CNS / ATM

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Infraestructures del transport aeri

Outline

Acronyms

- C: Communications
- N: Navigation
- S: Surveillance

Definition

CNS systems, employing **digital technologies**, including satellite systems together with various **levels of automation**, applied in support of a **seamless** global air traffic management system.

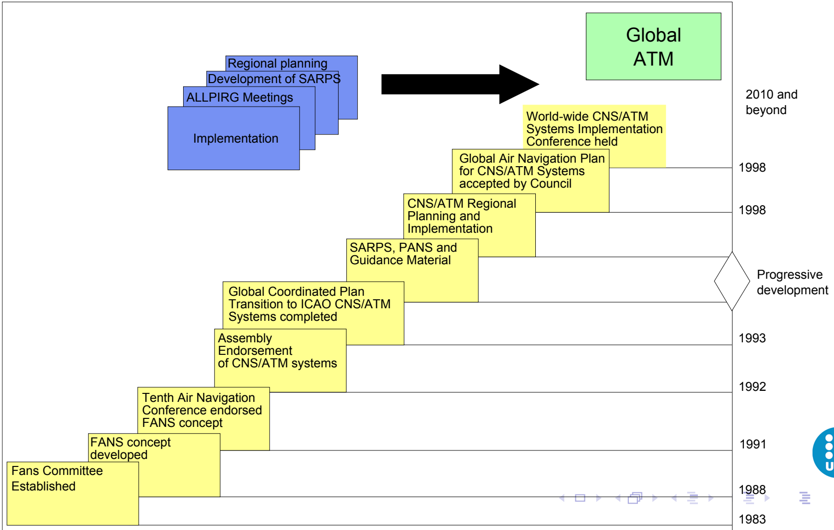
Strategic Vision

To foster implementation of a seamless, global ATM system that will enable aircraft operators to:

- meet their planned times of departure and arrival.
- adhere their preferred flight profiles with minimum constraints.

...without compromising agreed **levels of safety**.

Timeline


Global ATM
Regional planning
Development of SARPS
ALLPIRG Meetings
Implementation
2010 and beyond
World-wide CNS/ATM Systems Implementation Conference held
1998
Global Air Navigation Plan for CNS/ATM Systems accepted by Council
1998
CNS/ATM Regional Planning and Implementation
SARPS, PANS and Guidance Material
Progressive development
Global Coordinated Plan Transition to ICAO CNS/ATM Systems completed
1993
Assembly Endorsement of CNS/ATM systems
1992
Tenth Air Navigation Conference endorsed FANS concept
1991
FANS concept developed
1988
Fans Committee Established
1983

A high-level view of expected benefits of the CNS systems

Air Traffic Management

- Enhanced safety.
- Increased system capacity.
- Reduced delay.
- Reduced flight operating costs.
- More efficient use of the airspace; better accommodation of optimum flight profiles.
- Reduced controller workload $\rightarrow$ increased productivity.

A high-level view of expected benefits of the CNS systems.

Communications. Challenges

- More direct and efficient air-ground linkages.
- Improved data handling.
- Reduced channel congestion.
- Reduced communications errors.
- Interoperability across applications.
- Reduced workload.

A high-level view of expected benefits of the CNS systems

Communications. New concepts/systems

- Reduced VHF frequency spacing (8.33 kHz).
- Aircraft Communications Addressing and Reporting System (ACARS).
- Controller-Pilot DataLink Communications (CPDLC).

A high-level view of expected benefits of the CNS systems

Navigation. Challenges

- High integrity, high reliability, all-weather navigation services worldwide.
- Improved four-dimensional navigation accuracy.
- Cost savings from reduction or non-implementation of ground-based navigation aids.
- Better airport and runway utilization.
- Provision of NPA/PA capabilities at presently non-equipped airports.
- Reduced pilot workload.

A high-level view of expected benefits of the CNS systems

Navigation. New concepts/systems

- Global Navigation Satellite System (GNSS).
    - Global Positioning System (GPS).
    - Global'naya Navigatsionnaya Sputnikovaya Sistema (GLONASS).
    - European Global Satellite Navigation System (GALILEO).
    - (...)
- Augmentation systems.
    - Ground-Based Augmentation System (GBAS) / Local Area Augmentation System (LAAS).
    - Satellite-Based Augmentation System (SBAS) / Wide Area Augmentation System (WAAS).
    - Aircraft-Based Augmentation System (ABAS).

A high-level view of expected benefits of the CNS systems

Surveillance. Challenges

- Reduced error in position reports.
- Surveillance in non-radar airspace.
- Cost savings.
- Higher degree of controller responsiveness to flight profile changes.
- Conformance monitoring.
- Improved emergency assistance.

A high-level view of expected benefits of the CNS systems

Surveillance. New concepts/systems

- Transponder Mode-S.
- Automatic Dependent Surveillance (ADS):
  - Broadcast (ADS-B)
  - Contract (Addressed) (ADS-C)

The radio spectrum, a scarce resort

The radio spectrum within the electromagnetic spectrum

Radiation type	Frequency (f)	Wavelength (λ)
Ionizing	$>$ 3000 THz	$<$ 100 nm
Ultraviolet (UV)	75 - 3000 THz	100 - 400 nm
Visible	385 - 750 THz	400 - 780 nm
Infrared (IR)	0.3 - 385 THz	0.78 - 1000 μm
Microwaves	0.3 - 300 MHz	1 - 1000 mm
Radio Frequency (RF)	**0.1 - 300 MHz**	**1 - 3000 m**
Extrem. Low Freq. (ELF)	0 - 300 Hz	$>$ 1000 km

The radio spectrum, a scarce resort

Handbook on Radio Frequency Spectrum Requirements for Civil Aviation

7-4

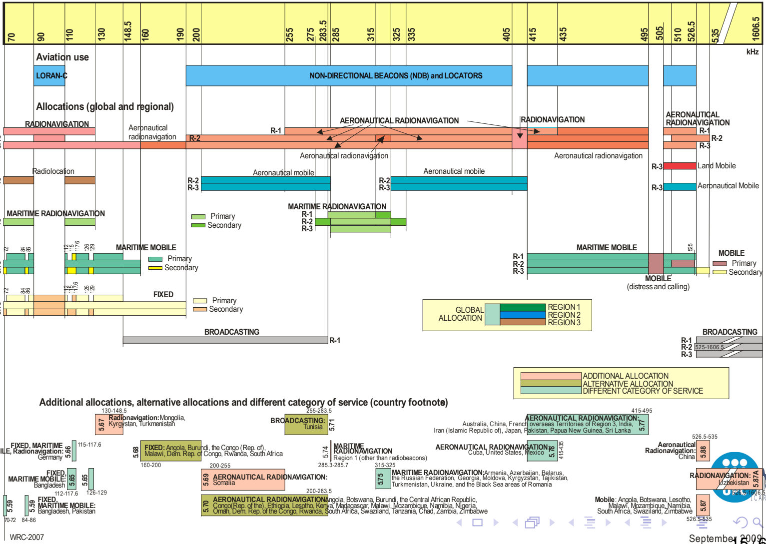
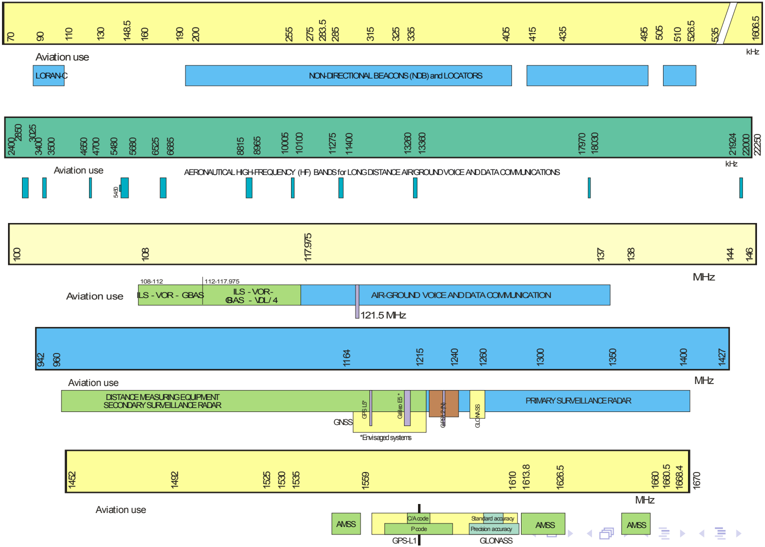


Figure 7-1 70–1 606.5 kHz

The radio spectrum, a scarce resort

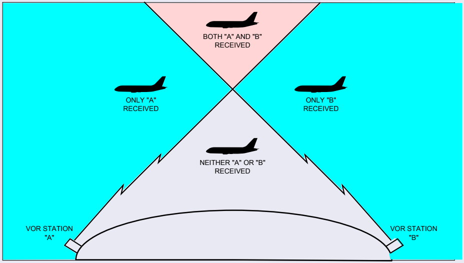


VHF Band

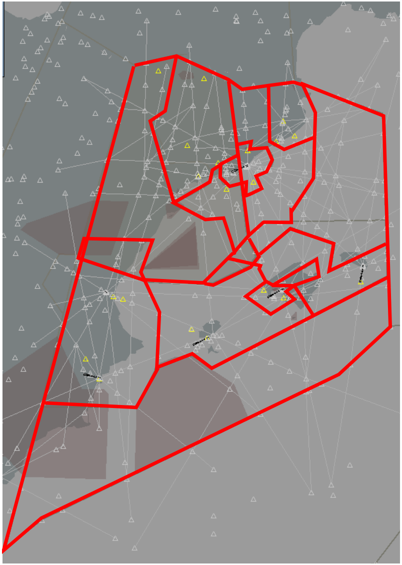
Acronym

- VHF: Very High Frequency (30-300 MHz).

VHF Fundamentals. The line-of-sight (LOS) principle



Airspace sectors. Use case: FIR-BCN



Reduced VHF channel spacing

Previous framework

Year	Airband	Channel Spacing
1947	118-132 MHz	200 kHz
1958	118-132 MHz	100 kHz
1959	118-136 MHz	100 kHz
1964	118-136 MHz	50 kHz
1972	118-136 MHz	25 kHz
1979	118-137 MHz	25 kHz

The problem & the solution

The problem

- Less delays $\rightarrow$ more capacity $\rightarrow$ smaller sectors $\rightarrow$ more frequencies.
- No more frequencies $\rightarrow$ no more smaller sectors $\rightarrow$ capacity deadlock $\rightarrow$ more delays.

The solution

- The European approach: 8.33 kHz channel spacing.
- The USA approach: VHF Data Link (VDL) Mode 3 S.

Introduction

Acronym

- ACARS: Aircraft Communications Addressing and Reporting System.

Definition

- ACARS is a digital datalink system for transmission of short, relatively simple messages between aircraft and ground stations via radio or satellite.

Motivation

VHF voice comm.

- Effective communication in the aviation environment is an essential pre-requisite to safety.
- Example: 80% Radio Telephone (RTF) are incorrect.

https://www.youtube.com/watch?v=whVXRrCH2VA

ACARS

http://en.wikipedia.org/wiki/File:Acars_sample.ogg

Working principle

How it works?

- An on board person or system can create a message and send it via ACARS to a system or user on the ground, and vice versa. Messages may be sent either automatically or manually.

Working principle

Physical layers

- VHF subnetwork.
  - A network of VHF ground radio stations ensures that aircraft can communicate with ground end systems in real-time from practically anywhere in the world.
  - The typical range depends on altitude, with a 200-mile transmission range common at high altitudes.
  - VHF communication is only applicable over land masses which have a VHF ground network installed.
- Satellite communication and HF subnetworks.
  - Satellite communication can provide worldwide However, coverage may be limited or absent at high latitudes.
  - HF datalink is a relatively new network whose installation began in 1995 and was completed in 2001.
  - Aircraft with HF or global satellite communication datalinks can fly polar routes and maintain communication with ground-based systems.

Introduction

Acronym

- CPDLC: Controller-Pilot Data Link Communications.

Definition

- CPDLC is a method by which air traffic controllers can communicate with pilots over a datalink system.

Motivation

Increasing levels of air traffic...

- Same frequency pilot-pilot interference.
- Controller workload (handover traffic).
- The number of available voice channels is limited.

Working principle

Characteristics

- The CPDLC application provides air-ground data communication for the ATC service.
- Complete set of messages:
  - Clearance
  - Information
  - Request

  ...which corresponds with voice phraseology employed by air traffic control procedures.
- Dialogue: The sequence of messages between the controller and a pilot relating to a particular transaction (e.g. request and receive a clearance).

Working principle

Characteristics

- The CPDLC application has three primary functions:
  - the exchange of controller/pilot messages with the current data authority,
  - the transfer of data authority involving current and next data authority, and
  - downstream clearance delivery with a downstream data authority.

Implementation

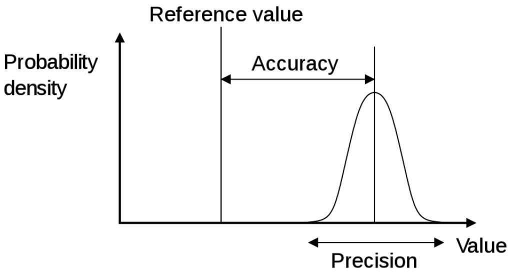
Two main implementations

- The FANS-1/A system:
  - It was originally developed by Boeing, and later adopted by Airbus.
  - It is is primarily used in oceanic routes by widebodied long haul aircraft.
  - It was originally deployed in the South Pacific in the late 1990s and was later extended to the North Atlantic.
  - FANS-1/A is an ACARS based service and, given its oceanic use, mainly uses satellite communications.
- The ICAO Doc 9705 compliant ATN/CPDLC system:
  - It is operational at Eurocontrol's Maastricht UAC Centre and has now been extended by Link 2000+ Programme to many other European FIRs.
  - The VDL Mode 2 networks operated by ARINC and SITA are used to support the European ATN/CPDLC service.

Accuracy, Integrity & Continuity

- Accuracy: Difference between the measured position at any given time to the actual or true position.

Operation	En-route	Terminal	NPA / Dept.	APV-I	APV-II	CAT I
Accuracy (hor.)	2.0 NM	0.4 NM	720 ft	52 ft	52 ft	52 ft
Accuracy (vert.)	N/A	N/A	N/A	66 ft	26 ft	13 ft



Accuracy, Integrity & Continuity

- Integrity: Ability of a system to provide timely warnings to users or to shut itself down when it should not be used for navigation.

Operation	En-route	Terminal	NPA / Dept.	APV-I	APV-II	CAT I
Time-to-alert	5 min	15 s	10 s	10 s	6 s	6 s

Accuracy, Integrity, Continuity & Availability

- Continuity: Ability of a system to perform its function without (unpredicted) interruptions during the intended operation.
- Availability: Ability of a system to perform its function at initiation of intended operation. System availability is the percentage of time that accuracy, integrity and continuity requirements are met.

Operation	En-route, Terminal, NPA / Dept.	APV-I, APV-II, CAT I
Continuity	$1 - 1 \cdot 10^{-4}$ / h to $1 - 1 \cdot 10^{-8}$ / h	$1 - 1 \cdot 10^{-6}$ per 15 s
Availability	0.99 to 0.99999	0.99 to 0.99999

Summary

- Radio determination (surveillance)
- Radio navigation
  - Ground-based (aka. Conventional) Radionavigation Aids
    - Non-Directional Beacon (NDB)
    - VHF Omni-directional Range (VOR)
    - Distance Measurement Equipment (DME)
    - Instrumental Landing System (ILS)
    - Microwave Landing System (MLS)
  - Satellite-based (aka. Conventional) Radionavigation Aids

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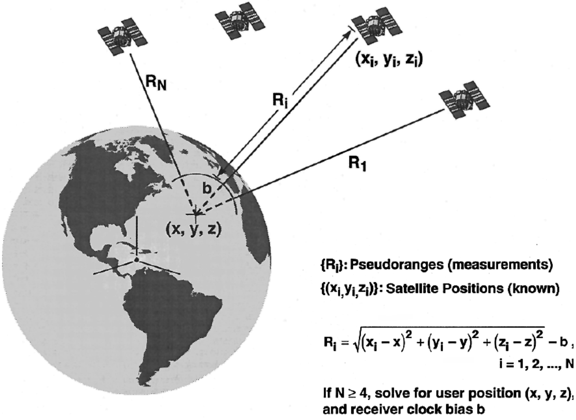
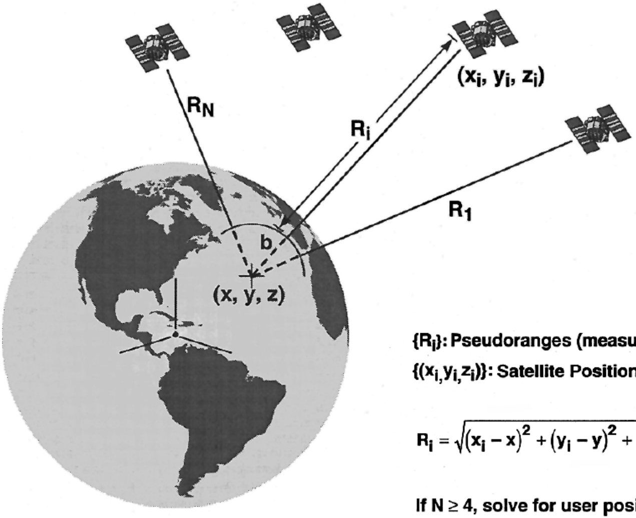
Working Principle



GPS Development

- Two key technologies:
  - Stable platforms. **Why?:**
  - Precise, ultra-stable clocks. **Why?**

GPS clocks



$\{R_i\}$: Pseudoranges (measurements)

$\{(x_i, y_i, z_i)\}$: Satellite Positions (known)

$$R_i = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2} - b\,, \quad i = 1, 2, \ldots, N$$

If $N \geq 4$, solve for user position (x, y, z), and receiver clock bias b

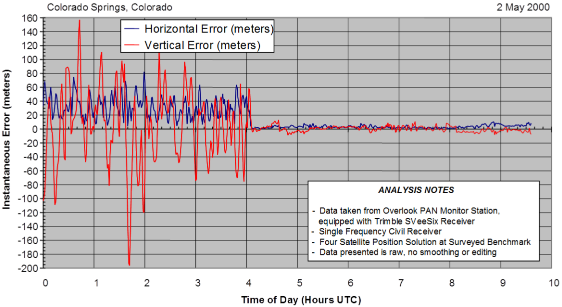
GPS Accuracy

- Selective Availability (S/A):
- Anti-spoofing (A/S):

GPS Accuracy, Integrity & Continuity

Accuracy

- Even with S/A off a Vertical Accuracy < 4 m 95% of the time cannot be guaranteed with the GPS.



GPS Accuracy, Integrity & Continuity

Integrity

- Standalone GPS integrity is not guaranteed.
- Time to alarm is from minutes to hours.
- No indication of quality of service.
- Example: Integrity requirements for CAT-I approaches:
    - Probability less than $2 \cdot 10^{-7}$ per approach than true error larger than confidence bound.
    - If Confidence bound exceeds the Alert Limit $\rightarrow$ Time to alarm less than 6 s

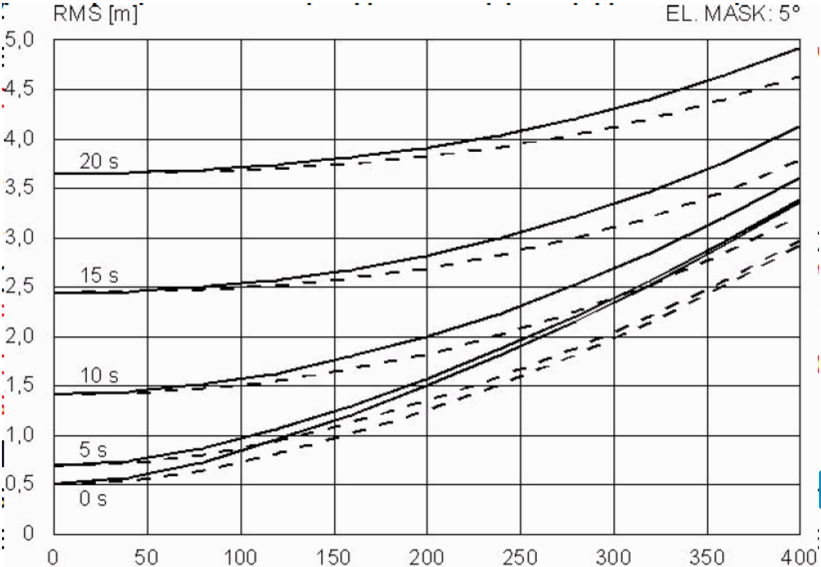
GNSS Augmentation Systems Taxonomy

- GBAS: Ground-Based Augmentation System
- SBAS: Satellite-Based Augmentation System
- ABAS: Aircraft-Based Augmentation System

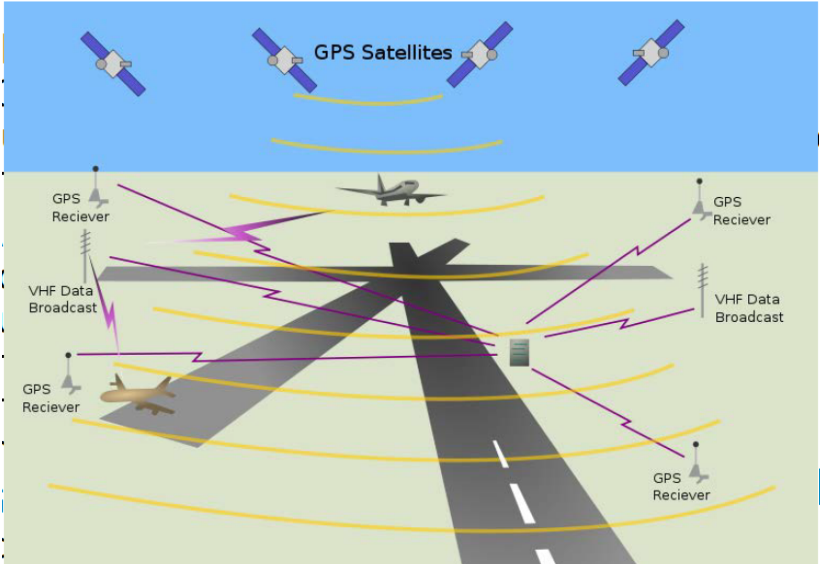
GNSS Augmentations and Differential GPS

- The quality of the position estimates from GPS depends upon the geometry of the satellite constellation and the error sources inherent to the measurements.
- The errors associated with the GPS measurements are similar for user located "not far" from each other , and they change "slowly" in time. In other words, the errors are correlated both spatially and temporally.
- The errors in the measurements of two users separated by tens of kilometers are generally similar e.g. atmospheric propagation delays change over minutes.

GNSS Augmentations and Differential GPS



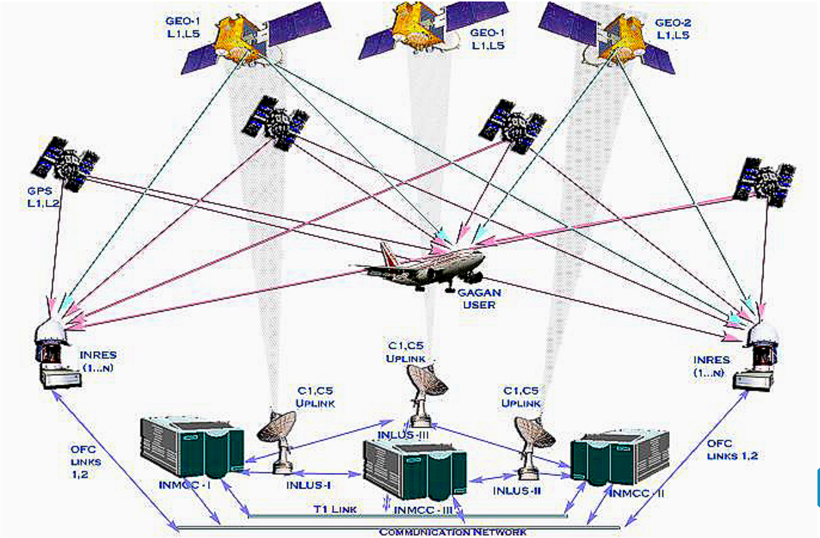
GNSS Augmentations and Differential GPS



Satellite-Based Augmentation System

- A Satellite Based Augmentation System (SBAS) is a system that supports a wide-area or regional augmentation through the use if additional satellite-broadcast messages.
- Such systems are commonly composed of multiple ground stations, located at accurately-surveyed points.
- The ground stations take measurements of one or more GNSS satellite signals and other environmental factors which may impact the signal received by the users.

Satellite-Based Augmentation System



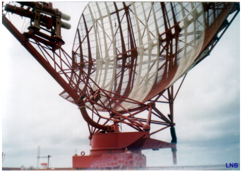
Aircraft-Based Augmentation System

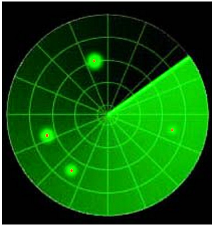
- The term Aircraft Based Augmentation System (ABAS) describes a system that supports augmentation through the use of avionics processing techniques or avionics integration to meet aviation requirements.
- ABAS augments and/or integrates GNSS information with information available on-board the aircraft in order to enhance the performance of the core satellite constellations.
- The most common ABAS technique is called Receiver Autonomous Integrity Monitoring (RAIM).
- RAIM requires redundant satellite range measurements to detect faulty signals and alert the pilot.

- PSR: Primary Surveillance Radar
- SSR: Secondary Surveillance Radar / Transponder

Primary surveillance Radar (PSR)

- Provides azimuth & range ('analogical').
- Independent of the aircraft → useful for non-cooperative surveillance.
- 'Brute force' technology: High power, low performance.





Secondary surveillance Radar (SSR)

- Extends PSR data.
- Dependent on the aircraft equipment → Only useful for cooperative surveillance.
- Aircraft equipment: Transponder

Secondary surveillance Radar (SSR)

- Divided into three modes:
  - **Mode A:** Provides aircraft identification (enhanced military 'Friend or Foe' system)
  - **Mode C:** Provides aircraft identification & altitude.
  - **Mode S:**
    - **ELS:** Elementary Surveillance. Unique aircraft identification & ACASII RAs (TCAS Resolution Advisories)
    - **EHS:** Enhanced Surveillance. Velocity & altitude. Vertical intention.
    - **E/S:** ADS-B. Position (airborne/surface). Status. Identification and type. Airborne velocity. Event-driven information (emergency & operational status).

Aircraft Communications Addressing and Reporting System (ACARS)

- **ADS-C** Automatic Dependent Surveillance - Contract.
  - Currently used in oceanic (and remote) areas.
  - Provides aircraft position, altitude, speed, intent, and meteorological data.

ADS-B

- Next years: Only OUT, not IN. $\rightarrow$ **NO ASAS!!**
- Support to long-term aircraft intent removed.
- It enhances the controller situational awareness, but nothing more than that.

ADS-C

- One or more reports are generated in response to an ADS contract, which is requested by the ground system.
- An ADS contract identifies the types of information and the conditions under which reports are to be sent by the aircraft.
- The aircraft can also send unsolicited ADS-C emergency reports to any ATSU that has an ADS contract with the aircraft.
- There are three types of contracts:
  - Periodic contract;
  - Demand contract; and
  - Event contract:
    - **WCE:** Waypoint change event.
    - **LRDE:** Level range deviation event.
    - (...)

Roadmap to the surveillance structure of 2030 (SESAR)

Surveillance Technique	Near Term — Long Term (+- 2030)	Comments
Independent non-cooperative	PSR	Independent Non Cooperative systems (i.e. PSR and/or MSPSR) deployed if necessary.
	MSPSR	MSPSR deployed to address spectrum charges and a more demanding operational environment (Subject to development).
Independent cooperative	SSR	Mode A/C sensors phased out due to RF inefficiencies, the availability of cost effective alternatives and also by an increasing dependency upon the use of ACID (ELS) and airborne parameters (EHS).
	Mode S SSR Remains in regions of high traffic density	Higher traffic density / ELS / EHS More spectrally efficient than Mode A/C
	WAM	Depending upon complexity of network, potential for cost effective surveillance in certain terrain and can support a reduction of spectrum usage.
Dependent cooperative	ADS-B In Non Radar Environment In Radar Environment as one layer of surveillance cover.	Depending upon complexity of network, potential for cost effective means to support more demanding future applications. Ground stations may be combined with WAM and in the longer term possibly even MSPSR.
	ADS-C ADS-B In Applications ADS-B Sat	In remote areas ADS-C (Surveillance) might be phased out depending on the feasibility of satellite ADS-B and the use of ADS-B In applications.

Roadmap to the surveillance structure of 2030 (SESAR)

Surveillance Application	Near Term ... Long Term (+- 2030)	comments
ACAS	SSR	Use Mode S and Mode A/C interrogations.
	Hybrid Surveillance ACAS II v7.1	High reduction of RF contribution achieved through improvements to the ACAS system. Improved knowledge of relative aircraft position.
Aircraft Applications	ADS-B In AIRB[1] VSA[2] ITP[3] SURF[4] IM[5] SURF-IA and Airborne Separation Airborne self separation	Requires ADS-OUT and also ADS-B IN (which will initially be under voluntary equipage). Future SESAR applications may place more demanding requirements on ADS-B necessitating design changes and cockpit system upgrades.

Figure 4: Aircraft to Aircraft Surveillance

1 AIRB: Enhanced Traffic Situational Awareness during Flight Operations
2 VSA: Enhanced Visual Separation on Approach
3 ITP. In-trail-procedure
4 SURF: Enhanced traffic situational awareness on the airport surface (includes aircraft to vehicles)
5 IM. Interval Management
6 IA: Indicators and Alerts