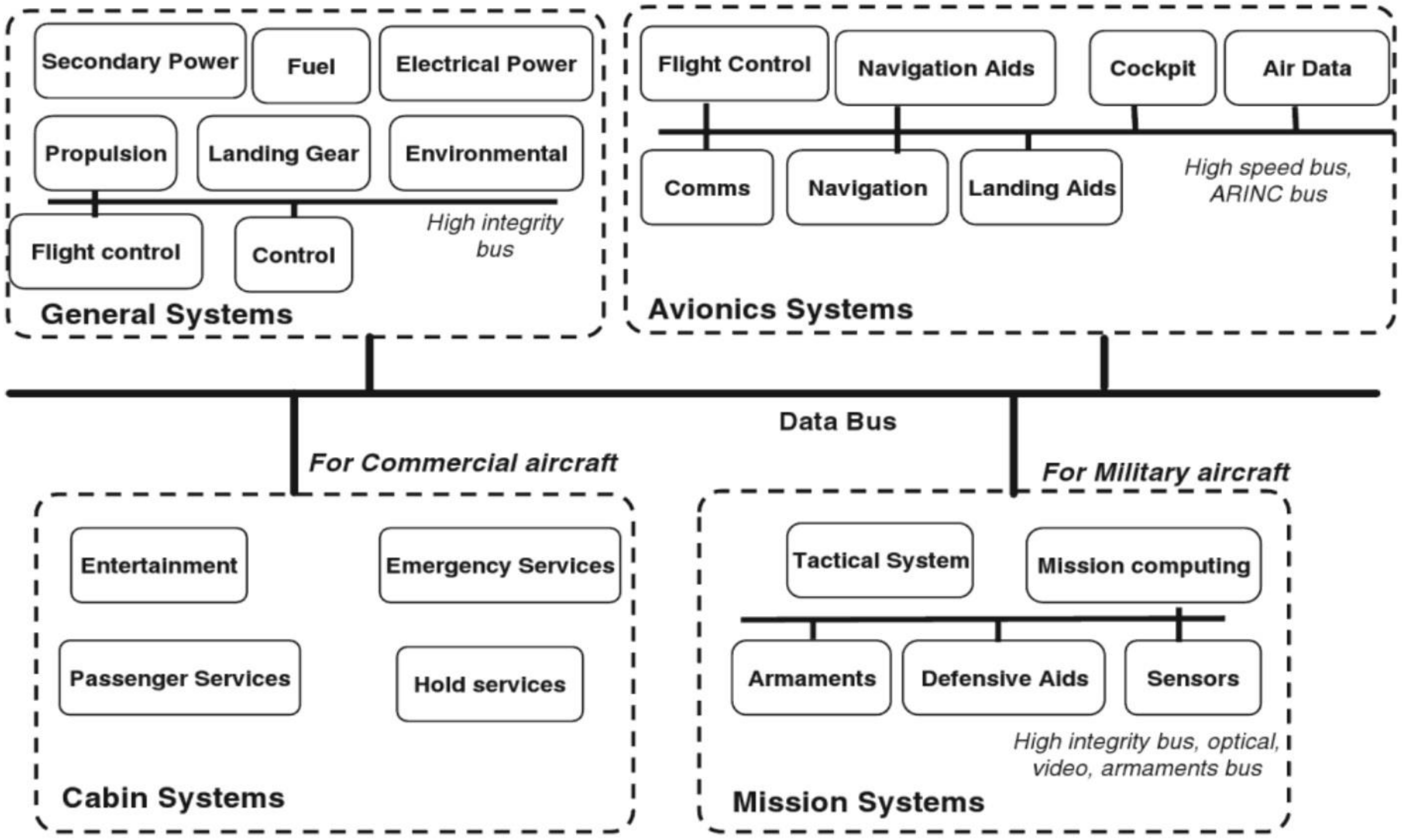

Figure 5.4 Aircraft systems.

Design and Development of Aircraft Systems Ref (a)

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MIL-STD-1553(B) Coded Language

-Manchester II Encoding

-Binary Phase Shift Keying (BPSK)

-1.0 mbps

-Accuracy of .1% Long term (1000hz)

-Accuracy of .01% short term (1second)

-each word is 16 bits plus sync wave and parity

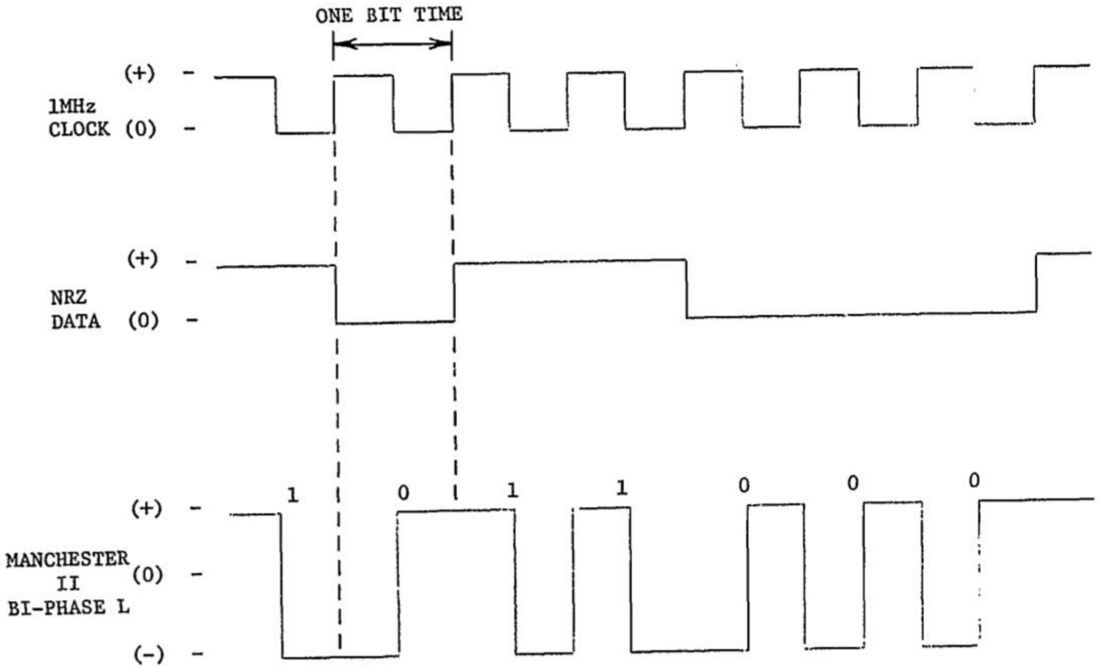

FIGURE 2. Data encoding.

MIL-STD-1553b Data bus Standard Ref(b)

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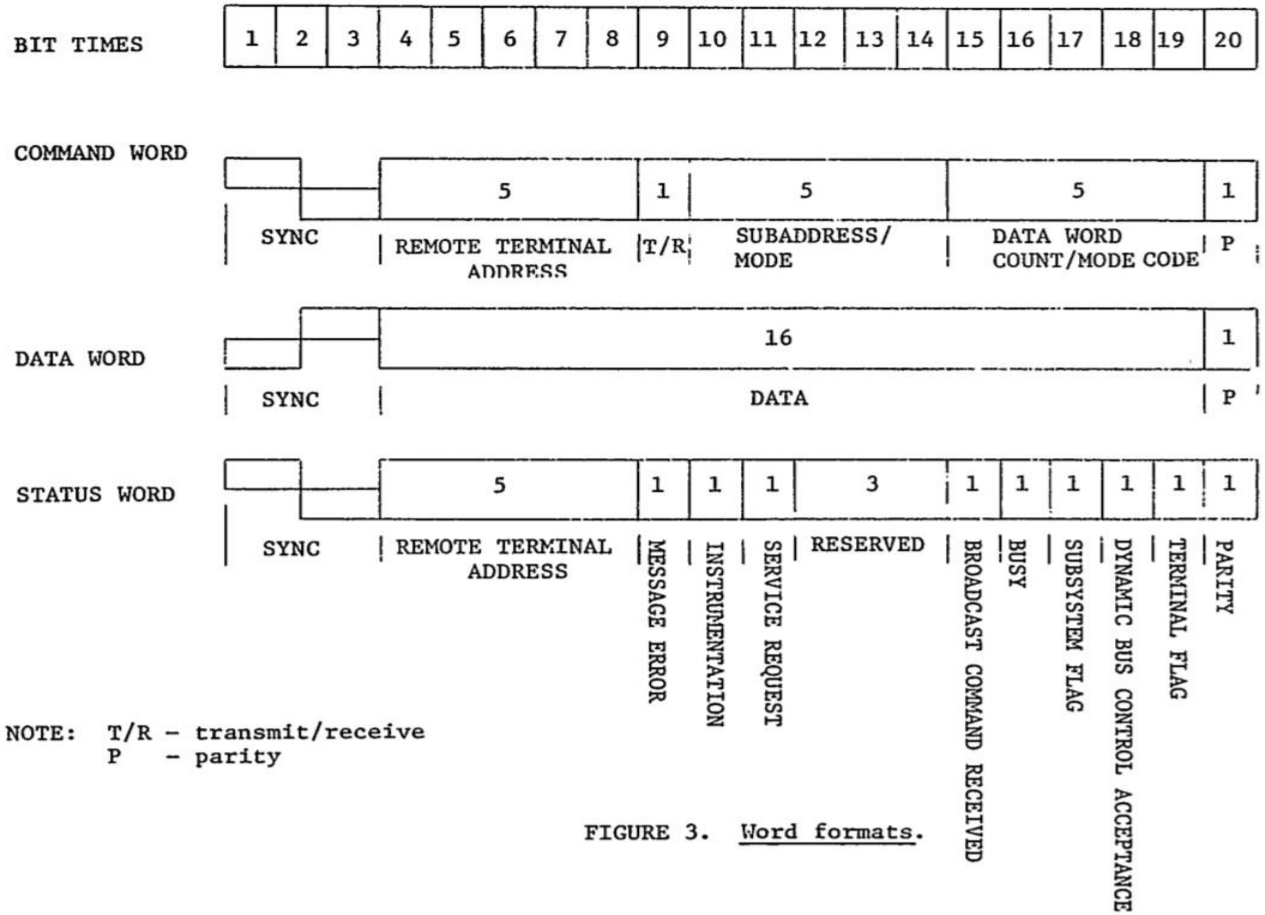
MIL-STD-1553(B) Word



NOTE: T/R – transmit/receive
P – parity

FIGURE 3. Word formats.

MIL-STD-1553b Data bus Standard Ref(b)

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ARINC-429 Coded Language

-BOEING Standard in legacy systems

-Each word is 32bits

-No more than 20 receivers on single wire

-Unidirectional (tx and rx are on different Ports)

-12.5, 50, or 100kbps

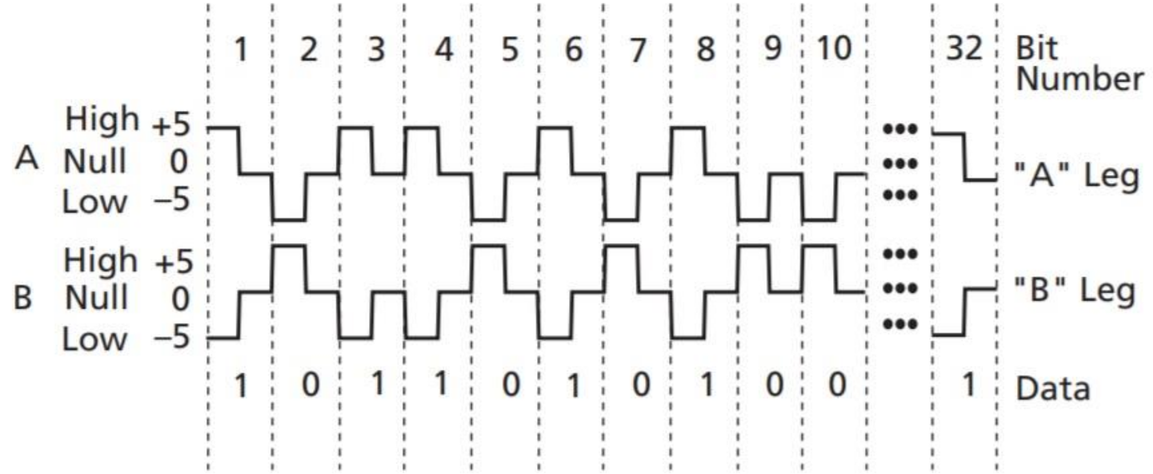

Figure 2 • **ARINC Standard**

ARINC-429 Bus Standard Ref(c)

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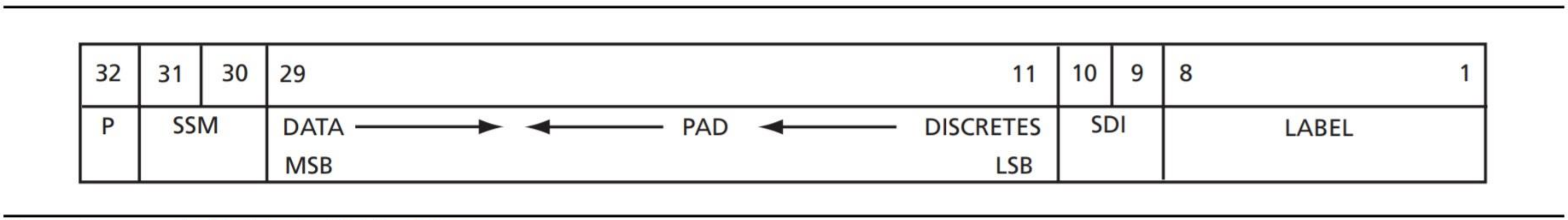
ARINC-429 Coded Word

-Contains five fields to every word: Parity Sign/Status Matrix Data Source/destination Label



32	31	30	29 11	10	9	8 1
P	SSM		DATA → ← PAD ← DISCRETES MSB LSB	SDI		LABEL

Figure 3 • **ARINC Data Bit Positions**

ARINC-429 Bus Standard Ref(c)

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AFDX® (ARINC-664)

Avionics Full-Duplex Ethernet Switching

-Airbus Standard

-Maximum 120 data terminals per controller

-2 Mbps

-Each word 32 bits

-COTS Integration

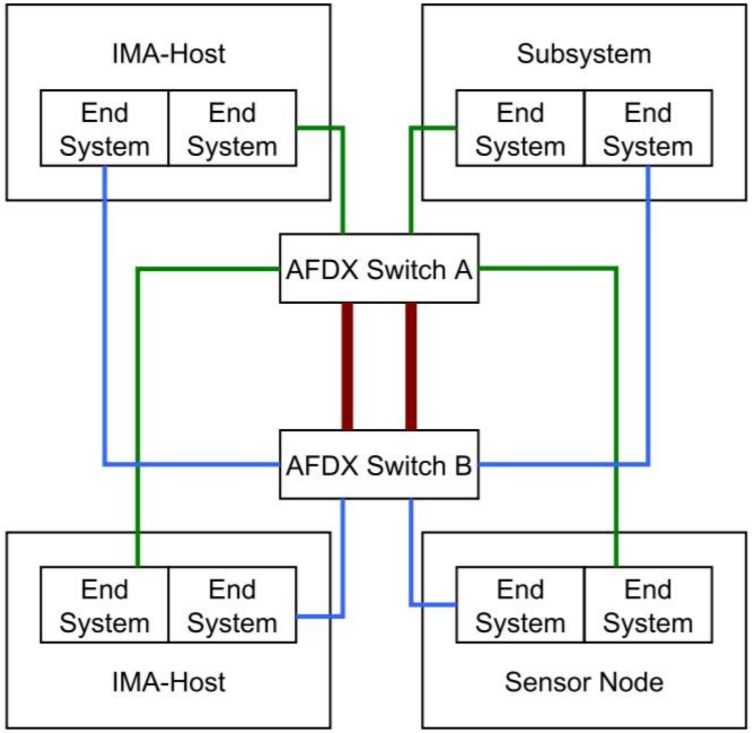

Figure 9: An example of an AFDX based network. Each subsystem is attached physically to the network by two *end systems*. [19]

ARINC-429 to AFDX ref(d)

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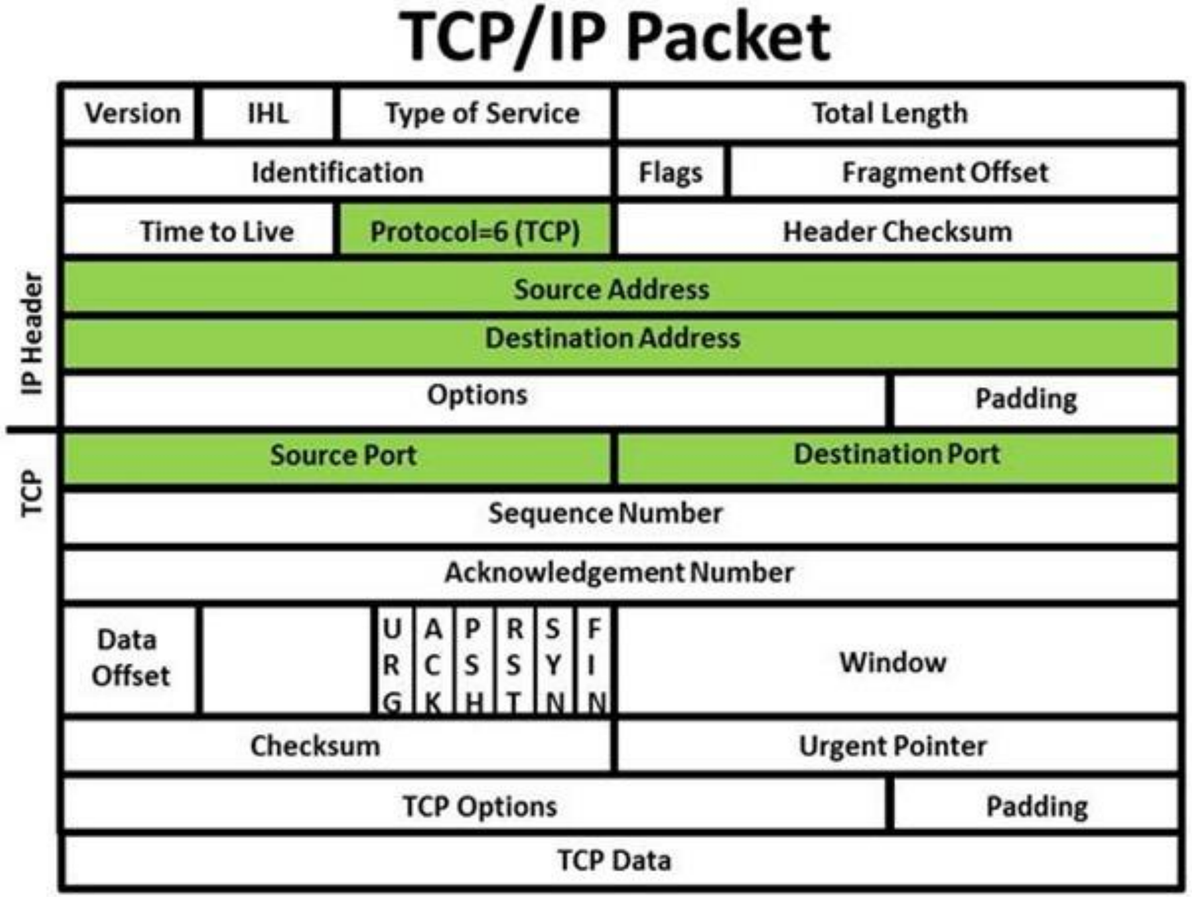
AFDX® (ARINC-664 upgraded)



TCP/IP Packet

IP Header

Version	IHL	Type of Service	Total Length	
Identification			Flags	Fragment Offset
Time to Live		Protocol=6 (TCP)	Header Checksum	
Source Address				
Destination Address				
Options				Padding

TCP

Source Port							Destination Port	
Sequence Number								
Acknowledgement Number								
Data Offset		URG	ACK	PSH	RST	SYN	FIN	Window
Checksum							Urgent Pointer	
TCP Options								Padding
TCP Data								

Packetpushers.net

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Attack Vectors (If they existed)

-COTS (Commercial Off the shelf Devices)

-Local Data Connections

-External Data Connections

-People (always with the People)

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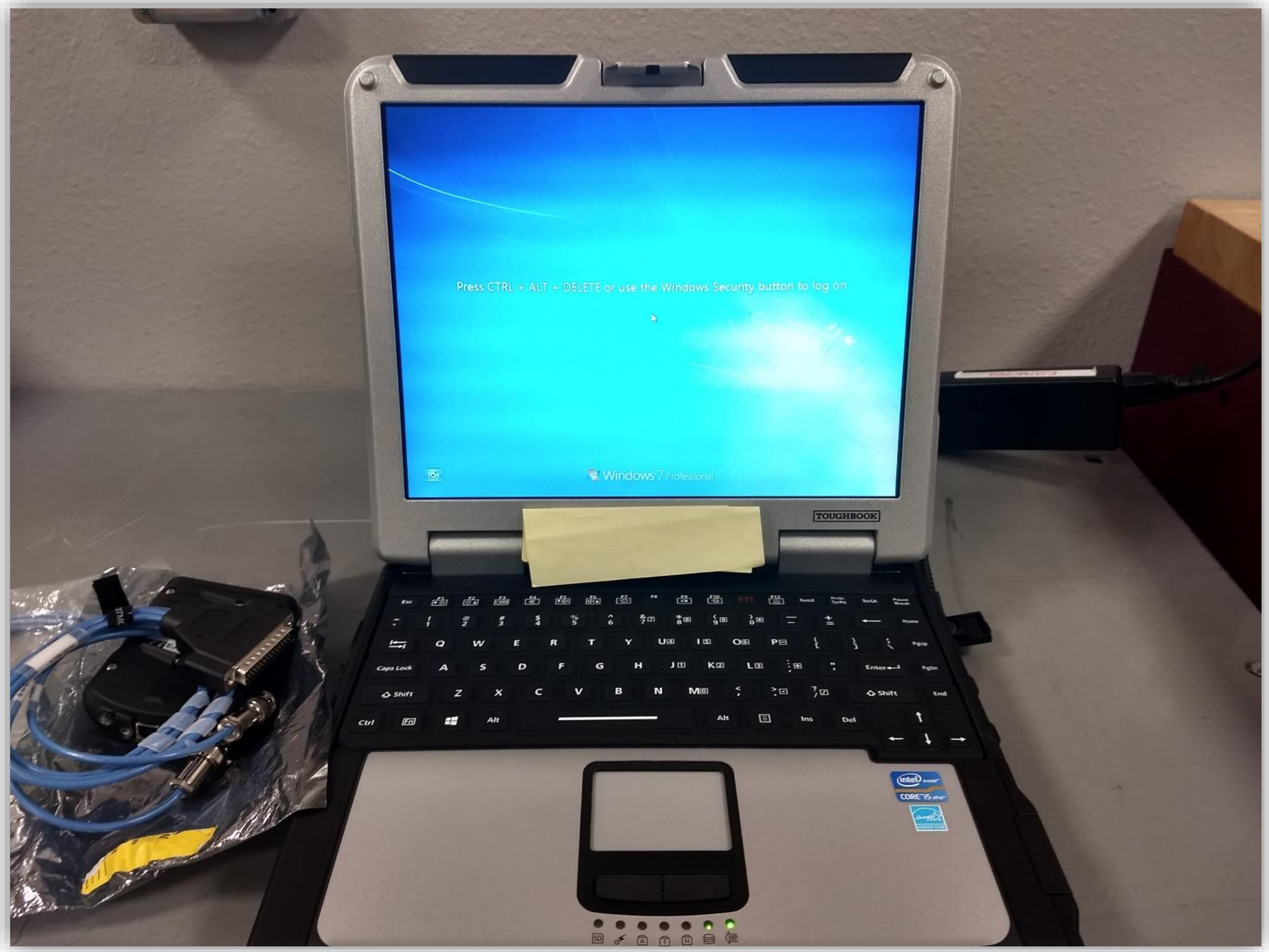
Vectors -COTS

- -network hubs
- -USB hubs
- -computers
- -personal devices


Press CTRL + ALT + DELETE or use the Windows Security button to log on
Windows 7 Professional
TOUGHBOOK

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Vectors – Local Data Connections

-OFP Loading (1553 Coax shown)

Using on A/C Data bus to load common Processors,

EX:

Primary Flight Computer OFP
SATCOM network Radio
Inertial Navigation Units
More updates as tech advances

-MX data Media

Hot swappable HDD
PCM/CIA Cards
USB drive
SD Cards

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Vectors –External Data Connections

-CPLDC (Controller Pilot Data Link)

-ACARS (Aircraft Communication, Addressing and reporting System) [injection vulnerable]

-Misdirection and wizard magic (TCAS)

-Preventative Measures Done Right

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Vectors –External Data Connections

TOWER, THIS IS DELTA 288
REQUESTING CLEARANCE TO LAND RUNWAY 4L
THANK YOU FOR CALLING AIR TRAFFIC CONTROL. YOUR CALL IS VERY IMPORTANT TO US. PLEASE STAY ON THE LINE AND WE WILL GET TO YOU AS SOON AS WE CAN
IF YOU ARE CALLING ABOUT A LANDING CLEARANCE, PLEASE PRESS 1. IF YOU ARE SHORT ON FUEL AND REQUIRE IMMEDIATE ASSISTANCE, PLEASE PRESS 2. FOR ALL OTHER INQUIRIES, PLEASE STAY ON THE LINE
made on imgur

-CPLDC (Controller Pilot Data Link)

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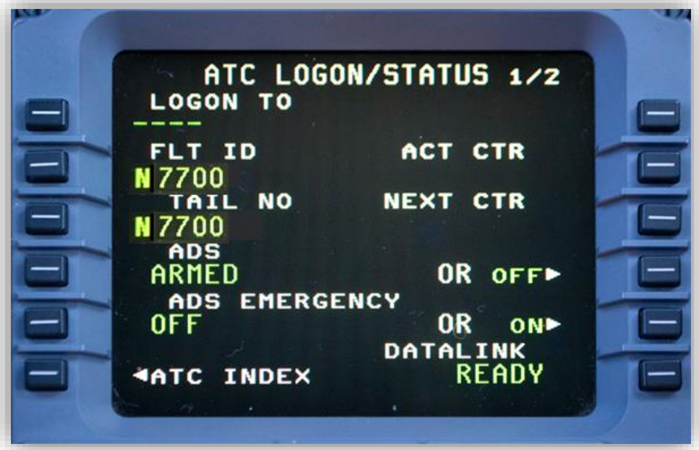
Vectors –External Data Connections

-CPLDC (Controller Pilot Data Link)

-CPLDC is Application layer relying on VDL2
-Used for sending Clear text messages between the ATC and Pilot operators
-Is based off a network to include Iridium Commercial Satellites and ground stations
-VHF band in use for data



```
     ATC LOGON/STATUS 1/2
 LOGON TO
----
 FLT ID              ACT CTR
N7700
  TAIL NO           NEXT CTR
N7700
  ADS
 ARMED                 OR OFF▶
  ADS EMERGENCY
 OFF                   OR  ON▶
                    DATALINK
◀ATC INDEX             READY
```

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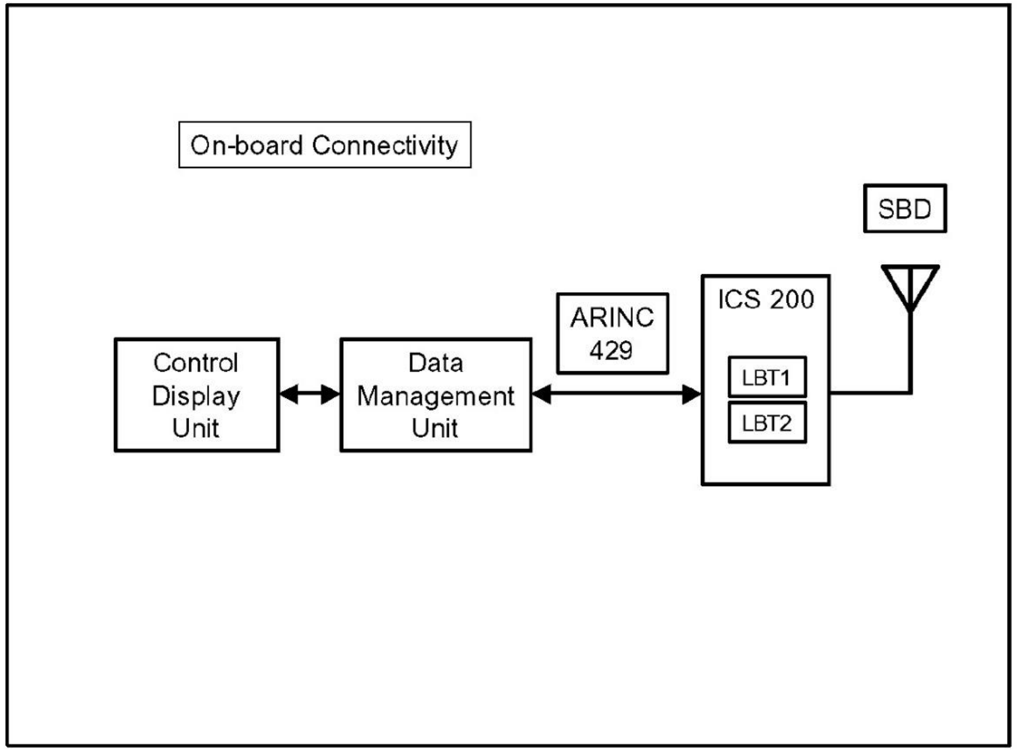
Vectors –External Data Connections

-ACARS (Aircraft Communication, Addressing and reporting System)

- VHF and HF
- Receive Data to print onto Thermal Paper
- Relies on Readily Available commercial networks
- Also a VDL2 product



ACARS ICS-200-1 ref(e)

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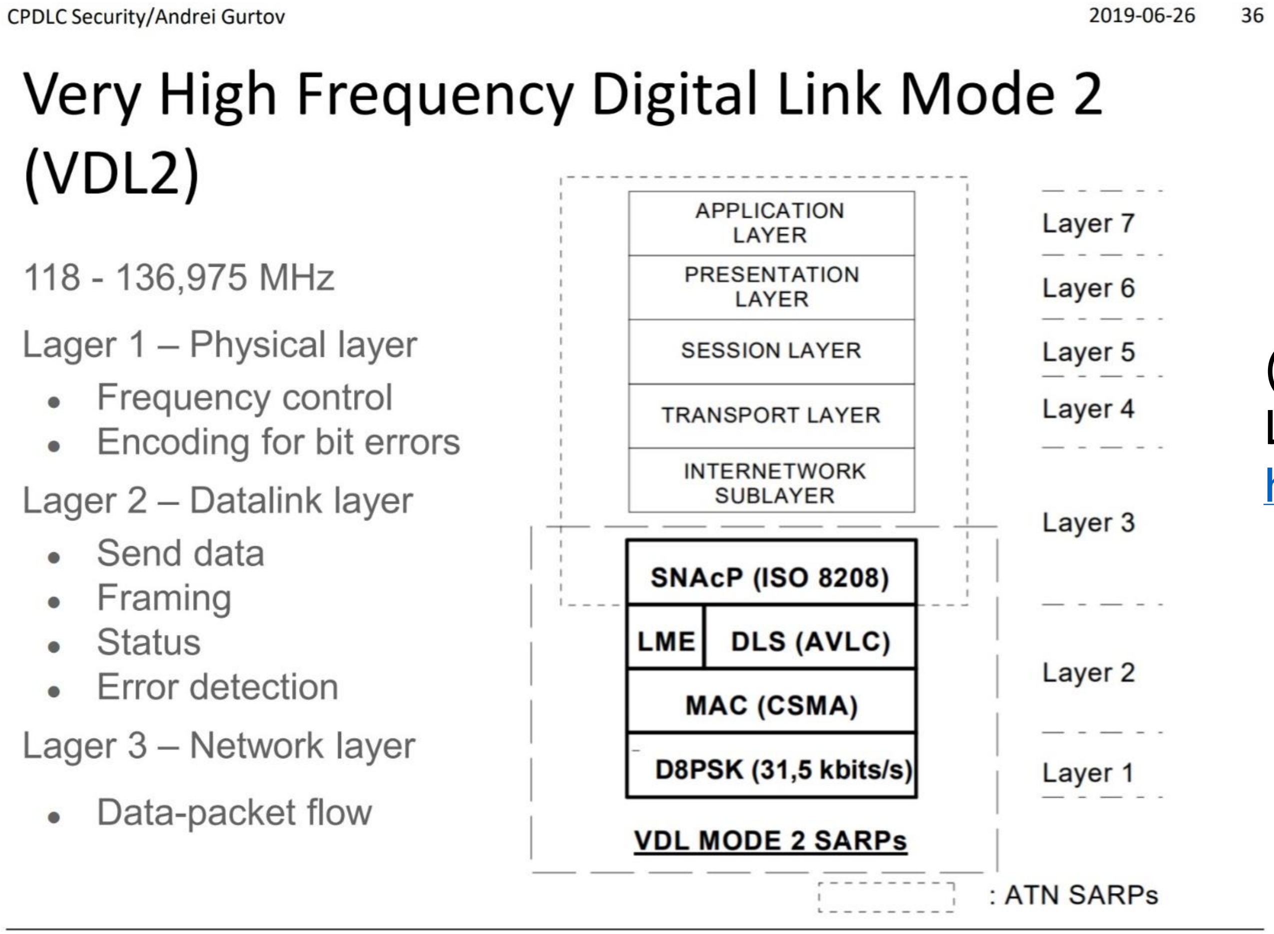
Vectors –External Data Connections



CPDLC Security/Andrei Gurtov 2019-06-26 36

Very High Frequency Digital Link Mode 2 (VDL2)

118 - 136,975 MHz

Lager 1 – Physical layer

- Frequency control
- Encoding for bit errors

Lager 2 – Datalink layer

- Send data
- Framing
- Status
- Error detection

Lager 3 – Network layer

- Data-packet flow

APPLICATION LAYER	Layer 7
PRESENTATION LAYER	Layer 6
SESSION LAYER	Layer 5
TRANSPORT LAYER	Layer 4
INTERNETWORK SUBLAYER SNAcP (ISO 8208)	Layer 3
LME DLS (AVLC) MAC (CSMA)	Layer 2
D8PSK (31,5 kbits/s)	Layer 1

VDL MODE 2 SARPs

: ATN SARPs

LINKÖPING UNIVERSITY

Andrei Gurtov Air Traffic Seminar 2019 ref(f)

(h)Github DumpVDL2 from Tomasz Lemiech(szpajder) https://github.com/szpajder/dumpvdl2

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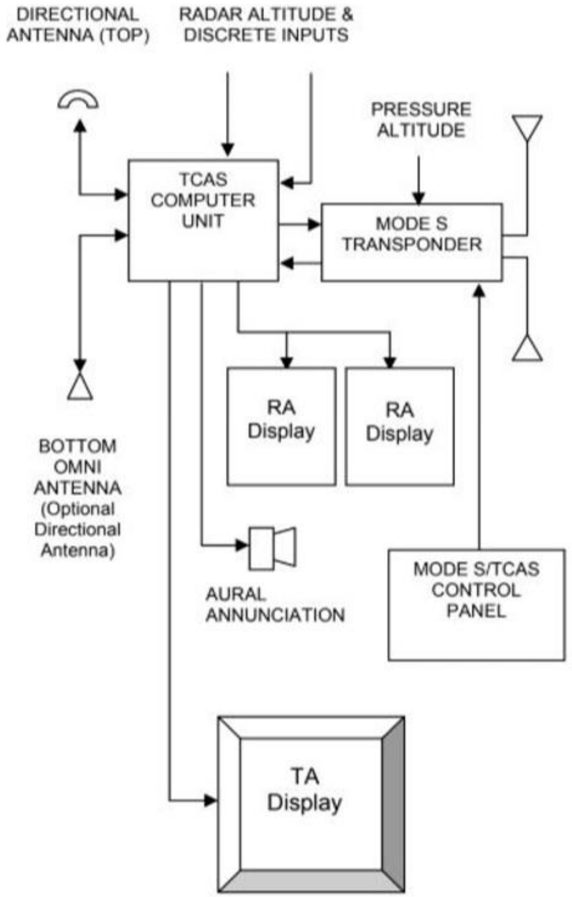
Misdirection and Wizard Magic – TCAS

- Operates with Mode S
- 1030 Mhz and 1090Mhz response
- DBPSK (Differential Binary Phase shift keyed
- Each A/C has a unique 24 Bit address (IFF)
- Examples of integration into AP


DIRECTIONAL ANTENNA (TOP)
RADAR ALTITUDE & DISCRETE INPUTS
PRESSURE ALTITUDE
TCAS COMPUTER UNIT
MODE S TRANSPONDER
RA Display
RA Display
BOTTOM OMNI ANTENNA (Optional Directional Antenna)
AURAL ANNUNCIATION
MODE S/TCAS CONTROL PANEL
TA Display

Exploring the Vulns of TCAS through SDR exploitation. Berges, P. (j)

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COMM/NAV & MISSION SYS

REDBALL?

WHO YOU GONNA CALL?

Misdirection and Wizard Magic – TCAS

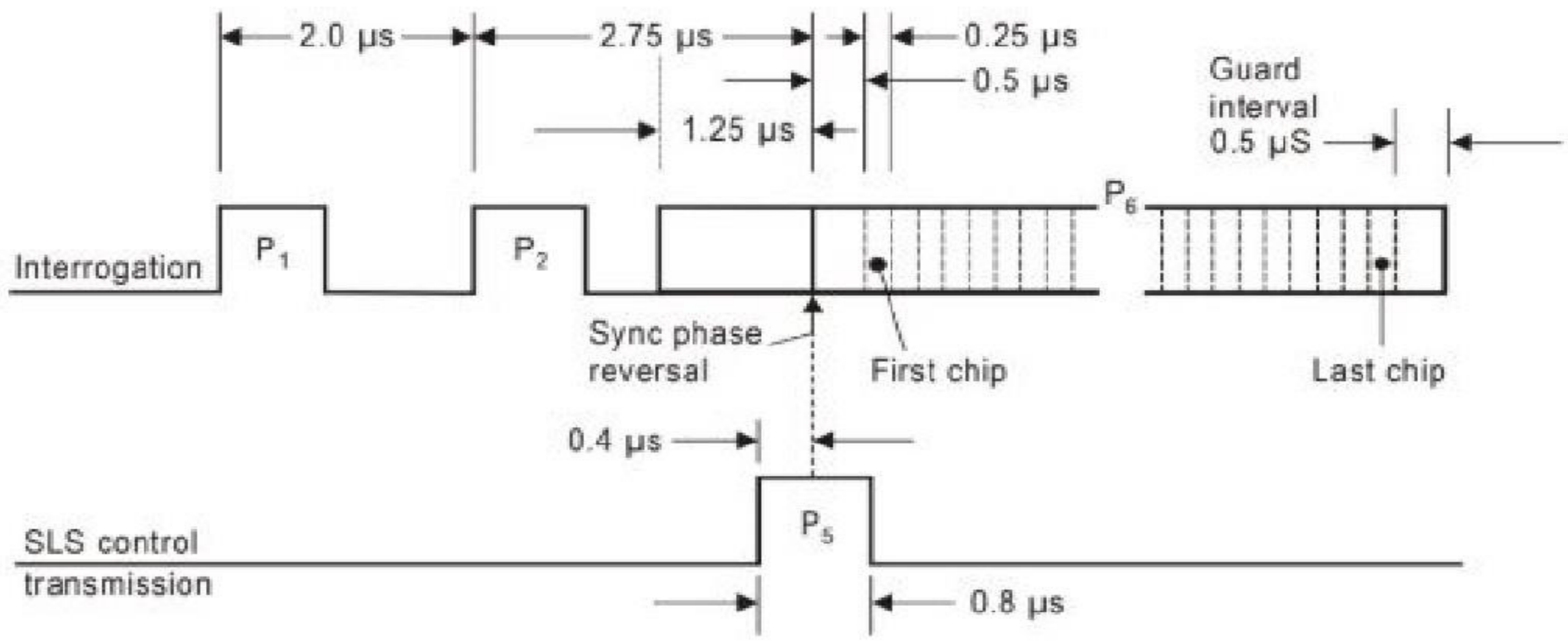

Figure 2.10: Interrogation Pulse Sequence [35].

Exploring the Vulns of TCAS through SDR exploitation. Berges, P. (j)

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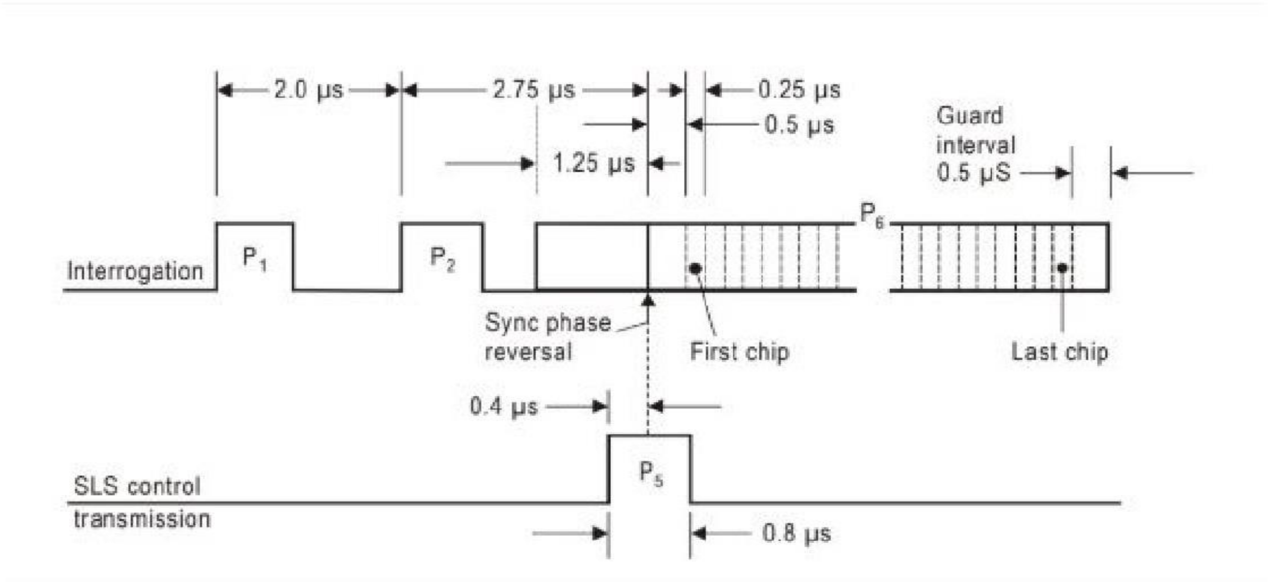

Figure 2.10: Interrogation Pulse Sequence [35].

01011	PR:4	IC:4	CL:3	16	AP:24

Exploring the Vulns of TCAS through SDR exploitation. Berges, P. (j)

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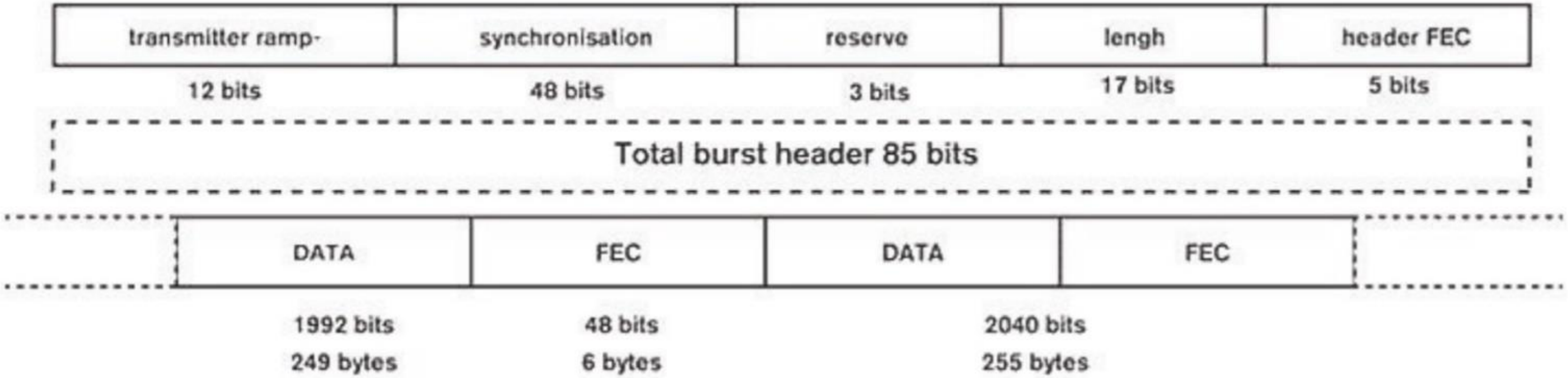
Vectors –External Data Connections

-A little bit about VDL

-ACARS and CPDLC are applications
-VDL is a point-to-point communication technology
-VHF, limited to 200NM of the Aircraft 3k-4k feet
-SDR project Dumpvdl2 on Github



VDL mode 2 burst (maximum length of a burst: 131 071 bits, N=65 maximum)

European Telecommunications Standards Institute Master Documentation for VDL
(Ref g)VDL Technical characteristics ETSI EN 301 841-1

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Vectors – preventative example

-Link-16 TADILJ (Tactical Digital Information Link)

-PSK on SECRET hardware devices (Air Gapped)

-Uses freq hop to prevent jamming, (WOD,TOD, Net number) HAVEQUICK

-960-1200MHZ VHF/UHF

-Limited to LOS but this includes Satellites

-Provides

- -target data
- -Friendly location data
- -command and control
- -Mesh Network
- -Different hardware performs different roles/functions

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Vectors – preventative example

-Link-16 TADILJ (Tactical Digital Information Link)

Message Catalogue

Network Management
Precise Participant Location and Identification
Surveillance
Antisubmarine Warfare
Intelligence
Information Management
Weapons Coordination and Management
Control
Platform and System Status
Electronic
Threat warning
National Use

TADIL J Introduction and Reference Guide Ref(i)

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Vectors –~~Users~~, Pilots & Maintainers

-Aircraft Software updates are time sensitive, especially combat DoD

-Chain of custody is not always verified in Commercial products

-Engineers use publicly available sources (such as VDL2)

-Pilots are starting to bring Personal devices to aircraft flight decks

-Civilian customers on the Aircraft Network.

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Hacker Hurdles

-Understanding Aircraft Infrastructure

-Understanding Specific components Functions

-Physical Access to hardware

-Testing / Tabletop Access to Software & Hardware

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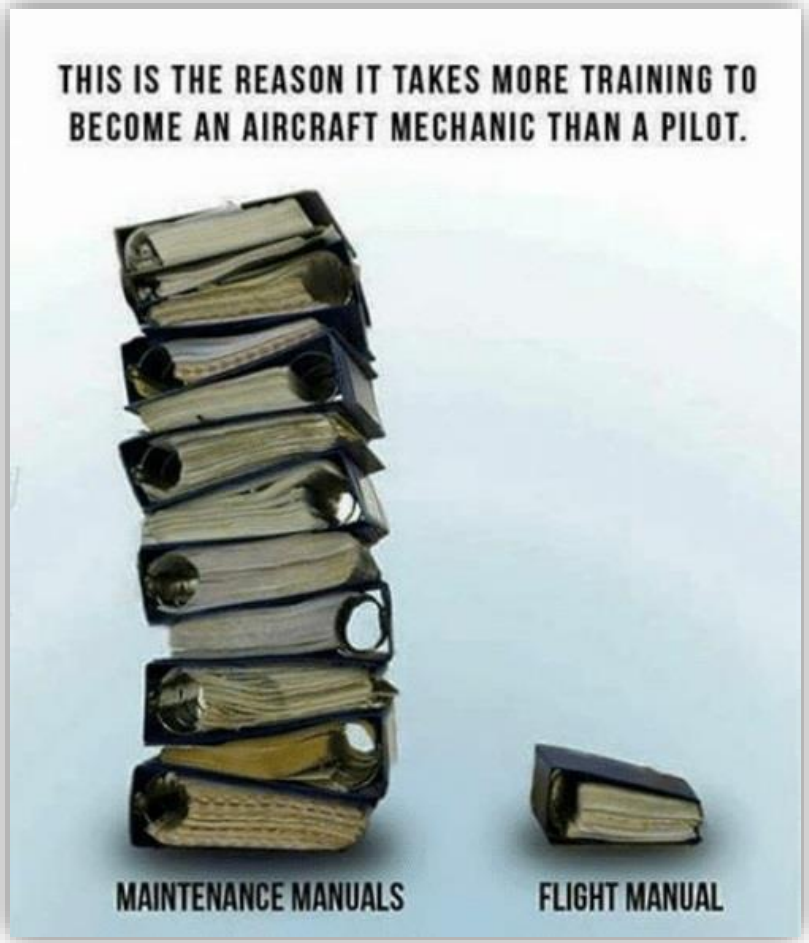
Addendum: Things are happening

- F-15 (Technical Assistance database System) TADS DEFCON'19
- Software Example, Boeing 737 MAX (OFP)
- US Government Probes A/C Vulns
- Devices inside company used for programming hardware found to be vulnerable/infected. (C.Kubecka)



THIS IS THE REASON IT TAKES MORE TRAINING TO BECOME AN AIRCRAFT MECHANIC THAN A PILOT.

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REDBALL?
WHO YOU GONNA CALL?

RESOURCES

(a)Design and Development of Aircraft systems Google-book http://bit.ly/2k6kICx

(b)MIL-STD-1553b Data bus Standard 1979/01/22 PDF http://bit.ly/39QFmLu

(c)ARINC-429 Bus Standard PDF (Archive.org) http://bit.ly/2qtYb5f

Data Link Advisory Circular PDF http://bit.ly/2pGR5Ke

(d)Evolution of Avionics Networks from ARINC-429 to AFDX PDF http://bit.ly/2N4DGnm

IRIG-106 Aeronautical telemetry Open source 1553 Mil standard format 0 http://bit.ly/31AMUgu

Data Comm Systems with FANS 1/A+, CPDLC DCL and ATN B1 PDF http://bit.ly/2N1jR0h

(e)ICAO International Introduction to ACARS ICS-200-1 PDF http://bit.ly/2Bvuhjp

SDRPlay Decoding ACARS Messages PDF http://bit.ly/2J9KMGf

(f)Andrei Gurtov Air Traffic Seminar 2019 http://bit.ly/2Na0pia

(g)VDL Technical characteristics ETSI EN 301 841-1 PDF http://bit.ly/2pI63Qj

(h)Github DumpVDL2 from Tomasz Lemiech(szpajder) https://github.com/szpajder/dumpvdl2

(i)TADIL J Introduction and Reference Guide PDF http://bit.ly/2obvLf0

(j)Exploring the Vulns. Of TCAS through SDR PDF http://bit.ly/2Wcjzd6