ENAC TELECOM LAB
Presentation of ENAC

Higher education in Science & Technology in France

220 Grandes Ecoles
114 000 students (~5%) in 2009

A « Grande Ecole » is a higher education establishment very selective in the admission of students.
Presentation of ENAC

ENAC is a French “Grande Ecole” in Civil Aviation under the authority of the French Ministry of Transportation, and more specifically under the French Civil Aviation Authority.

15 initial training programmes with ~1700 students/year (Integrated Master in Engineering, Air Traffic Controller, Air Safety Systems Electronic Engineer, Civil Aviation Design and Operations Senior Technician, Air Transport Pilot, etc...)

10 Specialized Master (including 3 in China)

550 graduated students/year

Strong professional training: 7500 professionals trained per year

4 research laboratories

International:

• 6000 foreigners trained (350/year),
• 35 exchange agreements signed with international universities
• Member of PEGASUS (Partnership of a European Group of Aeronautics and Space UniversitieS)
ENAC Research Structure

Research Laboratories Supporting the Development of Safe and Sustainable Air Transport Systems

- LEEA Lab
  - Economy and Econometry for Air Transport

- LII Lab
  - Architecture, Modeling and Engineering of Interactive Systems

- TELECOM Lab
  - * Signal Processing and Navigation
  - * Electromag. and Antenna
  - * Communication Networks

- MAIAA Lab
  - Mathematics and Computer Science Applied to Aeronautics

Transverse Programs for Integrated Systems

- UAV

- ATC/ATM*
  - Airports*
  - Airplanes*
  - HMI*

* Currently under development
Introduction

ENAC TELECOM Lab includes:

– Signal Processing and Navigation group (SIGNAV), created in 1993
  contact: ojulien@recherche.enac.fr

– Electromagnetics and Antenna group (EMA), created in 1989
  contact: chabory@recherche.enac.fr

– Data Communication Networks group (RESCO), created in 2006
  contact: pirovano@recherche.enac.fr
ENAC and TELECOM Lab organization

Marc HOUALLA
Head of ENAC

Gilles PERBOST
Head of Education and Research

Robert BAUDRAIN
Head of CNS Department

Bruno LAMISCARRE
Head of Research

Christophe MACABIAU
Head of TELECOM lab

Olivier JULIEN
Head of SIGNAV

Alexandre CHABORY
Head of EMA

Alain PIROVANO
Head of RESCO
Outline

1. Human Resources and Collaborations
2. Signal Processing and Navigation group
3. Electromagnetics and Antenna group
4. Data Communication Networks group
5. Key Figures
6. Current Ph.D. Theses
7. Involvement in ENAC Educational Program
Human Resources and Collaborations

• Human Resources (as of Sep 2012)
  • 15 (9 SIGNAV + 3 EMA + 3 RESCO) permanent researchers (2 HDRs)
  • 17 (8 SIGNAV + 4 EMA + 5 RESCO) Ph.D. students

• Academic Cooperation Agreements
  • TeSA Laboratory
  • CERFACS

• Collaborations
  • Public Entities: French Civil Aviation Authority (SNAs, DTI, DSNA), Eurocontrol, ESA, CNES, DGA, GSA, European Commission, CNRS, ONERA
  • Major Companies: TAS, THAV, Airbus, EADS ASTRIUM, Rockwell Collins
  • SMEs France: M3Systems, Diginext, FDC, CGx AEROinSYS, QUO VADIS
  • Academic France: ISAE, ENSEEIHT, ENST, INSA, UT Troyes, UPS
  • Academic International: Stanford U., U. of Calgary, UPC-Barcelona, U. FAF Munich, Politecnico di Torino, TU Delft, etc...
  • Partner of GUIDE (10 companies + ENAC + ISAE)
SIGNAV Application Fields of Expertise

• The research and expertise of the group focuses on:

  • Applications:
    • Civil Aviation: ENAC being a civil aviation university, this application is the natural field of application of the research group
    • Urban and Peri-Urban Navigation: This includes pedestrian and vehicular applications, which share the problem of navigation and positioning in constrained environments. These applications are of interest for SIGNAV in order to study state-of-the-art techniques that could be applied to the civil aviation field in the future (surface navigation, receiver architecture, etc...)

  • Transverse Fields:
    • GNSS Signal Design: This is based on the scientific expertise of the group regarding GNSS, signal processing and telecommunications
    • GNSS Software Receiver: This is key to test new solutions/algorithms on real or simulated signals, and to support the ENAC education offer in GNSS
SIGNAV Scientific Fields of Expertise

• The scientific expertise of the SIGNAV group is composed of:
  - GNSS integrity monitoring
  - GNSS receiver signal processing
  - Alternative navigation - Dead Reckoning, Signals-of-Opportunity (SoO)
  - Hybridization/fusion between sensors
  - Precise positioning techniques
  - Modulation/demodulation techniques

• SIGNAV research group is attached to Ecole Doctorale MITT (Mathématiques Informatique Télécommunication de Toulouse)
GNSS for Civil Aviation (1/5)

Integrity Monitoring

- Augmentation Systems (SBAS, GBAS, ABAS) (2 patents)
- Galileo Integrity Concept
- Combined GPS/Galileo Integrity (RAIM, ARAIM, ...)
- Impact of Rare Events (Ionosphere Anomalies, Interference, ...)

<table>
<thead>
<tr>
<th>Detection/Exclusion function mean availability</th>
<th>GPS/Galileo 4 unknowns</th>
<th>GPS/Galileo 5 unknowns</th>
<th>24 sat GPS constellation 5°mask angle</th>
<th>27 sat Galileo constellation 10°mask angle</th>
</tr>
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<tbody>
<tr>
<td>APV I</td>
<td>100 %</td>
<td>100 %</td>
<td>91.45 %</td>
<td>88.14 %</td>
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<tr>
<td>LPV 200 (VAL=35m)</td>
<td>100 %</td>
<td>100 %</td>
<td>80.20 %</td>
<td>81.39 %</td>
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</table>
GNSS for Civil Aviation (2/5)

GNSS Receiver Signal Processing

- Use of new GNSS signals
- Interoperability/Compatibility with Other Systems
- Resistance to Interference and Ionosphere Anomalies
- Protection against Evil Waveforms

C/N₀ Degradation at the Correlator Output Caused by DME/TACAN on the GPS L5/Galileo E5a Signals at FL400 (Left: DME/TACAN Distribution, Center: Temporal Blanker, Right: FDIS)
GNSS for Civil Aviation (3/5)

Surface Navigation

- Characterization of multipath environment
- Precise positioning
- Integrity monitoring
- Hybridization with sensors

Prediction of the Range Error on Toulouse-Blagnac Airport due to Multipath using a Hybrid Deterministic-Statistical GPS Multipath Simulator (Developed with EMA Research Group)
GNSS for Civil Aviation (4/5)

Contribution to Operational Needs (1/2)

- Online RAIM Prediction Tool

- SAT4Flight is a licensed software created in collaboration between ENAC SIGNAV, ENAC CA/PO, CGx AEROinSYS and QUOVADIS

- Development of a RAIM prediction tool in accordance with DO208/DO229C En-route to NPA integrity requirements

- Takes into account the onboard Rx assumed mask angle and the environment obstacles

- Algorithm for GPS L1 C/A LSR-RAIM with both GPS alone and baro-aided GPS

Figure from CGx AERO in SYS – Sat4Flight® Presentation, June 2010
GNSS for Civil Aviation (5/5)

Contribution to Operational Needs (2/2)

- Prediction of GAST-C and GAST-D Availability

GBAS Availability Prediction Software Interface (Left) and Example of Procedure Considered (Top)
Urban and Peri-Urban Navigation (1/3)

Receiver Signal Processing

- High-Sensitivity GNSS Receiver Techniques
- Robust Tracking in Difficult Environment
- Tracking of SoO (1 patent)

Performance of Pseudorange Measurements on DVB-T Signals in the Suburbs of Toulouse: Trajectory (Left), and Estimated Propagation Channel and Range (Right)
Urban and Peri-Urban Navigation (2/3)

Integrity Monitoring

- Characterization of the Propagation Channel
- Risk Assessment
- Reliability Checking
- Adapted Integrity Monitoring Algorithms

Electronic Toll Collection: Concept of Geo-objects (Top) and Probability of Undercharging the User as a Function of the Duration within the Geo-object for a GPS/Galileo L1 receiver based on an Adapted RAIM Algorithm (Assuming 5s between Independent Positions, Urban Environment, HAL=25 m) (Right)
Urban and Peri-Urban Navigation (3/3)

Hybridization / Precise Positioning

- Sensor Characterization / Hybridization with Multiple Sensors
- Carrier-Phase Positioning
- SoO Positioning (1 patent)

Real-Time Pedestrian Dead Reckoning (PDR) Solution
(3 acceleros, 3 gyros, 3 magnetos), that can be Hybridized with AGPS

Mono-Freq. GPS/GLONASS Precise Positioning Solution
GNSS Signal Design (1/2)

Signal Modulation and Receiver Design

- GNSS Signal Design
- GNSS Satellite Payload Optimization
- Processing Techniques for Future GNSS Signals (3 patents)

Running Average Multipath Error using the Binary TM61 Local Replica to Track Galileo E1 OS Pilot (Early-Late: 1/12 Chip, 12 MHz FE Filter)

Simulated Galileo E5 ALTBOC Signal Amplitude/Phase Constellation at the Output of a 92 MHz OMUX Filter
GNSS Signal Design (2/2)

GNSS Data Message

- Innovative GNSS Message Modulations and Structures
- GNSS Message Demodulation Performance Assessment

<table>
<thead>
<tr>
<th>Channel</th>
<th>AWGN</th>
<th>Mobile 30 km/h</th>
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<tr>
<td></td>
<td>C/N_0 (dB-Hz)</td>
<td>Diff. (dB)</td>
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<tr>
<td>Figure of Merit</td>
<td>GPS</td>
<td>Gal</td>
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<tr>
<td>BER 10^{-5}</td>
<td>25.1</td>
<td>28.2</td>
</tr>
<tr>
<td>WER 10^{-3}</td>
<td>24.9</td>
<td>28</td>
</tr>
<tr>
<td>EER 10^{-3}</td>
<td>23.9</td>
<td>28.5</td>
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</table>

Compared Demodulation Performance of GPS L1C and Galileo E1 OS, Assuming PLL Tracking

BER as Function of the C/N_0 for a CSK Modulation Applied to Galileo E1 OS - Each Bit Belongs to a Different Codeword Obtained using LDPC(600,1200)
GNSS Software Receiver (1/2)

GNSS Software Receiver

- C/C++ language
- Optimisation of the SW Receiver Resources
- Tests for Innovative Acquisition Tracking Algorithms
- Training Tool for Students

GPS L1 C/A Synchro-Bit Histogram (Left) and In-Phase Correlator Output (Right) after Successful Acquisition (from ENAC Software Receiver)
GNSS Software Receiver (2/2)

GNSS Receiver Simulator

- C and Matlab languages
- Faster-than-Real-Time Post-Correlation Simulator
- All Sources of Errors and Trajectories Simulated
- Performance Analysis of Innovative Tracking Algorithms
- Training Tool for Students

Investigation of the Carrier Tracking Modes \( (C/N_0 = 40 \text{ dB-Hz}, T_i = 20 \text{ ms}, B_L = 20 \text{ Hz}, \text{Initial Frequency Offset} = 10 \text{ Hz}) \)
Equipment
• Spirent STR4500 GPS L1 C/A+SBAS signal simulator
• Low-cost and high-end GNSS and TV antennas
• GNSS Receivers:
  • High-end GPS receivers from NovAtel and Septentrio
  • Low cost GPS receivers from U-Blox and SiRF
  • SW Receiver from IFEN
  • Civil aviation certified receiver from Garmin
• 2 GPS/Galileo L1 front-ends
• 2 USRP2 software transceiver platforms
• MEMS sensors from X Sense and Crossbow
• 1 EGNOS Data Collection Network station (ECTL)
• RTK software: WayPoint, Trimble Total Control
EMA – General presentation

Electromagnetics research group for aeronautical telecommunications

Staff
- 3 permanent researchers
- 4 PhD students

Main research topics
- Numerical methods for antenna/propagation modeling
- Antenna design
- Analysis of complex electromagnetic issues

Attached to Ecole Doctorale GEET (Génie Electrique Electronique Télécommunications)
Computational electromagnetics

Numerical methods for antenna/propagation modeling
- Integral equations,
- High-frequency asymptotics (physical optics, UTD, gaussian beams)
- Parabolic equation

Examples of applications
- GNSS multipath in airport environment
- Predict the performances of a VHF communication antenna in its environment
- Predict the performances of quasi optical systems
- Effects of windturbines on a nearby VOR ground station

Field radiated by the VOR station (dB)

VOR error at an altitude of 400m
Antenna design

Development of antennas for specific applications

- Satellite-based navigation (GNSS)
- Automatic direction finder (ADF)
- UAV antennas

Examples of applications

Printed wide-band antenna for UAV

Small ceramic-free GPS antenna

Precision GPS ground antenna
Analysis of specific problems related to electromagnetics

- Analysis of a jamming induced by electrostatic discharges on VHF ground antennas
- Specification of safety zone for radar antennas

Near field measurements on a secondary surveillance radar
Data Communication Networks

This research group deals with designing, studying and optimizing telecommunication network architectures. Its research areas are mainly related with aeronautical networks. Created in 2006. Attached to Ecole Doctorale SYS (Systèmes).

3 Researchers,
5 PhD students,
Areas of study and research

Main areas
- Network design from access to transport layer
- Wireless network architectures (mobile, satellite, …)
- Quality of Service
- Network security

Technical skills and methods
- Network simulation and modeling
- Network emulation
- Network traffic characterization
- Network metrology and engineering

Fields of application
- Datalink (air-ground communications)
- In-Flight Entertainment communications
- Embedded networks
- Internet and TCP/IP suite
- …
Some research projects

* Satellite System Performance Assessment for Aeronautical Communications – Ph.D. Study (ENAC/ISAE) – 2006->2009

* FAST Project - project funded by Aerospace Valley (a competitiveness cluster for aeronautics, space and embedded systems) in France – Ph.D. Study (System architecture design for security in aeronautical communications) - 2008->2011

* Capitole Project (Aerospace Valley) – Study on satellite link emulation platform with exogenous data traffic generator for aeronautical communications 2009 → 2011
Some research projects

* AeRAN - Aeronautical Ad Hoc Networks – Ph.D. Study (ENAC/Thales) – 2009 →

* D3COS (Designing Dynamic Distributed Cooperative Human-Machine Systems) – project funded by the Artemis Joint Undertaking – Ph.D. Study (Network architecture for mobile agent communication) 2011 ->

* MILSAVION: design and development of a new generation, secure, certified and embedded router for future aeronautical communications, this project is co-funded with THALES AVIONICS company. PhD Study - 2010 →

* Content-Based Routing in Aeronautical Ad Hoc Networks – Ph.D. Study (ENAC) - 2011->
Involvement in ATM - SESAR

Sesar contribution in WP15 « Ground CNS Systems »

WP 15.2.4 : End to end Quality Of Service Metrics
- Early Task (EW03 T1 et T2) : Integration and testing
  - Definition of QoS parameters
  - Network Security

WP 15.2.7 : Wimax aero
- T8 : Security and safety
- T6 : Integration and testing
Some recent publications


Frédéric Besse, Alain Pirovano, Fabien Garcia, José Radzik, “Aeronautical Ad Hoc Networks : a new Datalink for ATM”, INO 2010, 9th Innovative Research Workshop & Exhibition, 7-9 Dec. 2010, EUROCONTROL Experimental Center, Brétigny-sur-Orge, France


ENAC TELECOM LAB Key Figures

• 24 Ph.D. thesis defended, 3 post-docs
• 60+ expertise contracts
• 150+ papers published
• 7 patents (UTI/ENAC, 2xCNES/ENAC, TAS-F, AIRBUS, ENAC, Rockwell Collins)
• >600k€ revenues annually
• Support to French Civil Aviation Authority for EUROCAE WG62, RTCA SC159, ICAO NSP, WGC ARAIM SG; support to CNES for GALILEO STF and RFC
• Reviewers of 30+ journal papers (IEEE, RadioScience, ...)
• Reviewers of 3 GNSS Supervisory Authority (GSA) projects (EC), 1 ANR project
• Participation to IJNO editorial board
• Chairmen for 10 GNSS meeting sessions
• Chairs of JEE meeting sessions
• Instruction of international tutorials
<table>
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<tr>
<th>Ph.D. Title</th>
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<tr>
<td>1  Optimized GNSS-OFDM Receiver</td>
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<td>2  GNSS Software Receiver for Civil Aviation</td>
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<td>3  Ground Autonomous Aircraft Navigation</td>
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<tr>
<td>4  Multi-Frequency GNSS Receiver for Urban Precise Positioning</td>
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<tr>
<td>5  Optimization of a Software Receiver</td>
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<td>6  Study of Future GNSSS/IRS Architectures</td>
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<tr>
<td>7  Integrity Monitoring of GNSS Rare Normal Phenomena</td>
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<tr>
<td>8  Innovative signals for future GNSS</td>
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<td>9  Design of quasi-optical systems via gaussian beam-based techniques</td>
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<tr>
<td>10 Small antennas based on artificial magnetic conductors – Application to GNSS antennas</td>
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<tr>
<td>11 Corona discharges on VHF antennas caused by a natural electrostatic field</td>
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<td>12 Study of vectorial antennas for 3D direction finding</td>
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<td>13 System architecture design for security in aeronautical communications</td>
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<td>14 AeRAN - Aeronautical Ad Hoc Networks</td>
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**Current PhD Theses**

<table>
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<th>17 PhD theses</th>
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<td>11 funding sources</td>
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Involvement in ENAC Education Program (1/2)

• ENAC Engineers (IENAC): lecturers + 2 course directors
  • 1st year
    • Deterministic signal processing, GNSS, Information Theory
  • 2nd year
    • Stochastic Processes, Signal Theory/Processing, Digital Processing, Signal Transmission, Estimation/Detection, Data communication networks, Antennas and Propagation, Microwave Electronics
    • 70-hour projects
    • 1 or 2-month summer internship
  • 3rd year
    • Parametric Models, Kalman filtering, Channel Encoding, Spread spectrum techniques, Compression, Digital Receivers, GNSS, INS, Advanced data communication networks, Aeronautical Networks, Integral equations in electromagnetics, Microwave circuit modeling
    • 35h projects
    • 5-month internship

• DGAC Engineers (IESSA): lecturers
  • Signal Processing, GNSS, Antennas and Propagation, Microwaves Electronics

• Air Traffic Controllers (ATCO): lecturers
  • Basic elements of radio and propagation
Involvement in ENAC Education Program (2/2)

**ENAC Masters:**
- Courses in Specializing MASTER – postgraduate degree (CNS, AGCSE & ASAA),
- Master of Science RT (Networks and Telecommunications)
- Master of Science in GNSS, 1 course director

**Supervision of Ph.D. Studies**

**Professional Training:**
- Professional courses included in ENAC offer:
  - 7 professional GNSS courses (GNSS_BASIC, GNSS_FUTUR, GNSS_DIF, GNSS_AC, GNSS_GENE, GNSS_RAIM, GNSS_INT)
  - 4 professional Data Communication Networks courses (SECRE, NARCISSE, ETNA, RESOP)
  - 3 professional Electromagnetics courses (RDCOM, BAS3R, BROU)