ICAO GNSS RFI Mitigation Plan
and associated EUROCONTROL Efforts

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Overview

• High Level ICAO Provisions

• GNSS RFI Mitigation Plan Overview
  • Principles
  • Regional and Global Support to States

• Summary of Supporting Developments Plans
  • Short, Medium & Long Term Detection Capabilities
    • “Closed Loop GNSS Service Provision”
  • Intervention Capabilities to Locate and Stop RFI Events

This work has been supported by SESAR, Eurocontrol Network Manager and the GSA
State Responsibilities: ICAO ANC/12

Recommendation 6/8 – Planning for mitigation of global navigation satellite system vulnerabilities

That States:

a) **assess the likelihood and effects of global navigation satellite system vulnerabilities** in their airspace and apply, as necessary, recognized and available mitigation methods;

b) **provide effective spectrum management and protection of global navigation satellite system (GNSS) frequencies** to reduce the likelihood of unintentional interference or degradation of GNSS performance;

c) **report to ICAO cases of harmful interference to global navigation satellite system that may have an impact on international civil aviation operations**;

d) **develop and enforce a strong regulatory framework governing the use of global navigation satellite system repeaters, pseudolites, spoofers and jammers**;

e) allow for realization of the full advantages of on-board mitigation techniques, particularly inertial navigation systems; and

f) where it is determined that terrestrial aids are needed as part of a mitigation strategy, give priority to retention of distance measuring equipment (DME) in support of inertial navigation system (INS)/DME or DME/DME area navigation, and of instrument landing system at selected runways.
5.1.5 State regulators and ANS providers can take the measures described in this chapter to reduce the likelihood that GNSS service will be lost.

7.11.3.1 ANS providers must be prepared to act when anomaly reports from aircraft or ground-based units suggest signal interference. If an analysis concludes that interference is present, ANS providers must identify the area affected and issue an appropriate NOTAM.

7.12.5 National and international coordination of actions to prevent and mitigate GNSS interference is essential.

7.13.1.1 As described in Chapter 5, States can take measures to reduce the likelihood of service outages due to unintentional and intentional signal interference. ANS providers must still, however, complete a risk assessment by determining the residual likelihood of service outages and the impact of an outage on aircraft operations in specific airspace.

Appendix B, Roles of ANS Providers and Regulators: ANSP to establish appropriate strategies to mitigate GNSS outages, Regulator to validate the safety aspects of the mitigation strategies.
Introduction to RFI Mitigation Plan

• GNSS RFI Mitigation Plan History & Context
  • Initiated by Spring 2013 Workshop at Eurocontrol Navigation Steering Group Meeting
    • State / ANSP contributions on best practices
  • Guidance developed through ICAO Navigation Systems Panel
    • In response to ICAO 12th Air Navigation Conference Job Card
  • Inclusion in GNSS Manual, ICAO DOC 9849
    • Completed Navigation Systems Panel review, final review and adoption planned for NSP/3 in DEC 2016
    • Strongly supported by Airlines (ICAO Assembly Paper)

• Scope
  • Limited to threats requiring radio frequency propagation
  • Not dealing with corruption of position once it has left receiver
Moving from Vulnerability to Mitigation

• Objective of RFI Mitigation Plan
  • Define set of activities for States to ensure that risks to aviation from GNSS RFI are sufficiently mitigated
  • Checklists of set of activities to be considered
  • Much is already in place, State to decide depending on local environment
  • Not intended to impose a significant workload or investment
  • To enable reliance on GNSS and associated aviation benefits

• Focused on States
  • Spectrum a sovereign responsibility
  • Regulation and enforcement part of national oversight
  • Framework to encourage coordination and exchange of best practices
  • Supported by regional and global mechanisms due to system nature
Mitigation Plan Framework

Monitor Threats
- Proactive & Reactive Monitoring
- Environment Evolution

Assess Risks
- Scenario Variation & Escalation
- Impact Assessment
- Identify Existing Barriers

Deploy Mitigation Measures
- Reduce Risks to Acceptable Levels
- Integrate in SMS
Risk Trade Space

If probability difficult to quantify, only approach is to limit impact

Normal Events, Limited Severity

Unpredictable Catastrophic Event
Implementing Mitigation Barriers

Prevent Transmission of RFI
- Regulatory Control and Enforcement
- Outreach

Prevent GNSS Service Outage
- GNSS Resilience
- On-board Integration

Limit Severity of Impact
- CNS/ATM Integration
- A-PNT
- Detection & Resolution

GNSS RFI Vulnerability

Note: Limiting “success probability” of intentional RFI limits likelihood of events (exposure to detection)

Supported by Threat Monitoring Networks (Preventive & Reactive Role)
Identification of Probable Cause Through Elimination

**Due to Constellation / Satellite?**
- CSP Centers (GPS NAVCEN, etc.)
- Augmentation User Support (ESSP, etc.)

**Due to Space Weather?**
- Space Wx Agencies (NOAA, etc.)
- Iono Monitoring Networks

**Reported GNSS Outage Event**

**Due to Military Testing?**
- Receiver Manufacturers
- Avionics Integrators
- Civil-Military Coordination, NATO National Defense

**Due to Receiver Problem?**

**If all else can be excluded, must be RFI!**
- Local Verification & Resolution
No aggregate vision of events  ➔ Incomplete threat picture
Resolution depends on awareness of many individuals
Meeting “Stated ATCO Requirement”

- Budapest GPS Outage Simulations:
  - “Tell me when event starts, when it ends, and how many sectors are affected”
  - No simple technical solutions exist today
  - Allows contingency planning through planner ATCO

- Best to monitor at the impact source: aircraft receiver
  - Currently, only pilot can observe receiver outage
  - Subsequent reporting requires support at regional and global level to determine probable cause (only RFI is local problem)
  - Provides essential risk assessment link on operational impact

ATCO = Air Traffic Control Officer
Implemented: GNSS in EVAIR

- EVAIR = Eurocontrol Voluntary ATM Incident Reporting
  - Established Safety Process (Confidentiality, Anonymity)
  - 250 Participating Aircraft Operators
  - Coverage: Europe, Middle East, Northern Africa
  - Close cooperation with IATA
  - Part of Network Manager Functions

- Info Bulletin sent beginning 2015 and mid-2016
  - Initial wave of reports received covering 2013/2014
  - Additional reports coming in every few weeks
  - GNSS Outage one issue among many
  - Simple to set up because it is an existing process / framework
  - Working on further awareness materials
GPS Outage Reports in EVAIR

No of GPS reports
2013-Oct 2016

Steady increase especially in 2016

GPS Outages Phases of flight
2013-Oct 2016

En-Route is most affected flight phase!
Note: GPS OUT Report does NOT necessarily equate to RFI Event!

FIR = Flight Information Region

Other recent significant (confirmed) RFI cases: Sydney, Korea, Cairo, Madrid, Ankara, several (smaller cases) in France
GPS Outage Type and Duration

GPS failure 2013-Oct 2016

- Total loss; 171; 77%
- Not known 1 or total; 40; 18%
- GPS 1; 12; 5%

GPS Function normally regained during flight

Pilot reporting details and avionics impact vary

Duration of GPS outages 2013 - Oct 2016

- 15-30 min 31%
- From 30 min to 3 hours 16%
- 5-15 min 29%
- 1-5 min 24%
GPS Outage: Time and Type

Most Events Occur at Night!

B777 is most flown type in areas most affected
Geographic Distribution of Events

ECAC = European Civil Aviation Conference

ECAC 42 GPS reports

Non-ECAC 160 GPS reports
GNSS in EVAIR: Threat Monitoring

• Return to normal operations & impact on both receivers on few aircraft point to RFI with high probability
  • **Proves that RFI Outages are REAL but also limited in operational impact currently**

• Time-limited, single events do not warrant action
  • **Supports strategic objective of threat monitoring**
  • Enables setting boundaries on event probability and severity
  • Provides detection if environment changes

• Maintain central repository and statistics of GNSS Outage events
  • Consultation of GNSS service and space weather monitoring reports provide further refinement
  • May also benefit from data from local ground receivers
  • Clarify interfaces for aviation-relevant reporting
EVAIR: Trigger for Detection & Mitigation

- Significant accumulation of events in specific area leads to detection and triggers mitigation action
- Ensuring timely resolution reduces vulnerability / exposure

Detection by EVAIR

- 3rd Party Reports
- Pilot / Voice Reports
- Local ANSP - Confirm RFI Case

Inform AO’s

Locate & Eliminate Source in cooperation with local regulatory & enforcement authorities

- Deploy Operational Contingency Measures
- Publish NOTAM if reqd.
Interfaces with GNSS System Operators (GSO)

- Currently, mainly GPS NAVCEN and ESSP
  - Multi-constellation: GLONASS, Galileo, Beidou Service Centers
  - Regional SBAS User Support Centers (GBAS with local ANSP)

- **Case 1: Strategic Long Term Threat Monitoring**
  - Info from GSO to Aviation: Ensure comprehensive view of all aviation-relevant cases

- **Case 2: Tactical Mitigation: Actual Significant Outage Event**
  - Request from Aviation to GSO: Support in identifying probable cause
  - Benefit from established links (receiver issues, ionosphere, RFI testing)
Further Efforts & Ongoing Developments

• Medium Term
  • Use of ADS-B Position Integrity Category (PIC) Reports
    • Initial studies conducted, various issues
    • Derive independently on ATC side large area RFI event
  • Use of aerial work aircraft to quickly locate RFI sources
    • In cooperation with ground based resources
    • Studied use of Controlled Radiation Pattern Antenna
    • Significant increase in esp. broadband RFI localization sensitivity

• Long Term
  • Nest generation GNSS receivers: detect RFI and provide information to ATC
Summary

ICAO GNSS RFI Mitigation Plan

- Mature and available to States
- Hope to learn from feedback from local implementation

Regional and Global Support Process being put in place

- EVAIR Data and Network Manager Process
- Continuing work on appropriate airborne monitoring capabilities
- Continuing work on increased intervention capabilities
- ATCO training can mitigate until next generation capabilities in place

A lot can be done with relatively simple means

- So far, GNSS RFI threats have not lead to significant risks to aviation operations
- Continued cooperation and development of RFI vulnerability mitigation capabilities can ensure that this remains the case
- To enable full exploitation of Operational GNSS Benefits
Requests to UN ICG

• Support information exchange for aviation with GNSS system operators
  • For both threat monitoring and significant event mitigation
  • Help to identify non-RFI causes

• Forward aviation relevant reports to relevant entities (States, Regional Organizations)

• REF Slide 10 and 21
Back-Up

- Mitigation Plan Details
- Further EVAIR Details
- ADS-B based Monitoring
- CRPA Project Results
Operational Risk Context

• “Loss of Nav” is an event that each aircrew needs to be prepared for at any time
  • Safety Procedures are in place

• Potential of Wide Area GNSS Outage: ATM Context
  • Especially in busy airspace, significant workload risk if many aircraft ask controller for navigation assistance
  • Very busy airspaces tend to be mainly vectored already but move to PBN should reduce this
  • NAV has multiple roles including pilot SA to manage flight

• Reversion Scenarios for PBN
  • Majority of Air Transport Users has DME/DME and INS
  • “Budapest Real Time Simulation”
  • VOR/DME does not provide suitable RNAV capability
  • PBN implementation planning
  • ICAO Annex 10 NAVAIDS Strategy
Threat Types

• Unintentional
  • TV Broadcast Harmonics, Equipment Failure

• Intentional, not directed at aviation
  • Avoiding charges or tracking

• Intentional, directed at aviation
  • Ranges from nuisance to military threat

• Special Types
  • Military Testing
  • Spoofing

• Classification drives mitigation strategies
Key Starting Challenges

• **Observability** of RFI Events
  • Lack of reports does not mean that RFI cases don’t exist
  • Existing Spectrum Groups receive few reports
  • NOTAM search produced few results
    • Standardized terminology developed
  • Need to know what happens at aircraft!

• **Confirmation** of RFI Event
  • Difficult to conclude that GNSS outage is result of RFI
  • All other causes of outages are not local ANSP issue

• Both Challenges require State-external support
Generic RFI Mitigation: 4 Steps

Note: applies to all RFI types & scenarios!

1. Detection of RFI
   - Ground monitoring networks (aviation & non-aviation)
   - Pilot reports: difficulty in cause-effect recognition & subsequent processing
     - Automated in-flight detection would be better?
   - Flight Inspection: continuous or on occasion (non-uniform capabilities!)
   - Determination of affected area and impact critical to launch response

2. Localization of Source: ranges from simple to extremely difficult
   - In cooperation with telecom regulator / affected non-aviation parties
   - Identification of operator

3. Termination of RFI:
   - Need clear legal basis and resources for enforcement action
   - Cross border issues can be lengthy to resolve

4. Application of Consequences: fine, publicity - future deterrent
   - Update of RFI Mitigation planning as needed
EVAIR GPS Mitigation Information Flow

EVAIR- GPS focal point → Review (SAF, NAV, AOLC) → “GPS Group” Review & Next Step

Yes, potential issue:
- Determine probable cause through consultation with GNSS channels

Heads-up to Other SH
- Heads-up to AO’s
- Inform if important
- Inform if important
- Inform if important
- Inform if important
- Notify ANSP(s)
- NM Coordination

No Action (await more reports)

ECTL NM internal

EASA

No issues

No issues

No issues
EVAIR Report Possibilities?

- If precise report of start and stop coordinate of outage event are known, bisector line of potential RFI source location can be derived
  - Assumes omnidirectional RFI source
  - Multiple aircraft reports could lead to localization
  - Requires data support from airline
- Within limits, a minimum power level can also be hypothesized
Medium Term Improvements (1 of 2)

- Not really Pilot’s job to determine cause of GPS outage or to report signal in space issues
  - In the age of SWIM, should be automated
  - RFI detection standard feature in many commercial receivers

- CNS Idea: Reporting through ADS-B Figure of Merit
  - Part of ongoing investigations
  - Feasibility demonstration: Australia
  - Demonstrated benefit of air-ground cooperative approach
  - Need to test and build experience in how to integrate information

- Some guessing remains with respect to probable cause
  - Especially for wide-area outage where resolution should be fast
  - Serendipitous capability, but not ideal
ADS-B PIC Use for GNSS Monitoring

- **ADS-B:**
  - Different versions of the ADS-B Out MOPS in use
    - Different ways to encode integrity
  - Not all aircraft are “proper” ADS-B Out:
    - Version 0 implemented on voluntary basis (along with Mode S mandates, ADS-B only certified on a non-interference basis)
    - Later AMC 20-24 certification only applies to subset of fleet
    - Not necessarily using GNSS as position source
    - Some known avionics issues with version 0

- **GNSS:**
  - Different levels of performance
    - Limited information about the position source (SA On/Off, SBAS etc.)
ADS-B based GNSS Monitoring: Issues

• Difficult Capability to Test without significant RFI Event
  • Study tried to correlate ADS-B Position Integrity Category with events:
    • Known RFI Events
    • Predicted RAIM Outages
    • Iono Events
    • None of the investigated events produced reliable correlation

• But learned about use of ADS-B data
  • Careful filtering of reliable data – establish white list?
  • On-board issues usually result in a certain NUCp/NIC behaviour
    • not so common – can be filtered out
  • Most of the fleet has stable quality indicators
  • SPI IR implementation of ADS-B Out version 2 (ED-102A / DO-260B) expected to further improve the picture

• Still think that method has promise at least for “massive” RFI events
Sydney Case: ADS-B Lessons Learned

- ADS-B reports key to identifying probable source location: Aerospace Industrial Park
  - “Search” proved sufficient to terminate 3h event
- Most Ground Monitor Stations didn’t see RFI
  - Some outages on WAM network, but difficult to locate
  - Need to evaluate line of sight

- Lessons Learned
  - Aircraft with INS didn’t lose NAV
  - Contingency procedures worked
  - Some aircraft GPS receivers didn’t recover (even on turnaround!)
  - Air Services Australia recommends recording of GPS status on QAR
  - Ground and aircraft based localization must work in complement
  - Implementation simplest if within existing processes & infrastructure
Position Integrity Category

- Ground system notation (Asterix) for integrity containment bound encoding

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RFI Localization Developments
Medium Term Improvements (2 of 2)

• Controlled Radiation Pattern Antennas CRPA
  • Multi-element GNSS antenna used in defence applications
  • Not an option for airliners, but maybe flight inspection aircraft?
  • Cooperative project with FAA and DSNA

• Project Goals
  • Develop and Demonstrate Concept & Feasibility
  • Increase localization antenna sensitivity
  • Maintain own-ship position during RFI

• Process
  • Directly obtain pointing to RFI source with reduced search time
  • Allow efficient deployment of ground capabilities
  • Reduce vulnerability by dramatically reducing intervention time
Can we use a “MOTS” Solution?

- Rockwell Collins DIGAR: Digital GNSS Anti-jam Receiver
- Algorithms able to detect wide range of RFI sources (Continuous Wave (CW), swept CW, Broadband, …)
- AHRS and Direct Geolocation Processing
  NOT YET implemented / investigated

Proposed Principle of Operations

Installed system includes:
- CRPA
- Antenna & interface cabling
- DIGAR with GNSS Baseband Processing
- Laptop with DF Software

Jammer Direction Finder Display

- White area: possible RFI direction
- Red dot: received power above specified threshold

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Lab Detection Performance (AZ)

- CW Azimuth Performance, Ground Support Loiter
- Good matches mixed with directional ambiguity

Sympathetic nulls typically move in the opposite direction
Lab Detection Performance Histogram

Azimuth Error from Truth

Elevation Error from Truth
Test Results

- Trigger and Hunt search strategy not ideal
  - Figure 8 probably best
- Elevation information generally not useful with top mount CRPA
  - Consider extending DF processing to negative elevation angles
- Azimuth pointing better than ±10 degrees
  - Also when subject to ground multipath
  - Banking helps, but not dramatically
  - Detection performance not sensitive to signal type
- Need to develop smoothing filter to eliminate sympathetic nulls
  - Investigate algorithm with variable probability of false detection
- Overall results promising
  - Good match between wavefront simulator and van tests
  - AHRS and RF Calibration requirements acceptable for FI Orgs
  - Flight tests with fully integrated prototype would be useful
FAA Overflight: Technology Comparison

- Spectrum Analyzer and DF-4400 performance depend on correct mode selection and settings suitable to RFI source
- CW detection better with DF-4400, but worse for Broadband
- Bottom-mounted numbers estimated from lab measurements

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Conclusions of CRPA Project

• FAA and DSNA both prefer bottom-mount option to improve detection performance
  • Loss of ownship position not a significant concern when chasing weak RFI signal sources
  • FI A/C have alternate positioning capabilities

• CRPA-based system has higher detection performance
  • Especially for Broadband signals
    • Most PPD Signals are broadband
    • Estimated 25dB Improvement very significant
  • Not dependent on operator settings
  • Does come at an increased price

• FI Organizations and Industry encouraged to further develop GNSS RFI Geolocation Capabilities
  • Technical, Operational and Human Factors
  • Complementary role in overall RFI Mitigation Plan
Long Term RFI Mitigation Improvements

- A lot can be done with current capabilities at reasonable cost
  - EVAIR is available now
    - *Mostly a matter of setting up interfaces and data integration*
  - ADS-B FOM Monitoring excellent example of CNS synergy use without introducing additional complexity
    - Still want to reduce guesswork in future equipment
- Next Generation MC GNSS Avionics
  - ICAO NSP requested implementation of reasonable mitigation capabilities from RTCA / EUROCAE
    - Must be careful to not impact continuity of service
  - Detection capability seen as a feasible minimum
    - Permit aircraft to switch to “A-PNT capability”
  - Information must reach ANSP
    - Quick Access Recorder, Flight Operations Quality Monitoring
    - *Future: SUR Downlink Aircraft Parameters (DAP) ??*