COURSE 5
AERONAUTICAL COMMUNICATION SYSTEMS

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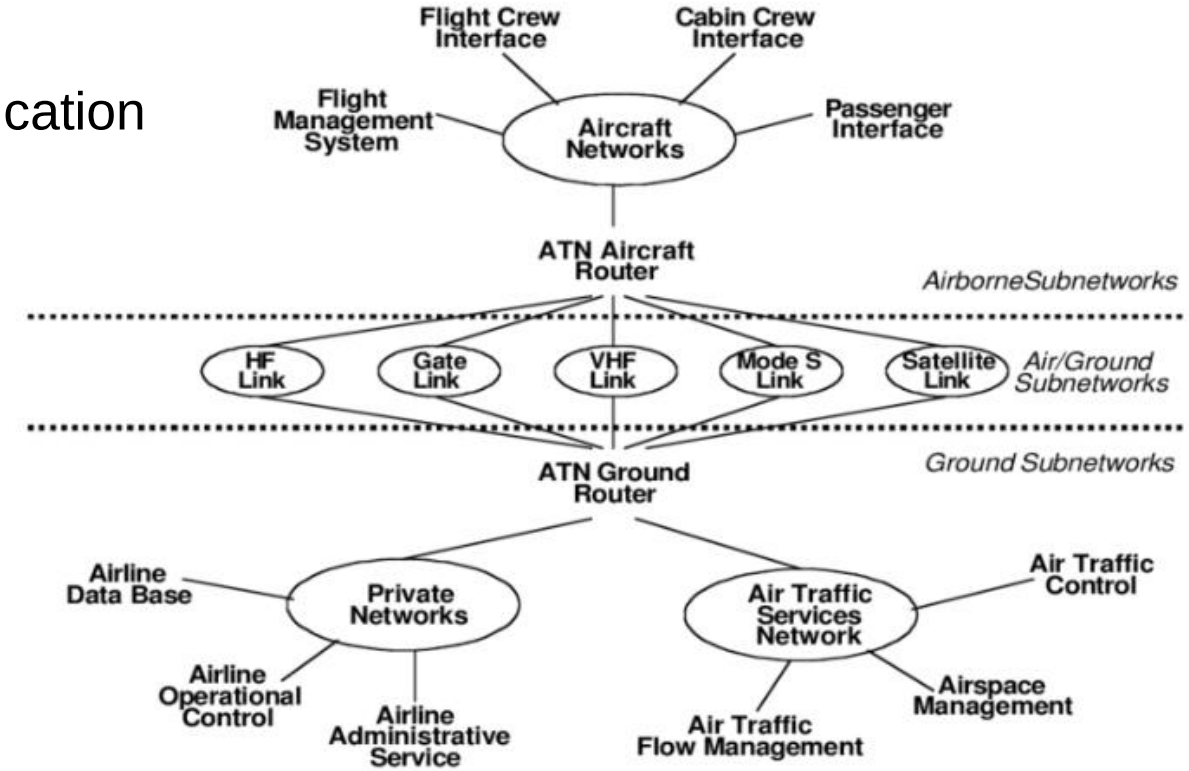
COMMUNICATIONS DEPARTMENT

CONTENT

- Introduction
- Radio navigation
- Communication systems
- Collision monitoring and avoidance systems
- Usage of the radio spectrum

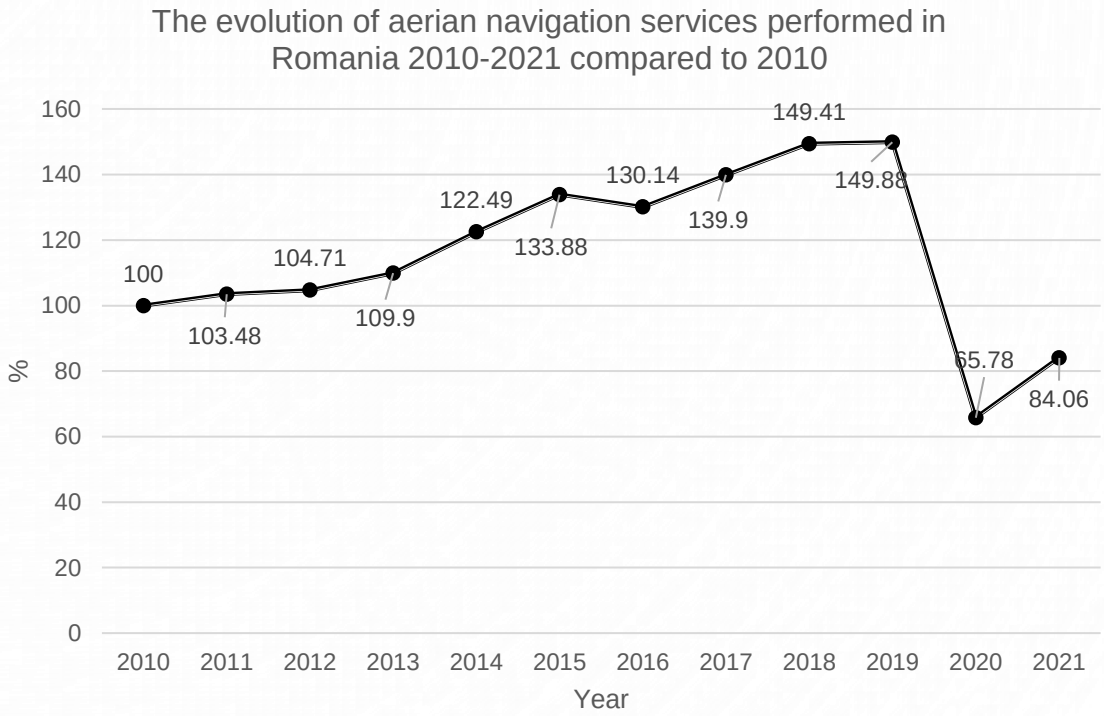
INTRODUCTION

- Aeronautical communication systems are specified by ICAO (International Civil Aviation Organization) Annex 10
- There are standards used for communication
  - Airplane – ground
  - Airplane – airplane
- Communication types specified:
  - Voice
  - Data



INTRODUCTION

- Air traffic controllers are becoming more and more overloaded
  - The volume of ROMATSA services increased by 50% during 2010-2019
    - The latest report is from 2021, but according to other sources in 2023 the 2019 level is already exceeded
  - An increasing trend is expected as plane tickets become more and more affordable
  - Communication systems can significantly reduce the load on air traffic controllers and pilots



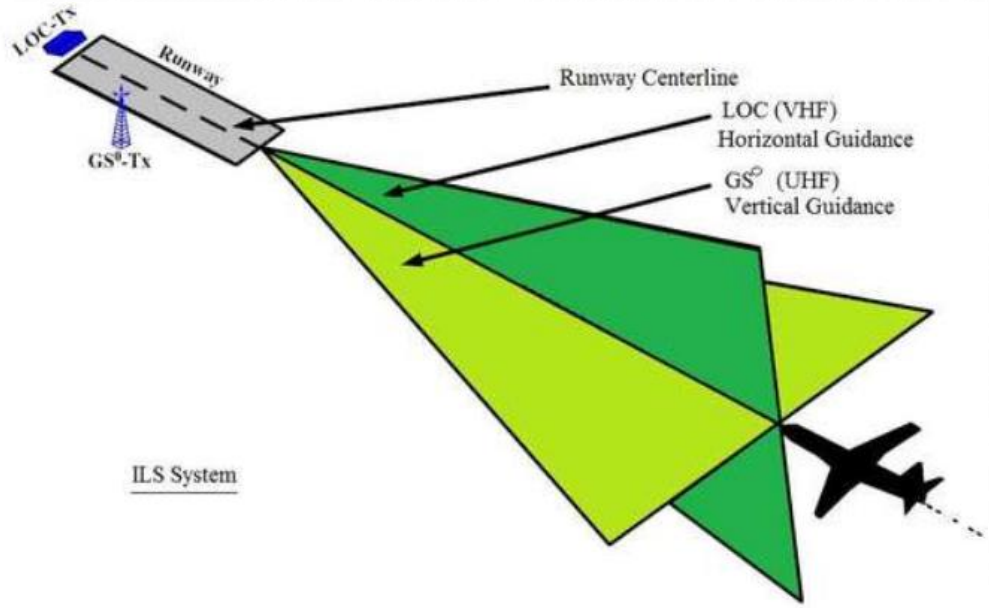
*Based on ROMATSA data

RADIO NAVIGATION

- The most important radio navigation systems used are the following:
  - ILS – Instrumented Landing System
  - MLS – Microwave Landing System
    - No longer in use
  - GNSS – Global Navigation Satellite System
  - VOR – VHF Omnidirectional Radio Range
  - NDB – Non-directional Radio Beacon
  - DME – Distance Measuring Equipment
    - It is co-located with ILS or VOR
  - En-route VHF marker beacon

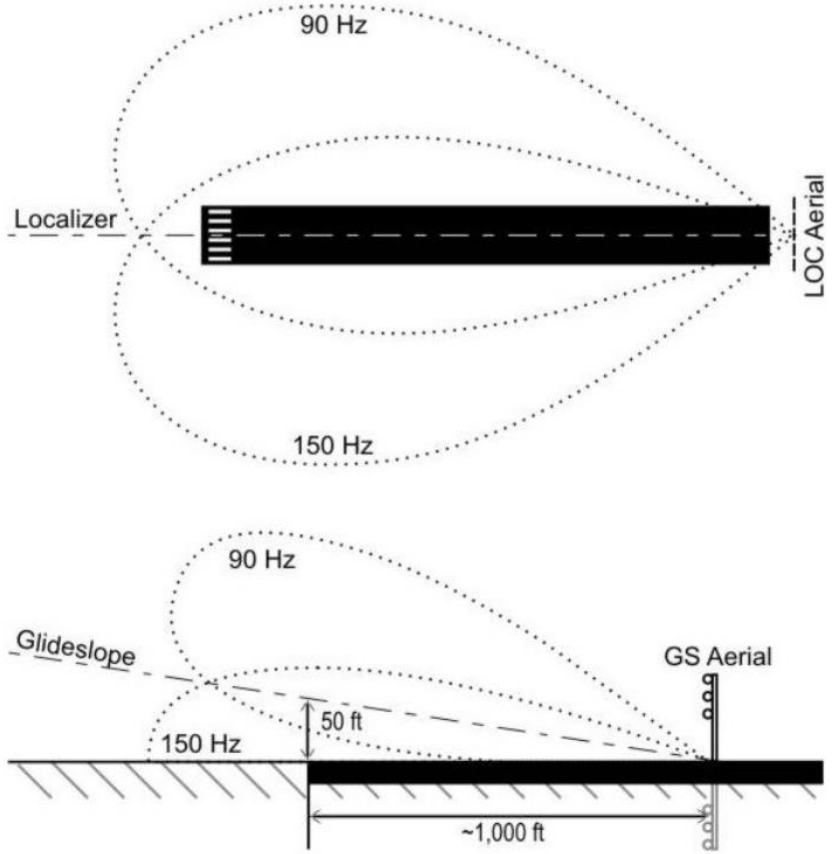
RADIO NAVIGATION – ILS

- The ILS provides guidance to the aircraft horizontally and vertically during landing
- There are 3 categories of ILS depending on the decision altitude (DH – Decision Height) and visibility conditions (RVR – Runway Visual Range)
  - Cat I: DH > 60m, RVR > 550m
  - Cat II: 60m > DH > 30m, RVR > 200m (CLJ)
    - In 2023 a contract was signed for Cat. III ILS for CLJ
  - Cat III is divided in 3 subcategories:
    - Cat IIIa: 30m > DH, RVR > 200m
    - Cat IIIb: 15m > DH, 200m > RVR > 50m
    - Cat IIIc: without DH and RVR limitations



RADIO NAVIGATION – ILS

- ILS is composed of:
  - VHF localization equipment (LOC - localizer)
    - Provides alignment with the runway
    - It is positioned at the end of the runway
      - Transmits 2 intersecting radio beacons: one beacon to right of the runway, one to the left
    - It operates in the 108-111.975 MHz band
    - These are AM modulated signals with a frequency of 90/150 Hz
    - The coverage must be up to 46.3km

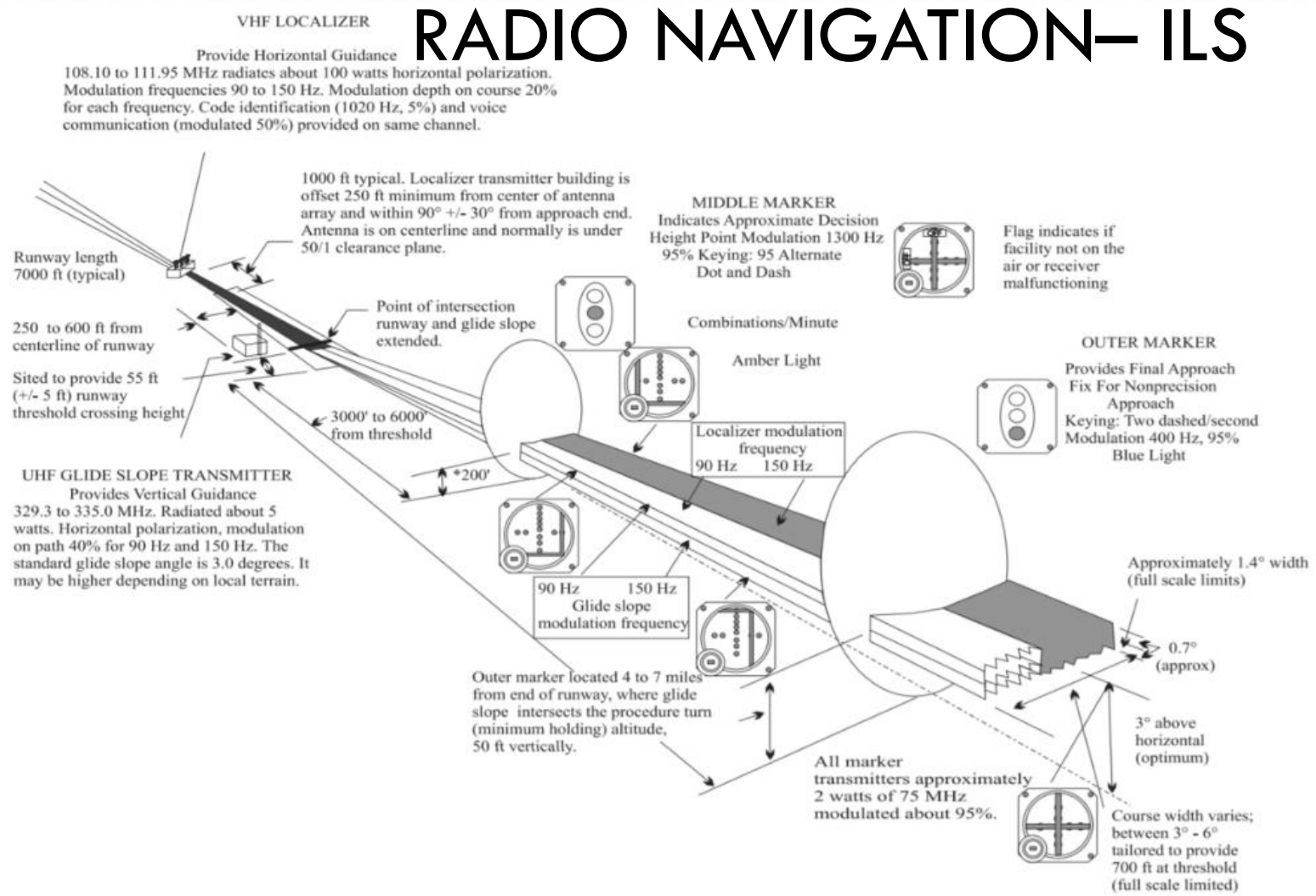


RADIO NAVIGATION – ILS

- UHF landing slope equipment (GS - Glideslope)
  - It transmits 2 intersecting radio beacons: one above, one below the required vertical profile
  - The frequency band is 328.6-335.4 MHz
  - The signals are AM modulated with the frequency 90/150 Hz
  - The landing angle must be <= 3°
  - The coverage must be at least 18.5km
- Verification equipment

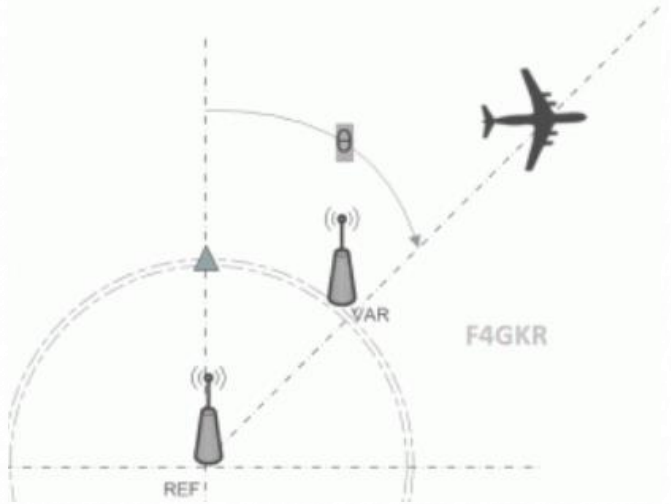
Localizer (MHz)	*Glide path (MHz)*	*Localizer (MHz)*	*Glide path (MHz)*
108.1	334.7	110.1	334.4
108.15	334.55	110.15	334.25
108.3	334.1	110.3	335.0
108.35	333.95	110.35	334.85
108.5	329.9	110.5	329.6
108.55	329.75	110.55	329.45
108.7	330.5	110.7	330.2
108.75	330.35	110.75	330.05
108.9	329.3	110.9	330.8
108.95	329.15	110.95	330.65
109.1	331.4	111.1	331.7
109.15	331.25	111.15	331.55
109.3	332.0	111.3	332.3
109.35	331.85	111.35	332.15
109.5	332.6	111.5	332.9
109.55	332.45	111.55	332.75
109.7	333.2	111.7	333.5
109.75	333.05	111.75	333.35
109.9	333.8	111.9	331.1
109.95	333.65	111.95	330.95

RADIO NAVIGATION– ILS



RADIO NAVIGATION – VOR

- Allows the determination of the position of the airplane by receiving radio signals emitted by a fixed terrestrial network of VOR stations
  - VOR – Very high frequency Omni-directional Range
- It operates in the 108-117.95 MHz frequency band with 50 kHz channel separation
- The VOR station broadcasts 2 signals
  - Primary omnidirectional signal
    - 9960 Hz constant amplitude subcarrier FM modulated at 30 Hz
  - Variable phase secondary unidirectional signal
    - AM modulated signal at 30 Hz



RADIO NAVIGATION – VOR

- The phase difference between the two signals determines the angle between the airplane and the VOR station
  - Based on the angle of the airplane to VOR stations, the position of the airplane can be determined
  - The accuracy is 90m
- There are 3000 VOR stations worldwide
  - Also, at Cluj-Napoca
- VOR provides higher accuracy than NDB (Non-Directional Beacon)
- VOR will be replaced by GNSS
  - It will be maintained as a backup system

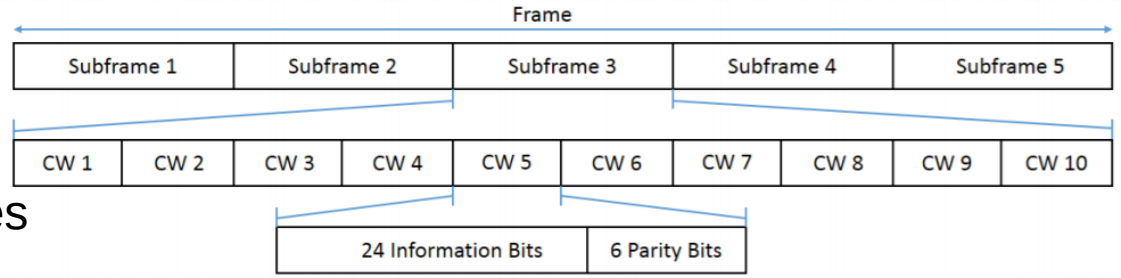
RADIO NAVIGATION – GNSS

- GNSS provides position and time information for the aircraft
- The GNSS navigation service consists of one or more elements
  - GPS – Global Positionioning System
    - Sends SPS (Standard Positioning Service) signals
    - A maximum error of 17m horizontally and 37m vertically in location is allowed
    - A maximum error of 40ns is allowed for time information
    - It covers the surface of the Earth up to an altitude of 3000 km
    - The carrier frequency for SPS is 1575.42 MHz, SPS is BPSK modulated, and CDMA is used
    - Transmitted data includes transmission time, satellite position, satellite integrity, satellite clock correction, effects of propagation delays, UTC time, and so on.

RADIO NAVIGATION – GNSS

- GLONASS – Global Navigation Satellite System
- ABAS – Aircraft Based Augmentation System
  - Integrates GNSS information with on-board information
- SBAS – Satellite Based Augmentation System
  - Extends the constellation of basic satellites to increase the accuracy, integrity, continuity and availability of GNSS services
- GBAS – Ground Based Augmentation System
  - Provides support for landing, takeoff, ground operations, etc.
- GRAS – Ground Based Regional Augmentation System
- The aircraft's GNSS receiver

RADIO NAVIGATION – GNSS



- Structure of GPS L1 C/A navigation messages
  - A frame consists of 1500 bits and has 5 subframes
  - Each subframe is formed of 10 code words
    - 1 code word for telemetry data (TLM)
    - 1 handover code word (HOW)
    - 8 data code words
    - A code word has 24 bits of information and 6 parity bits
  - The first subframe contains information about the clock integrity of the satellite
    - GPS week number; URA (User Range Accuracy)
    - Satellite integrity (0 = all navigation data is valid)
    - Issue of data, clock; estimated group delay; clock correction parameters

URA	Accuracy
0	2 m
1	2.8 m
2	4 m
3	5.7 m
4	8 m
5	11.3 m
6	16 m
7	32 m
8	64 m
9	128 m
10	256 m
11	512 m
12	1 024 m
13	2 048 m
14	4 096 m
15	Do not use

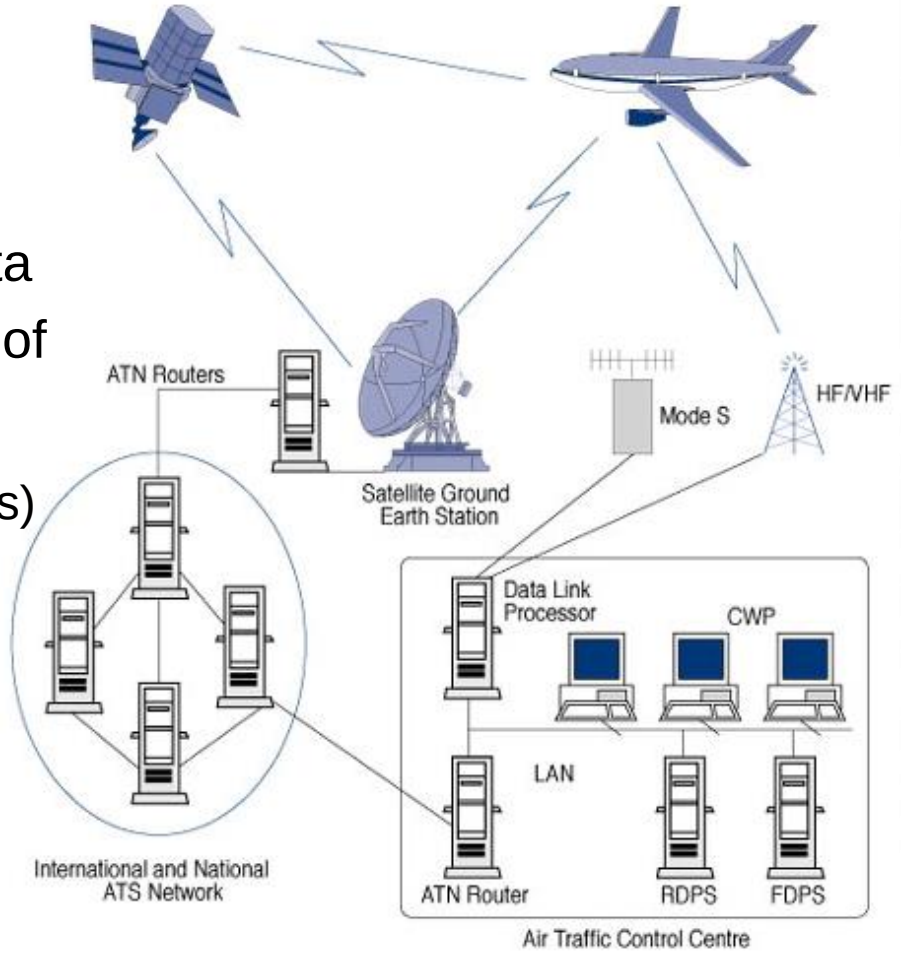
RADIO NAVIGATION – GNSS

- Subframes 2 and 3 contain satellite data
- Subframes 4 and 5 contain support information
  - Special messages
  - Ionospheric data and UTC
  - Satellite configurations
  - The orbits of the other satellites, etc.

M_0	Mean anomaly at reference time
Δn	Mean motion difference from computed value
e	Eccentricity
$\sqrt{A}$	Square root of the semi-major axis
$OMEGA_0$	Longitude of ascending node of orbit plane at weekly epoch
i_0	Inclination angle at reference time
ω	Argument of perigee
OMEGADOT	Rate of right ascension
iDOT	Rate of inclination angle
C_{uc}	Amplitude of the cosine harmonic correction term to the argument of latitude
C_{us}	Amplitude of the sine harmonic correction term to the argument of latitude
C_{rc}	Amplitude of the cosine harmonic correction term to the orbit radius
C_{rs}	Amplitude of the sine harmonic correction term to the orbit radius
C_{ic}	Amplitude of the cosine harmonic correction term to the angle of inclination
C_{is}	Amplitude of the sine harmonic correction term to the angle of inclination
t_{oe}	Reference time, ephemeris
IODE	Issue of data, ephemeris

DATA COMMUNICATION SYSTEMS – ATN

- ATN – Aeronautical Telecommunications Network: is an international network that allows the interoperability of ground/ground, air/ground and data subnets providing data communication services and supports the following types of traffic:
  - Air traffic communication services (ATS – Air Traffic Services)
  - Air traffic communication services between ATS units
  - Operational control communications (AOC – Aeronautical Operation Control Communications)
  - Administrative communications (AAC – Aeronautical Administrative Communications)



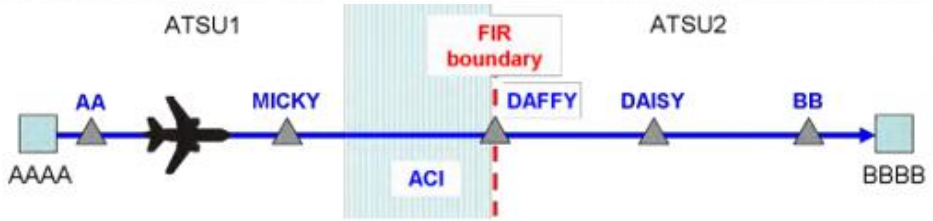
DATA COMMUNICATION SYSTEMS – ATN

- ATN transmits messages based on priorities
- ATN must support:
  - CPDLC (Controller-Pilot Data Link Communications)
    - Communication between the pilot and the controller usually takes place via voice messages
    - All pilots use the same frequency to communicate with a specific controller – congestion in the channel
    - CPDLC allows the transmission of request/information messages
      - The pilot can ask for permission/information and can respond to messages
      - The controller can send information about flight altitude, side deviations, change of route, flight speeds, assignment of radio frequencies, etc.
    - CPDLC is implemented by 2 systems:
      - FANS-1/A which is used for overseas communications, is based on ACARS and uses satellite communications provided by the Inmarsat Data-2 (Classic Aero) service

DATA COMMUNICATION SYSTEMS – ATN

- ICAO Doc 9705 ATN/CPDLC system that uses VDL Mode 2 networks

- FIS (Flight Information Service)
  - Includes information on conflicting traffic, meteorological information, airport information, information on possible flight hazards
  - It is a form of air traffic service which is available to any aircraft within a FIR (Flight Information Region)

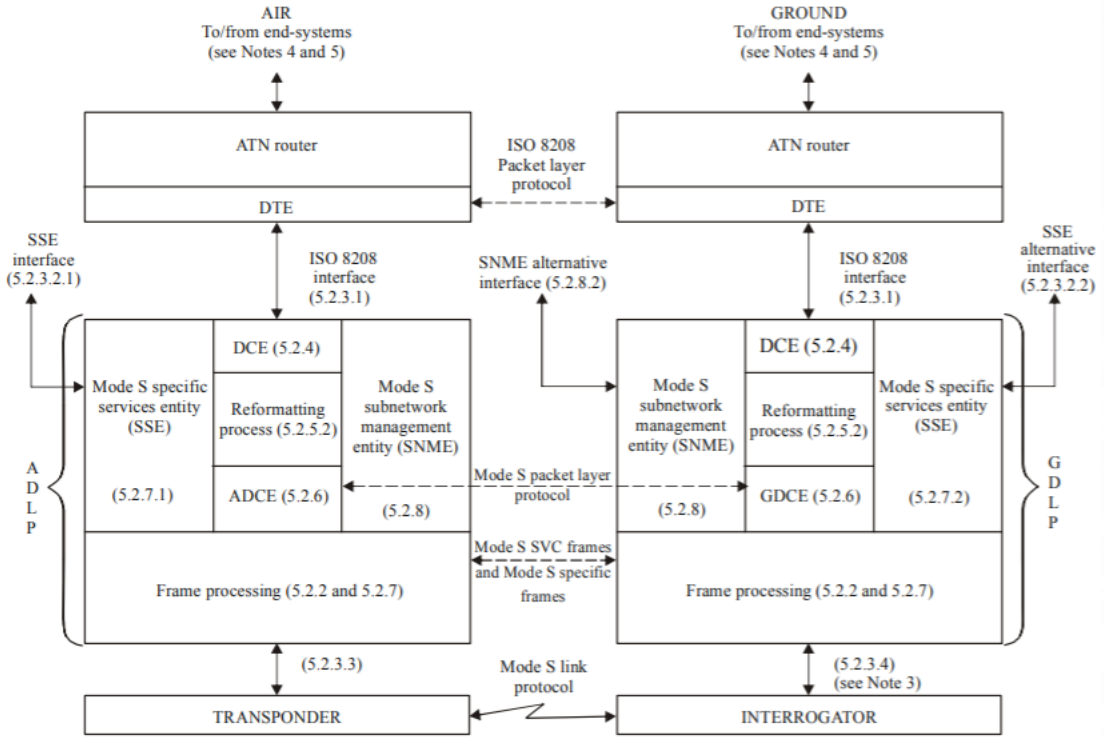


- AIDC (ATS Interfacility Data Communications)
  - Used for information exchange between ATS units
    - AIDC messages are mainly used for transferring control
    - The messages include information about aircraft identification origin/destination, flight altitude, flight speed, speed restriction, possible deviations from route due to weather conditions

- ATSMHS (ATS Message Handling Services)

DATA COMMUNICATION SYSTEMS – MODE S

- It is an important technology for air traffic management, used by:
  - SSR (Secondary Surveillance Radar)
  - TCAS (Traffic Alert and Collision Avoidance System)
  - ADS-B (Automatic Dependent Surveillance – Broadcast)
- In the case of SSR, the transponder in the aircraft is periodically interrogated by ground radars



DATA COMMUNICATION SYSTEMS – MODE S

- The query signals have a frequency of 1030 MHz
- The transponder response signals have the frequency of 1090 MHz

- Queries are dedicated to a specific aircraft, the unique 24-bit address of the aircraft is used
- There are 3 types of query/response:
  - Supervision: position update
  - Comm-A/Comm-B: 56 bits of data
  - Comm-C/Comm-D: up to 1280 bits
- Message structure:
  - The first 5 bits represent the query type
  - The last 24 bits represent the plane address and parity

DATA COMMUNICATION SYSTEMS – VDL

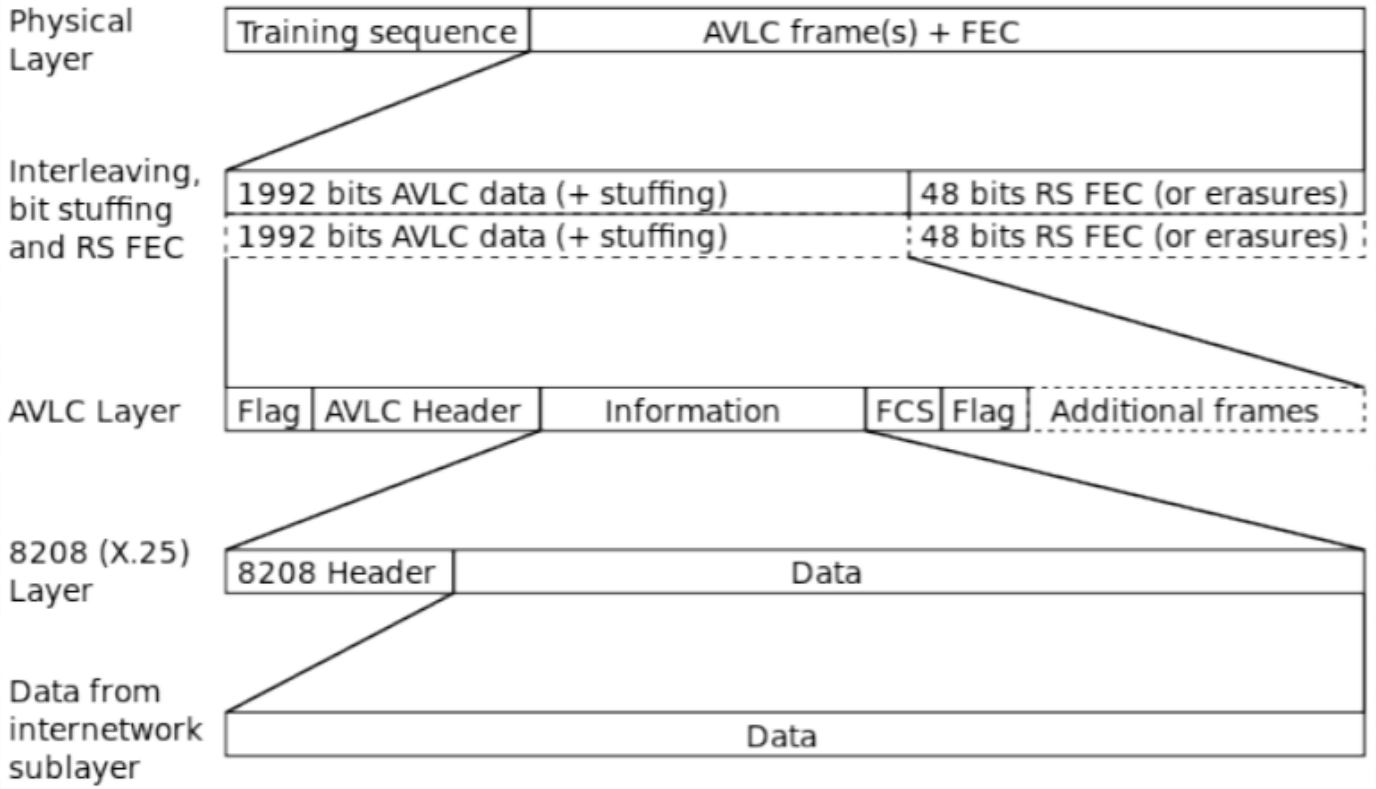
- VDL – VHF Air-Ground Data Link is used for communication between aircraft and ground
- There are 3 VDL modes:
  - Mode 2: data communications with CPDLC support
  - Mode 3: voice and data communications
  - Mode 4: also allows plane-plane communications
- Mode 2
  - Physical layer
    - The frequency band is 117.975-137 MHz with 25 kHz channel spacing
    - Common channel signaling at 136.975 MHz is used
    - TDD is used

DATA COMMUNICATION SYSTEMS – VDL

- VDL uses D8PSK modulation
- The bit rate is 31500 bps
- Reed-Solomon codes are used for error correction

- MAC layer:
  - The access technique is CSMA (Carrier Sense Multiple Access)
- Frame structure
  - The data is grouped in 8208-type (ISO/IEC 8208) frames and an 8208-type header is added
  - The 8208-type frame is inserted into an AVLC (Aviation VHF Link Control) frame and the AVLC header and FCS (Frame Check Sequence) sequence are added
  - Several AVLC frames are interleaved, and the RS FEC code is applied
  - The obtained frames are inserted after the training sequence

DATA COMMUNICATION SYSTEMS – VDL



DATA COMMUNICATION SYSTEMS – ACARS

- ACARS – Aircraft Communications and Reporting System is a system for transmitting short messages between aircrafts and ground stations
- ACARS message types:
  - Air traffic control messages
  - Operational control messages
  - Administrative messages
- MSK (Minimum Shift Keying) modulation is used for ACARS messages
- The data link can be VHF, HF or satellite

VOICE COMMUNICATION SYSTEMS – VHF

- Dual sideband AM signals are used for voice communications
- Use the frequency band 117.975-137 MHz, with 8.33, 25, 50 or 100 kHz channel separation
- The maximum frequency in the spectrum of the voice signal is 3-4 kHz
- The communication is standardized
  - For example, MAYDAY is used in critical situations, and PAN PAN in emergency situations

Letter	*Word*
A	Alfa
B	Bravo
C	Charlie
D	Delta
E	Echo
F	Foxtrot
G	Golf
H	Hotel
I	India
J	Juliett
K	Kilo
L	Lima
M	Mike
N	November
O	Oscar
P	Papa
Q	Quebec
R	Romeo
S	Sierra
T	Tango
U	Uniform
V	Victor
W	Whiskey
X	X-ray
Y	Yankee
Z	Zulu

SELCAL SYSTEM

- It is a radio system with selective calling that alerts the crew about communication messages intended for them
  - Each aircraft has an associated SELCAL code
  - The ground station transforms the 4-letter SELCAL code into 4 specific audio tones
  - The tones are broadcasted
  - Each SELCAL receiver decodes the message and checks if it contains its own SELCAL code
  - If yes, the crew is alerted by an audible/visual signal that they will receive an audio message

A	312.6 Hz	**E**	473.2 Hz	**J**	716.1 Hz	**P**	1083.9 Hz
B	346.7 Hz	**F**	524.8 Hz	**K**	794.3 Hz	**Q**	1202.3 Hz
C	384.6 Hz	**G**	582.1 Hz	**L**	881.0 Hz	**R**	1333.5 Hz
D	426.6 Hz	**H**	645.7 Hz	**M**	977.2 Hz	**S**	1479.1 Hz

EMERGENCY LOCALIZATION SYSTEM

- ELT (Emergency Locator Transmitter) can operate at 121.5 MHz or 406 MHz
  - Modern ELTs use radio beacons at 406 MHz
  - Messages are sent periodically at 50s
  - These are received by transponders on COSPAS-SARSAT (Space System for Search of Vessels in Distress – Search and Rescue Satellite-Aided Tracking) satellites
  - The location is detected with a precision of 2-5 km
  - ELT also transmits the identity of the aircraft, including the 24-bit address of the aircraft
  - ELT activates automatically in the event of an impact

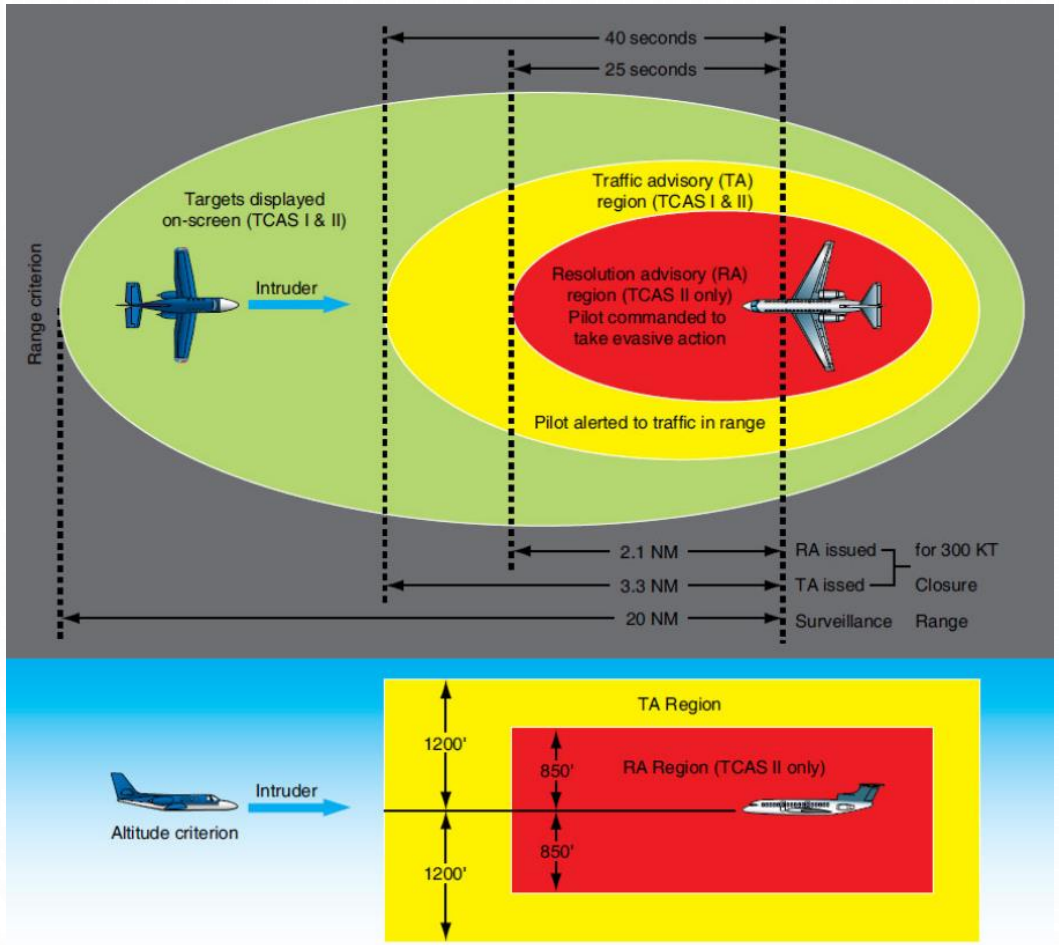
SUPERVISION SYSTEMS – ACAS

- ACAS – Airborne Collision Avoidance System
  - Allows the identification of surrounding aircrafts via the SSR transponder and provides their position to facilitate visual identification
  - ACAS must have the following functionalities:
    - Surveillance
    - TA (Traffic Advisory) generation
    - Hazard detection
    - RA (Resolution Advisory) generation
    - Coordination
    - Communication with ground stations
  - An implementation of ACAS is the TCAS (Traffic Collision Avoidance System)

SUPERVISION SYSTEMS – TCAS

- The transponder interrogates SSR at 1030 MHz and receives a response from surrounding aircrafts at 1090 MHz
  - The planes also appear on a display
  - If a plane is closer than 3.3 NM (1 Nautical Mile = 1.852 km) a TA will be issued that will warn the pilot of a nearby aircraft and help visually identify the aircraft
  - If the airplane approaches more than 2.1 NM, an RA will be emitted, which will indicate the actions necessary to avoid the collision (e.g., climb, climb)
    - The other aircraft will receive RA in reverse (e.g., descend, descend)
    - The pilot must follow the RA instructions even if they contradict the instructions received from the air traffic controller and inform the controller of the RA
    - RA refers only to vertical avoidance maneuvers

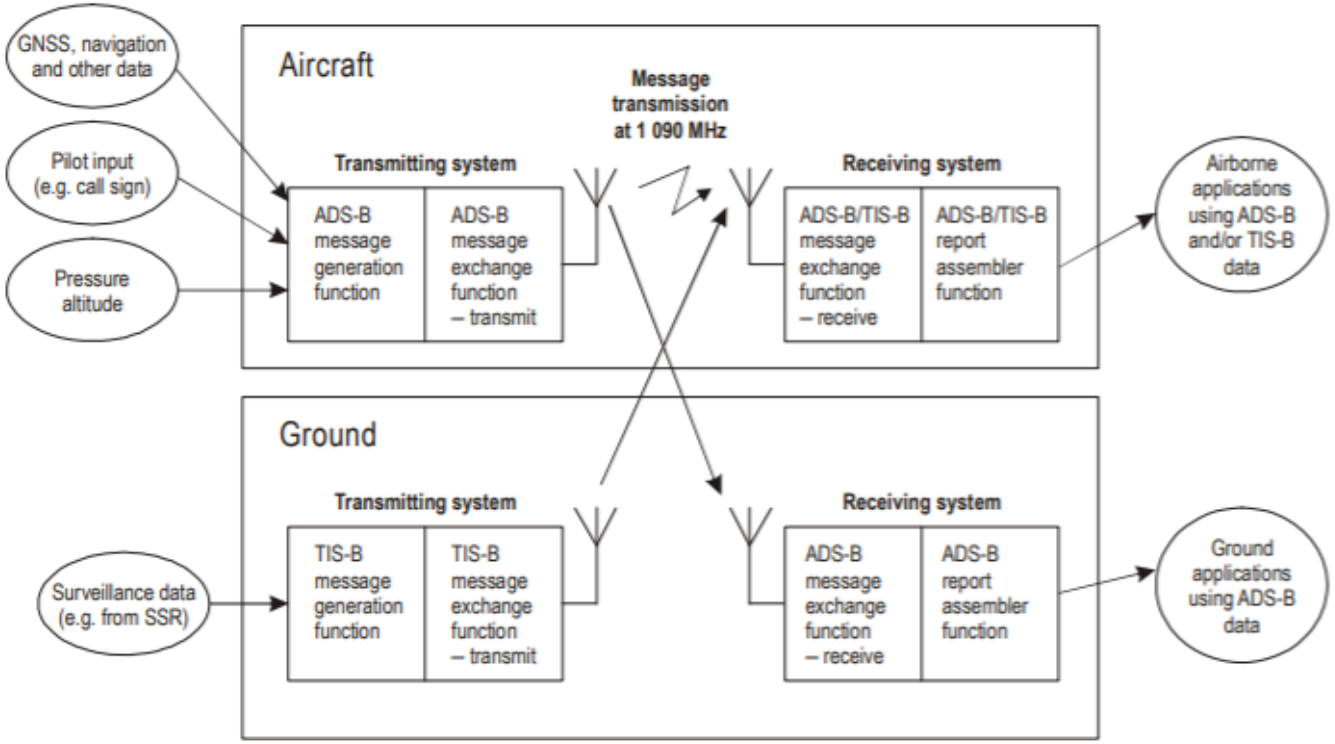
SUPERVISION SYSTEMS – TCAS



TA	*Traffic; traffic.*	Intruder near both horizontally and vertically.	Attempt visual contact, and be prepared to manoeuvre if an RA occurs.
RA	*Climb; climb.*	Intruder will pass below	Begin climbing at 1500–2000 ft/min
RA	*Descend. Descend.*	Intruder will pass above.	Begin descending at 1500–2000 ft/min
RA	*Increase climb.*	Intruder will pass just below	Climb at 2500 – 3000 ft/min.
RA	*Increase descent.*	Intruder will pass just above.	Descend at 2500 – 3000 ft/min.
RA	*Reduce climb.*	Intruder is probably well below.	Climb at a slower rate.
RA	*Reduce descent.*	Intruder is probably well above.	Descend at a slower rate.
RA	*Climb; climb now.*	Intruder that was passing above, will now pass below.	Change from a descent to a climb.
RA	*Descend; descend now.*	Intruder that was passing below, will now pass above.	Change from a climb to a descent.
RA	*Maintain vertical speed; maintain.*	Intruder will be avoided if vertical rate is maintained.	Maintain current vertical rate.
RA	*Level off, level off.*	Intruder considerably away, or weakening of initial RA.	Begin to level off.
RA	*Monitor vertical speed.*	Intruder ahead in level flight, above or below.	Remain in level flight.
RA	*Crossing.*	Passing through the intruder's level. Usually added to any other RA.	Proceed according to the associated RA.
CC	*Clear of conflict.*	Intruder is no longer a threat.	Return promptly to previous ATC clearance.

SUPERVISION SYSTEMS – EXTENDED SQUITTER

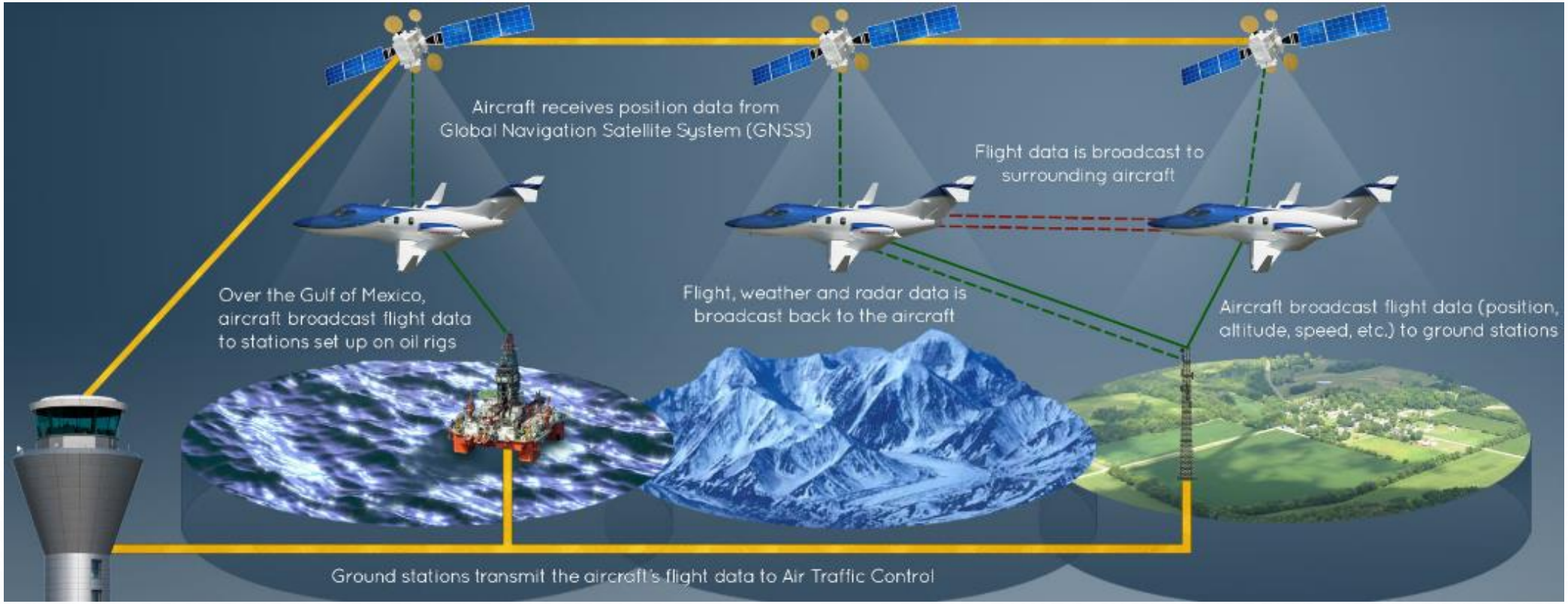
- Used for transmitting and receiving ADS-B/TIS-B (Automatic Dependent Surveillance Broadcast/Traffic Information Service Broadcast) messages



SUPERVISION SYSTEMS – ADS-B

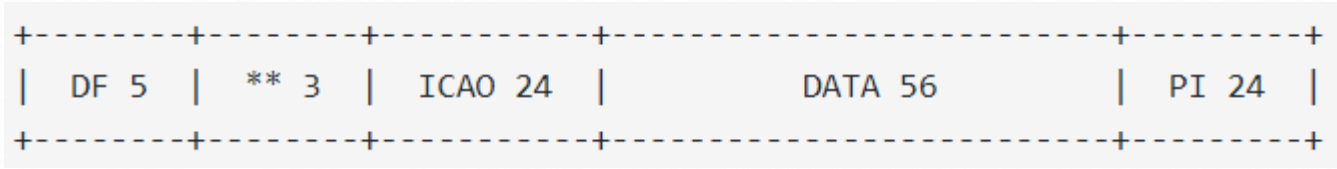
- ADS-B makes aircraft visible to both controllers and other aircrafts and consists of two services:
  - ADS-B Out
    - Each aircraft periodically sends information about identification, position, altitude, speed
  - ADS-B In
    - Used to receive TIS-B/FIS-B/ADS-B messages
- The system is based on 2 components:
  - Satellite navigation source – GPS or other GNSS receivers
  - Data link
    - Usually provided by a Mode S transponder

SUPERVISION SYSTEMS – ADS-B



SUPERVISION SYSTEMS – ADS-B

- ADS-B message structure
  - 112 bits
    - DF: Downlink format
    - Bits 6-8: additional identifier
    - ICAO 24: aircraft address
    - Data 56
    - PI 24: parity, interrogator ID



Type Code	Content
1 - 4	Aircraft identification
5 - 8	Surface position
9 - 18	Airborne position (w/ Baro Altitude)
19	Airborne velocities
20 - 22	Airborne position (w/ GNSS Height)
23 - 27	Reserved
28	Aircraft status
29	Target state and status information
31	Aircraft operation status

ALLOCATION OF FREQUENCY BANDS

- Frequencies used in emergencies
  - 2182 kHz is the international emergency frequency for maritime and aeronautical radiocommunications
  - 4125 kHz can be used for communication with maritime stations in emergency situations
  - 3023 and 5680 kHz are used to coordinate rescue operations
  - 406, 121.5 and 243 MHz are used for emergency location beacons
- Frequencies below 30 MHz
  - The 2.8-22 MHz band is used for the aeronautical mobile service

ALLOCATION OF FREQUENCY BANDS

- Band 117.975-137 MHz with a minimum separation of 8.33 kHz
  - It is used for national and international aeronautical mobile service, with exceptions:
    - 121.5 MHz – emergency frequency
    - 121.55-121.9917 MHz – ground communication frequency
    - 123.1 MHz – auxiliary emergency frequency
    - 123.45 MHz – air-to-air communications
    - 136.975 MHz – common signaling channel for VDL Mode 2
- Band 108-117.975 MHz
  - Is used for ILS, VOR, GNSS GBAS without overlaps
- Band 960-1215 MHz
  - is used for DME (Distance Measuring Equipment)

EUROPEAN AVIATION NETWORK

- EAN is a hybrid network built by Inmarsat, Deutsche Telekom and Nokia
- It is used for WiFi in the plane and consists of a ground-assisted LTE network with satellite connection
  - The LTE network is dedicated, the aircraft receivers are modified to compensate for the Doppler effect
  - Airlines using EAN: British Airways, Lufthansa, Vueling, etc.

CONCLUSIONS

- Telecommunication functions are processed by different equipment:
  - Communications: VHF or satellite unit
  - Supervision: Mode S transponder and GNSS data link
  - Navigation: GPS and ILS
- Aviation accidents involving communication systems:
  - 2014 Malaysia Airlines Flight 370: the last messages were received through Classic Aero, after the disappearance from the radar there were 7 handshake procedures (one per hour)
  - 2002 Ueberlingen mid air collision: one of the planes followed the TCAS, the other did not
  - 1990 Alitalia Flight 404: different ILS indications at the pilot and co pilot
  - 1977 Tenerife airport collision: misunderstanding by repeating the word "takeoff" in different contexts, without effective take off permission