GNSS LABORATORY

GNSS Laboratory: using the GPS as an interdisciplinary Laboratory on Theory of Telecommunications

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Summary

- **OBJECTIVES**
- **TRAINING METHODOLOGY DESCRIPTION**
- **GNSS LABORATORY: AREAS DESCRIPTION**
- **PROJECTS DEVELOPED**
- **CONCLUSIONS AND RESULTS**

OBJECTIVES

Generate human resources (RH) capable of overcoming the technological challenges and changes imposed to the aeronautical fields in the imminent presence of three main GNSS systems.

TRAINING METHODOLOGY DESCRIPTION

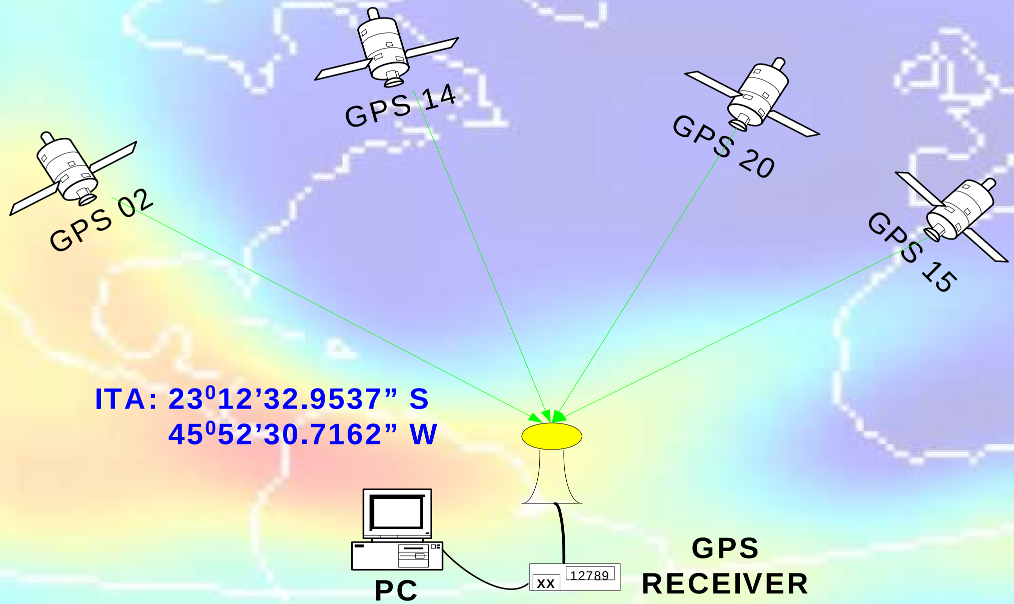
The Training Methodology at ITA GNSS Laboratory consists on the analysis of constitutive parts or segments of the GPS, and is implemented in three stages:

– **Adaptation stage** - development of skills in basic Geodesy and Navigation;

– **Basic GPS Topics stage** - deep analysis of constitutive GPS segments;

– **Advanced GPS Topics stage** – development of applications (results).

GNSS LABORATORY: AREAS DESCRIPTION



Linear Algebra	CDMA	Digital Circuits
Navigation PVT	Coding Theory	Adaptive Filtering
Propagation & Atmospheric Models	Detection & Estimation	Signal Tracking & Synchronization
Satellite Communication	Software Development	Software receiver techniques

LABORATORY OF GNSS

OBJECTIVES:

- Get qualified Human Resource to implement and/or to use the new navigation receiver systems of present (GPS/Glonass) and future GNSS (Galileo).
- Simulating, testing and design of different architectures for GNSS receivers.
- Enhance and strengthen the knowledge of telecommunications engineers, using all the operational and implementation criteria of GNSS.

STUDY PROGRAM

The study program of the Laboratory is presently based in the analyses of GPS because it is the only GNSS in fully operative conditions.

Every functioning principle is tested within an academic and research environment as a multidisciplinary laboratory of telecommunications.

In a short term it is intended to expand the research for GLONASS and in medium term for Galileo.

SUMMARY OF THE PROGRAM

Adaptation:

Topics	Subtopics
Basic Geodesic Concepts	Orbit representation (projections and maps) ECEF and ECI systems Lat/Long/Alt and UTM coordinates Reference ellipsoids and local datum (WGS-84) Datums and the geoid's problem
Navigation Basic Topics	Navigation history Triangulation Trilateration Dilution of precision (DOP)
Orbital Concepts	Kepler's laws Sideral day Anomalies

GPS Basic Topics:

Topics	Subtopics
General Description of the GPS System	Beginning and history Constitutive segments and expected performance according to FRP and ICD-GPS 200 Employment principle: Time of Arriving(*TOA*)
Spatial Segment	Satellites constellation: orbits and coverage. Generation of navigation signals and messages Expected power Real orbits data
Control Segment	Description Ephemeris constitution
User's Segment	Receiver description URA, UERE and RAIM Use of GPS receivers practice: data acquisition and processing. Use of GPS receivers practice: differential corrections.
Analysis of error and perturbation factors	SV and user clock errors Delays due to atmospheric effects Noise, resolution and hardware Selective Availability (SA) Multipath User – satellite geometry
Simulation and Analysis of Receiver's Processes	PRN Code generation Doppler shift Frequency planing and direct digitalization Acquisition and tracking Navigation message decoding and satellite coordinate calculation

Advanced GPS Topics:

Topics	Subtopics
Pseudolite	Analysis and improvement of DOP
Differential GPS	Receivers errors correlation in the same geographic region Messages in RTCM-104 format Messages in RTCA format
GBAS and SBAS	Atmospheric local models Ionospheric models Expected characteristics and performance
Attitude Determination	Actual speed calculation Quaternion use
Statistic Modeling	ARIMA models Integrity control
Receiver's Architectures	Multipath reduction Tracking algorithms
Systems Integration	GPS and inertial platforms

TEACHING STAFF:
Alessandro Anzaloni– (ATN,ATM)
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José C. da Silva Lacava–lacava@ele.ita.br (*micro strip antennas*)

Multidisciplinary Telecommunications Laboratory

The GNSS Laboratory program allows it to be used as a multidisciplinary Telecommunications Laboratory comprising:

Topic	Application Areas
Linear Algebra	-Navigation calculus and coordinates changes -Coordinates calculus with short and extended base lines -Expected Doppler shifting -User – satellite geometry
Adaptive Filtering	-LMS and LS algorithms applications for navigation -Blind deconvolution, LMS and LS for multipath rejection -Antennas arrays and spatial filtering (*smart antenna*)
Spread Spectrum Systems	-PRN codes generation -Autocorrelation in the acquisition and tracking processes
Digital Communica-tions	-Generation and simulation of the signal expected in the receiver -Frequency planning -Digital modulation: BPSK
Atmospheric and Propagation modeling	-Current ionospheric models; Klobuchar model for GPS -Analysis of the Ionospheric model of WAAS -Ray tracing
Signal Tracking with PLL/Costas Loop	-Tracking process -Coherent and non coherent PLL -Signal real and complex processing
Detection and Estimation Theory	-Acquisition process
Codes Theory	-Generation and decoding of navigation messages. -Generation and decoding of differential corrections.
Digital Signal Processing	-Sampling and DAC in the RF processing block in the receptor. -Autocorrelation -Radar

INFORMATION:
Graduation:
bruno@ita.br
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sakane@ele.ita.br
GNSS LABORATORY:
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Support:
Projects: **ICAO** and **DCEA/CTA**

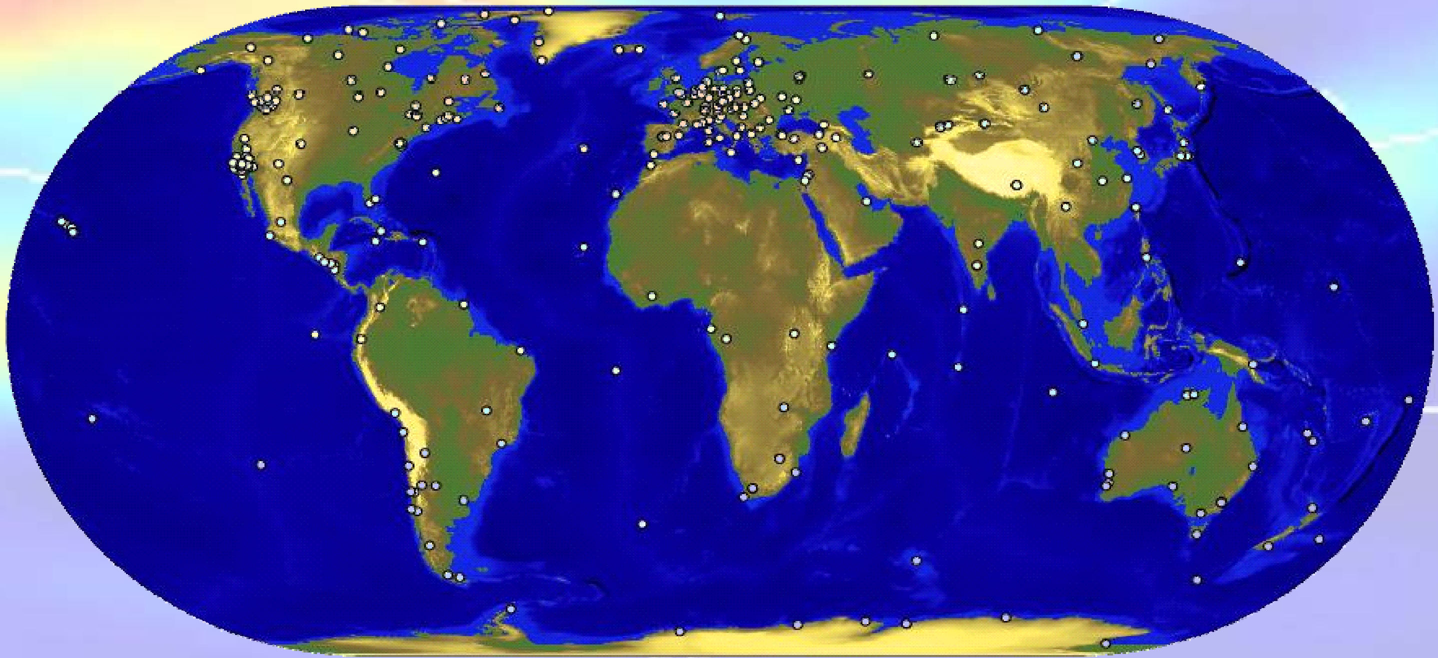
Location:
ITA is located at the Centro Técnico Aeroespacial (**CTA**), in São José dos Campos (www.sjc.com.br), city that concentrates the Brazilian Aerospace Industry. The CTA are also located near of the National Institute of Spatial Research (**INPE** – www.inpe.br) and the Brazilian Aeronautics Enterprise (**EMBRAER** – www.embraer.com.br).

Projects developed

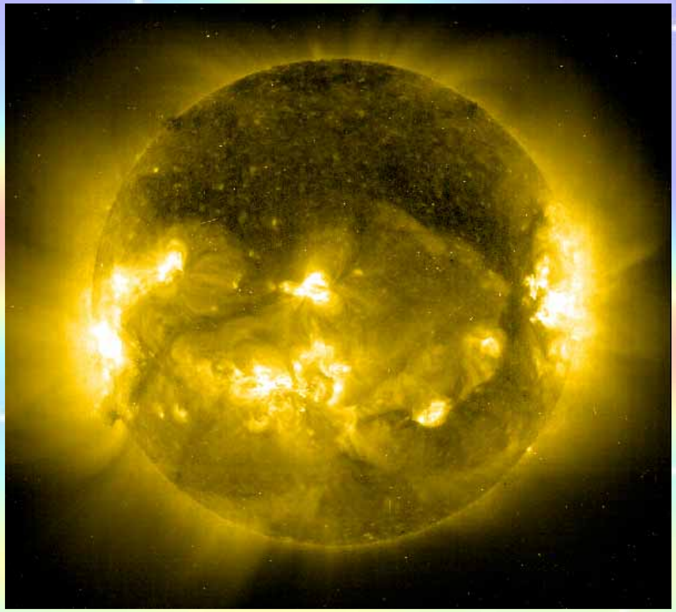
Equatorial Anomaly Modeling

IGS (INTERNATIONAL GPS SERVICE) STATIONS

- around 359 Stations;
- ~ 200 with dual frequency GPS.



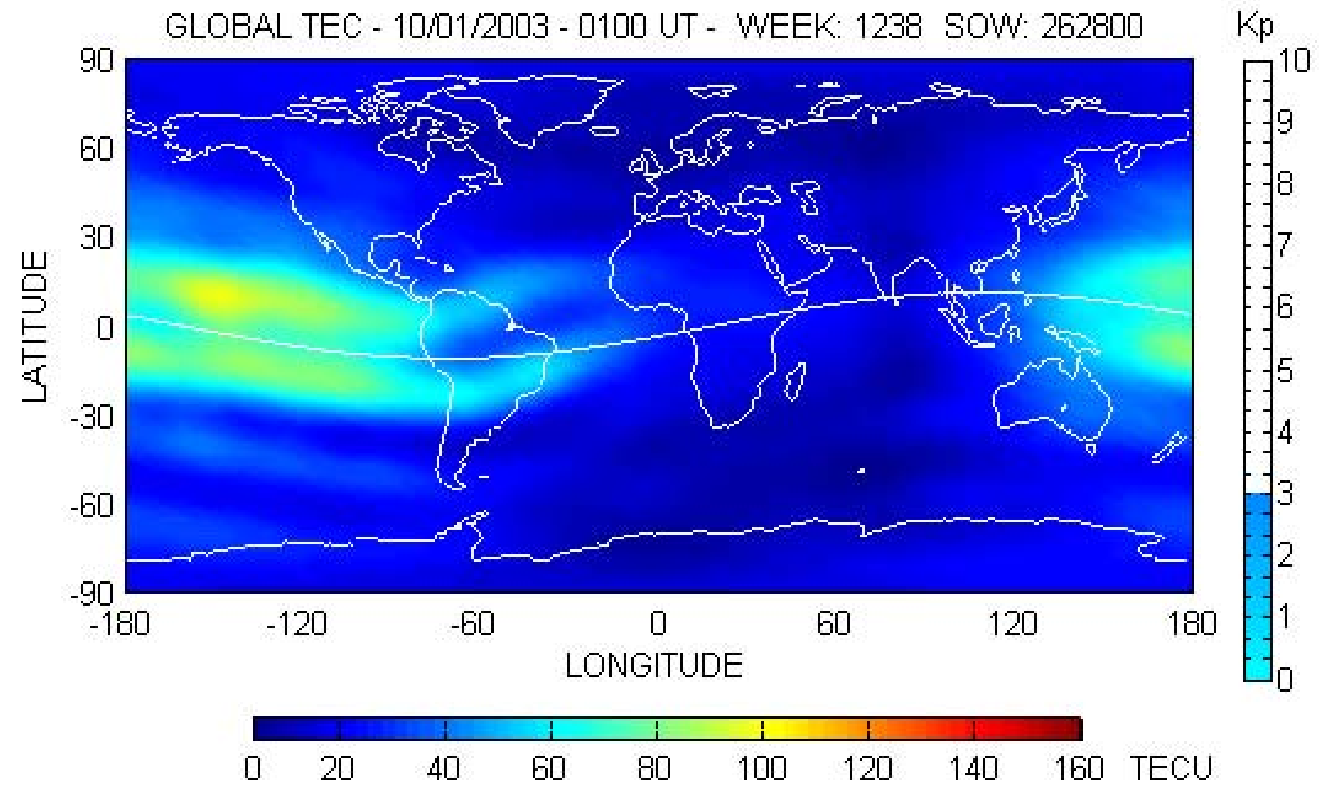
SOLAR STORMS STUDIES



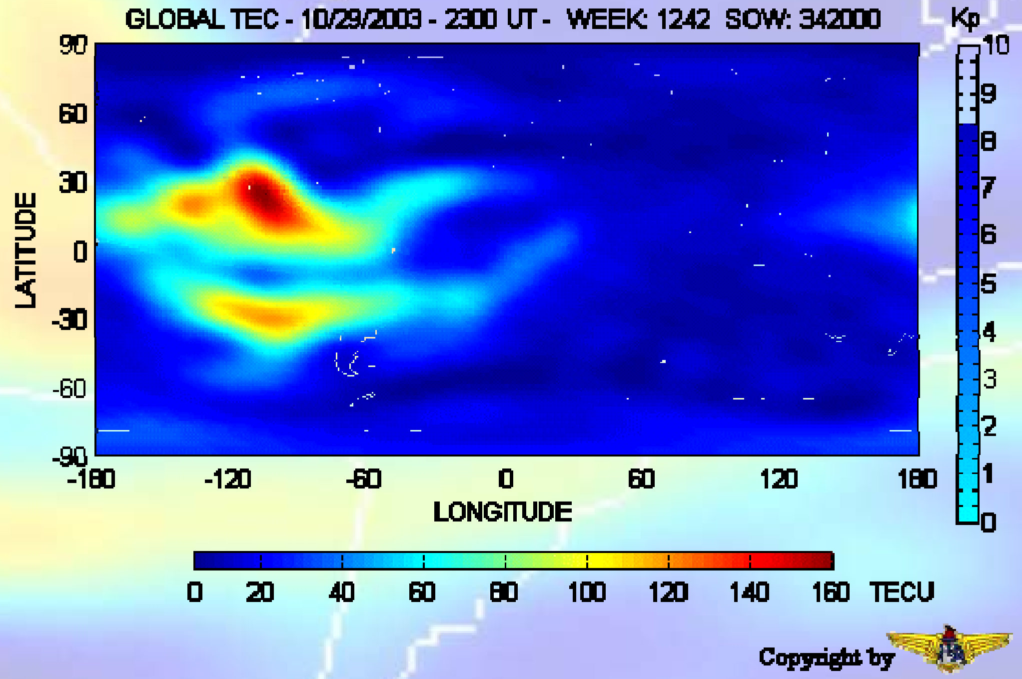
Sun Image at Oct. 28 when a great solar storm occurred (SOHO satellite).

It has been analyzed the months with more intense solar activity and correlated with the Kp index (geomagnetic Activity). In this way it can be studied the effects of the Solar storms on the GPS signals.

Project: Klobuchar Model adaptation to SBAS in Brazil (SGB)



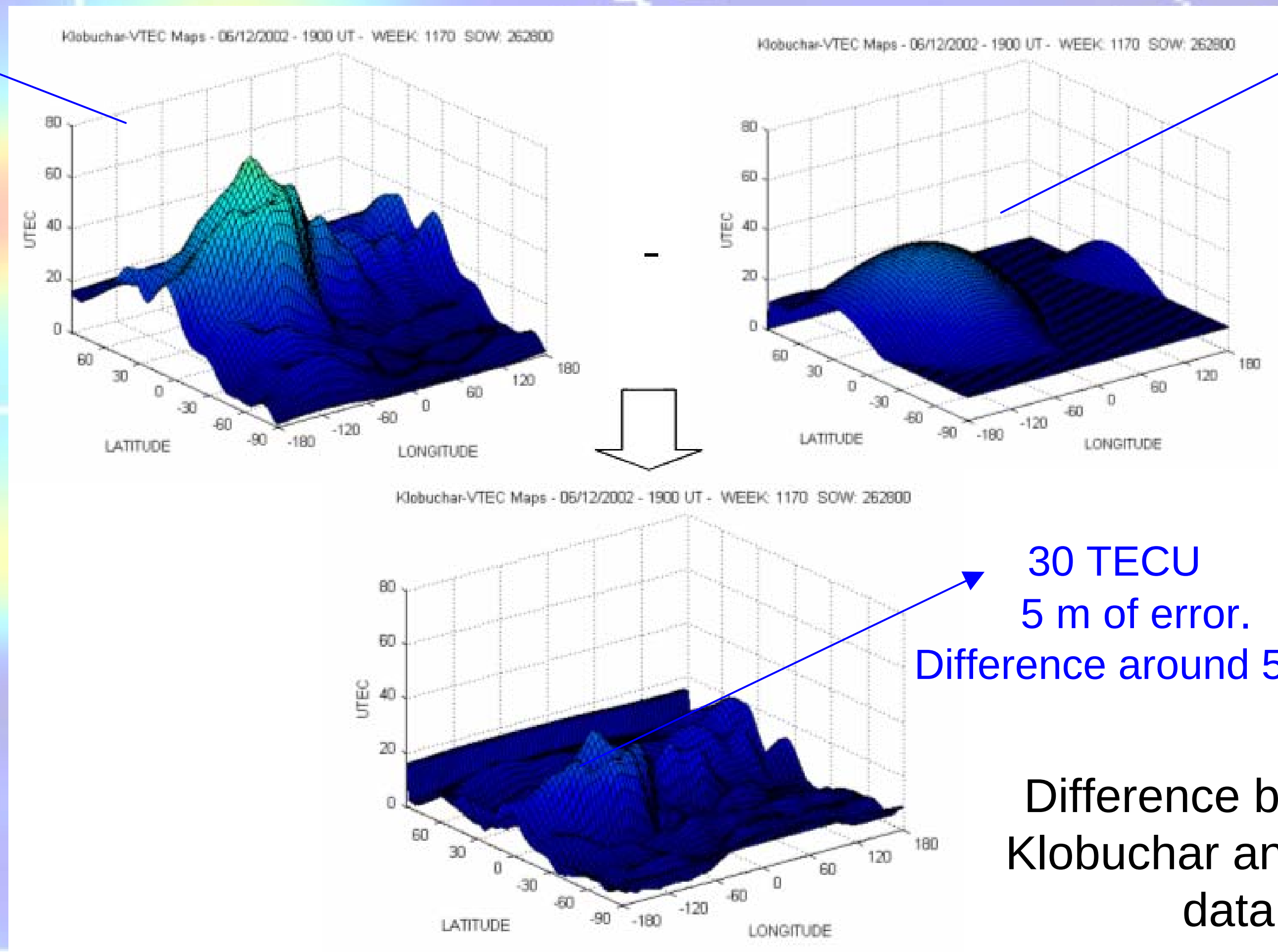
GNSS LABORATORY



DIFFERENCE BETWEEN KLOBUCHAR MODEL AND ACTUAL DATA

60 TECU
10 m of error

30 TECU
5 m of error



Actual $VTEC_M$

Klobuchar Model $VTEC_K$

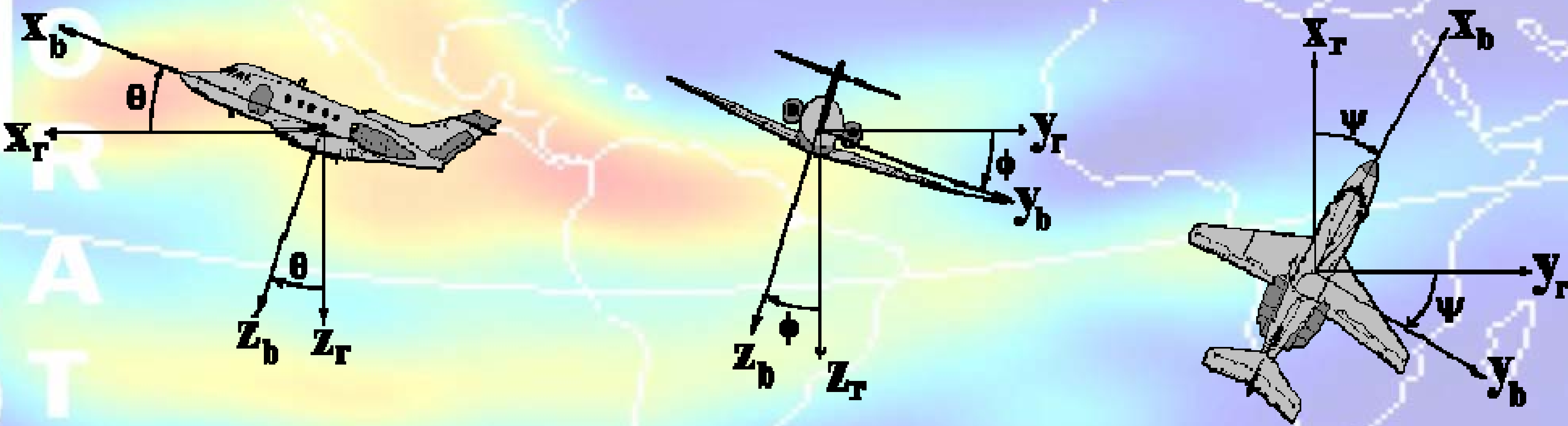
30 TECU
5 m of error.
Difference around 50%.

Difference between Klobuchar and actual data

$VTEC_M - VTEC_K$

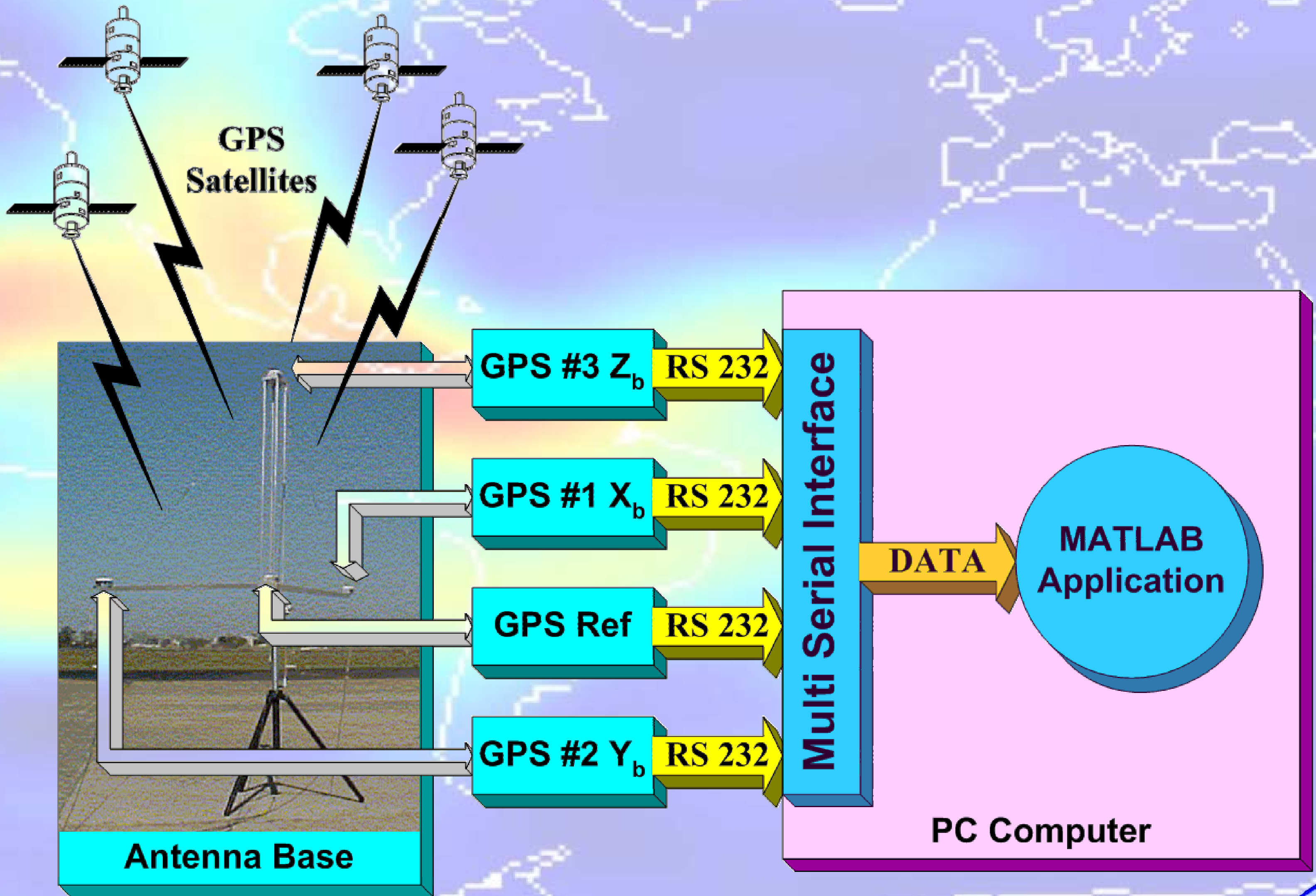
Attitude Determination

AIRCRAFT ATTITUDE



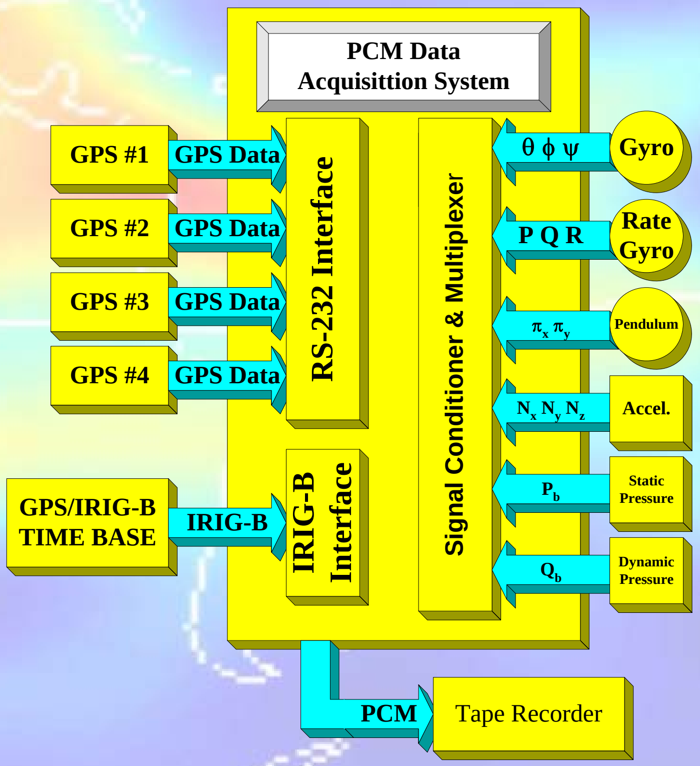
θ = Pitch Angle φ = Roll Angle Ψ = Yaw Angle

GROUND TESTS

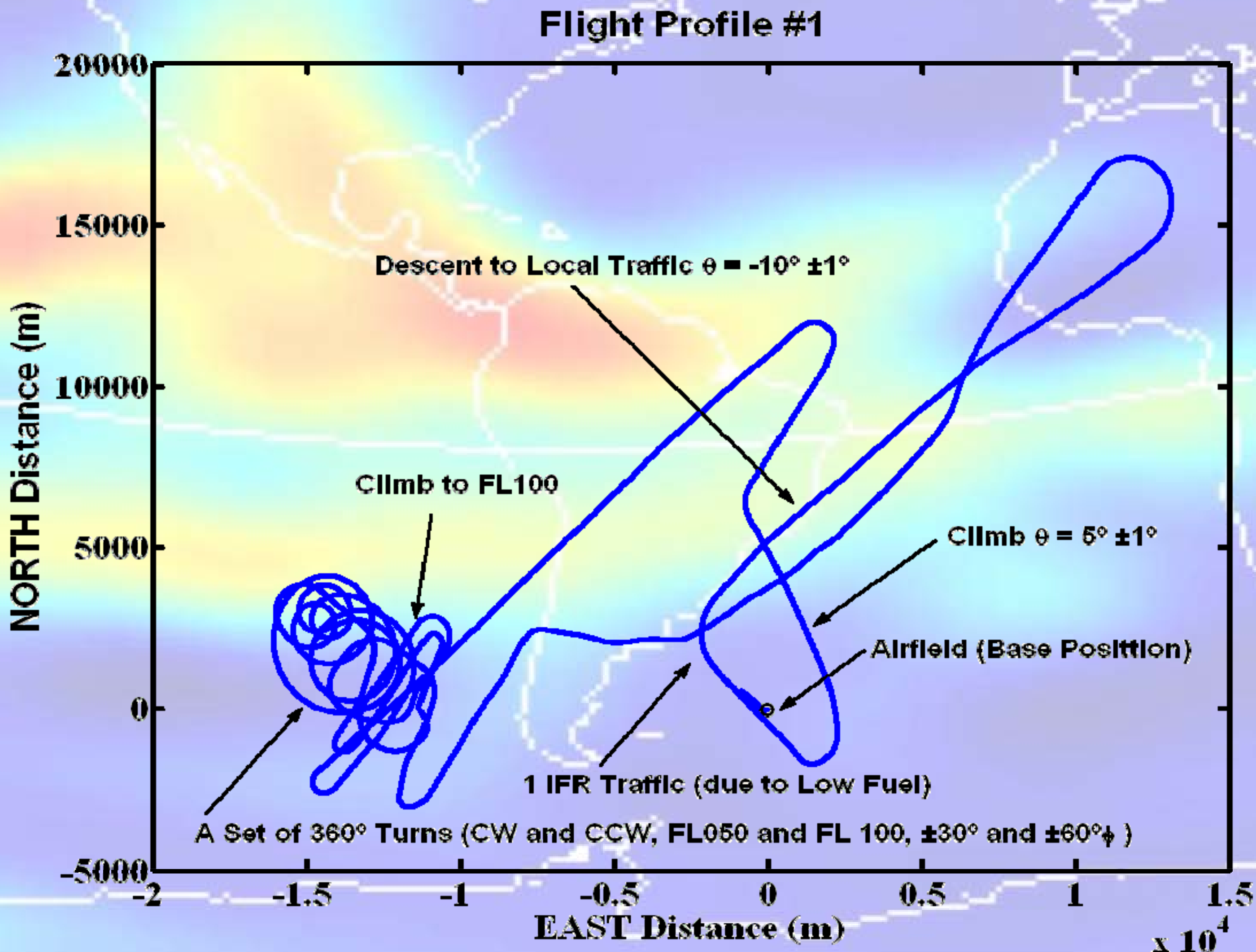


BRAÇO MECÂNICO E CONJUNTO DE ANTENAS PARA DETERMINAÇÃO DE ATITUDE USANDO GPS

FLIGHT TESTS INSTRUMENTATION (SYSTEM ARCHITECTURE)



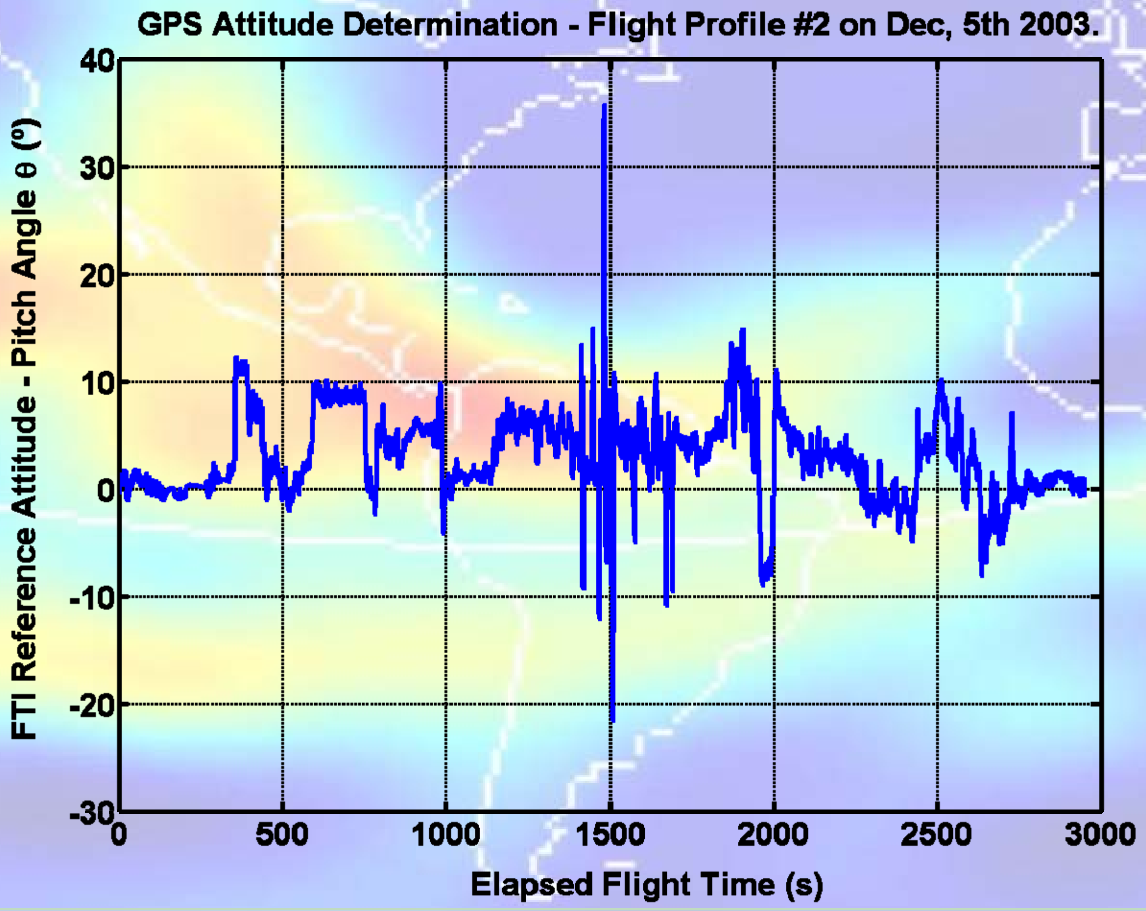
Flight Profile #1 View



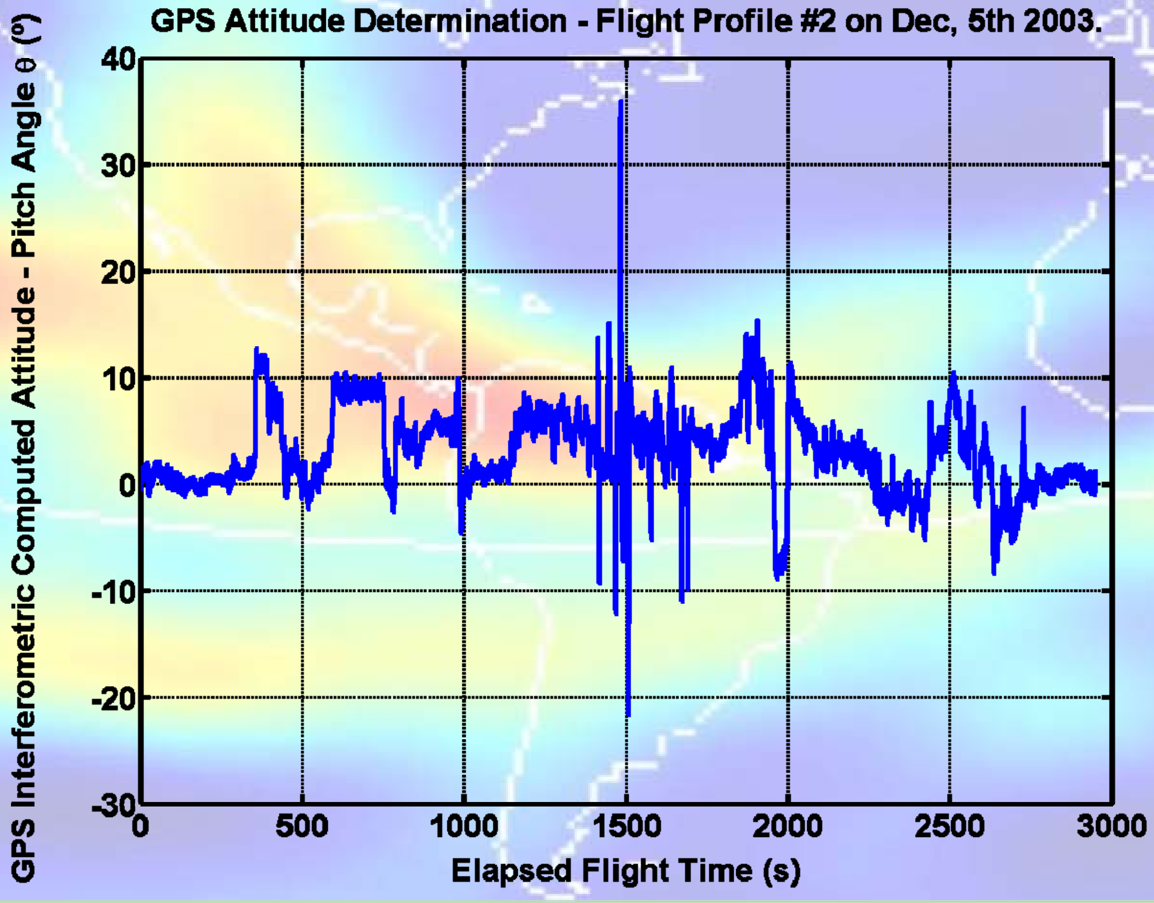
ASSEMBLED ANTENNA ARRAY

GNSS LABORATORY

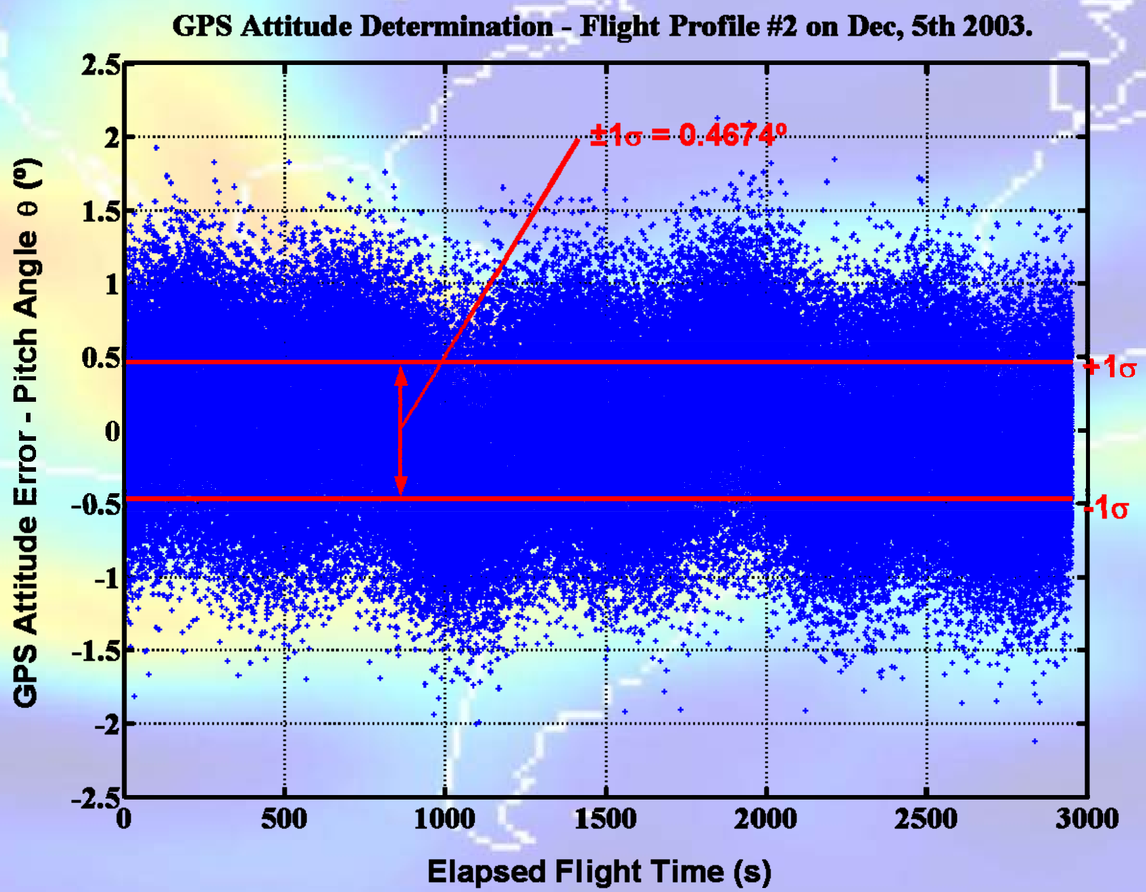
Flight Tests Results (Pitch Angle - θ)



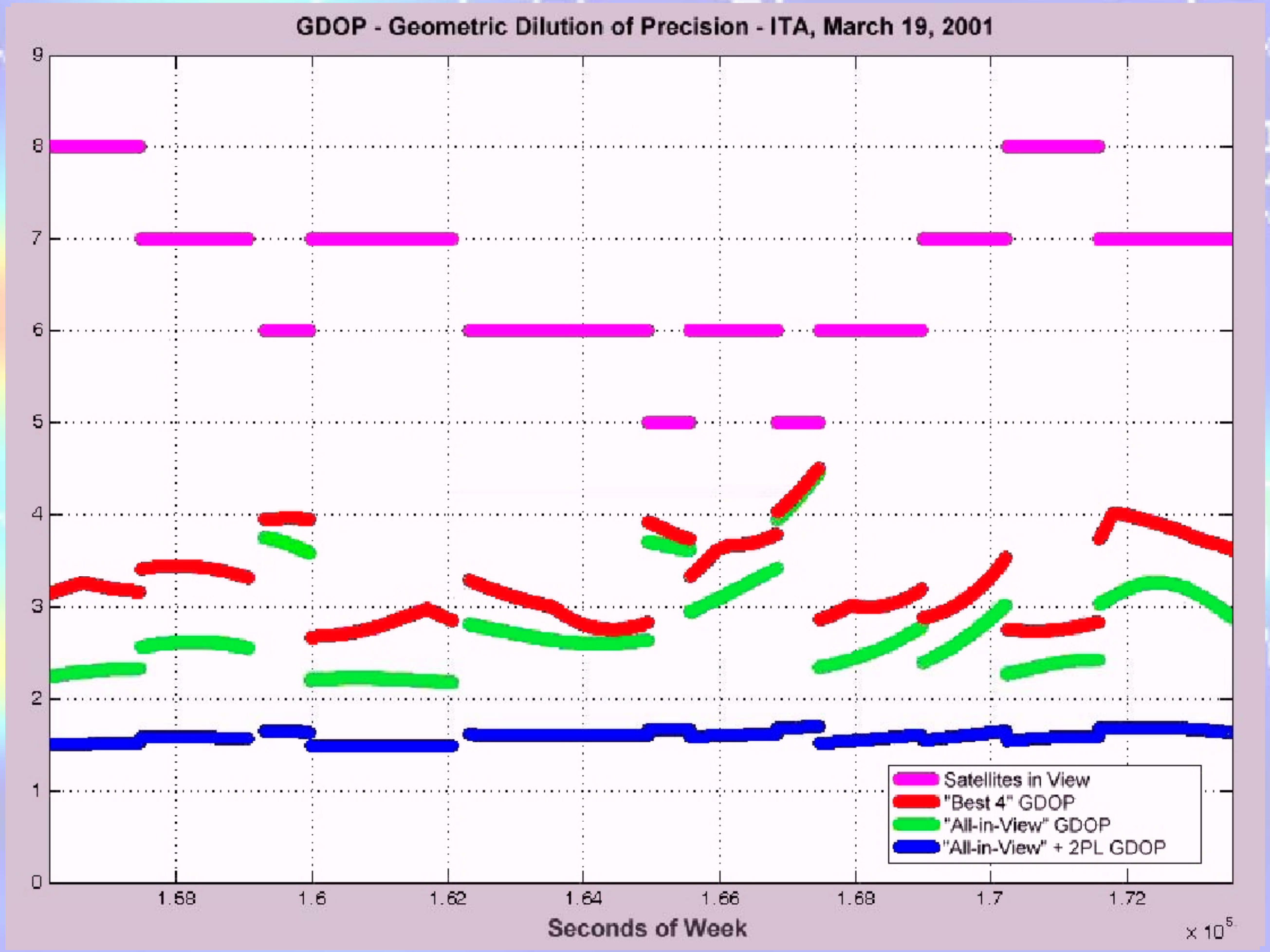
Flight Tests Results (Pitch Angle - θ)



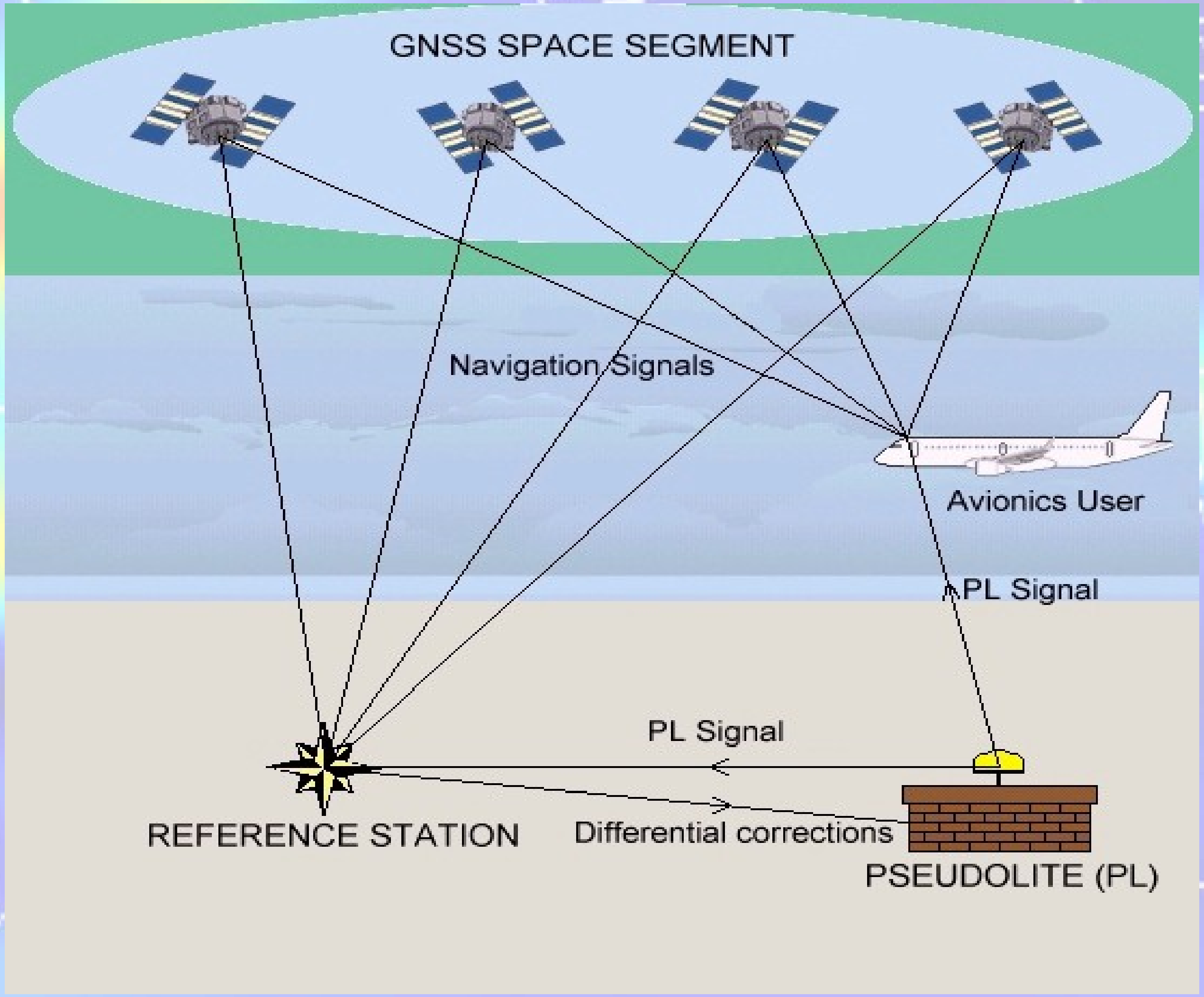
Flight Tests Results (Pitch Angle - θ)



Pseudolite

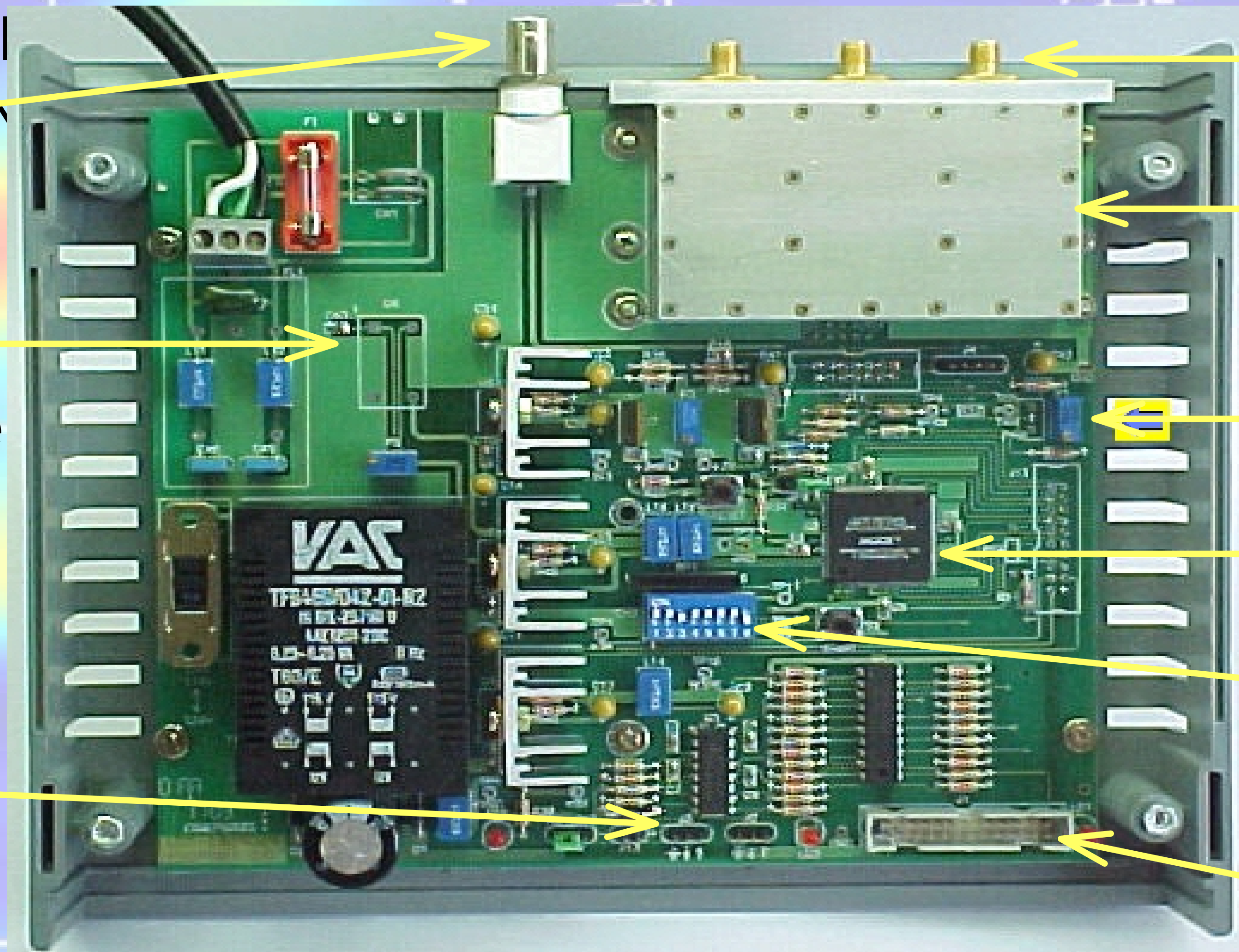

GDOP - Geometric Dilution of Precision - ITA, March 19, 2001
Satellites in View
"Best 4" GDOP
"All-in-View" GDOP
"All-in-View" + 2PL GDOP
Seconds of Week
x 10^5
0
1
2
3
4
5
6
7
8
9
1.58
1.6
1.62
1.64
1.66
1.68
1.7
1.72

PSEUDOLITES AND SYSTEM AUGMENTATION



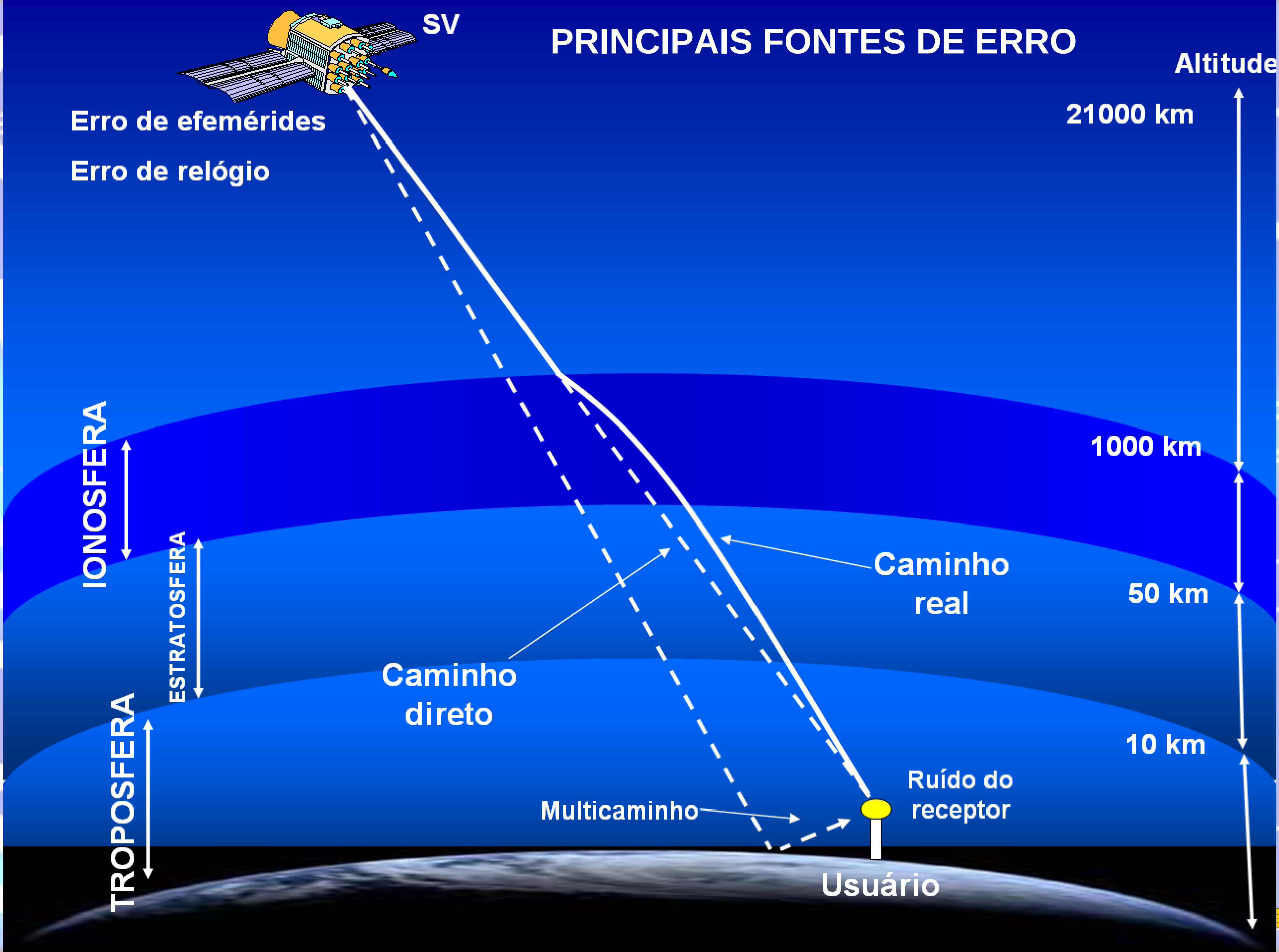
CONCEPTION AND DESIGN

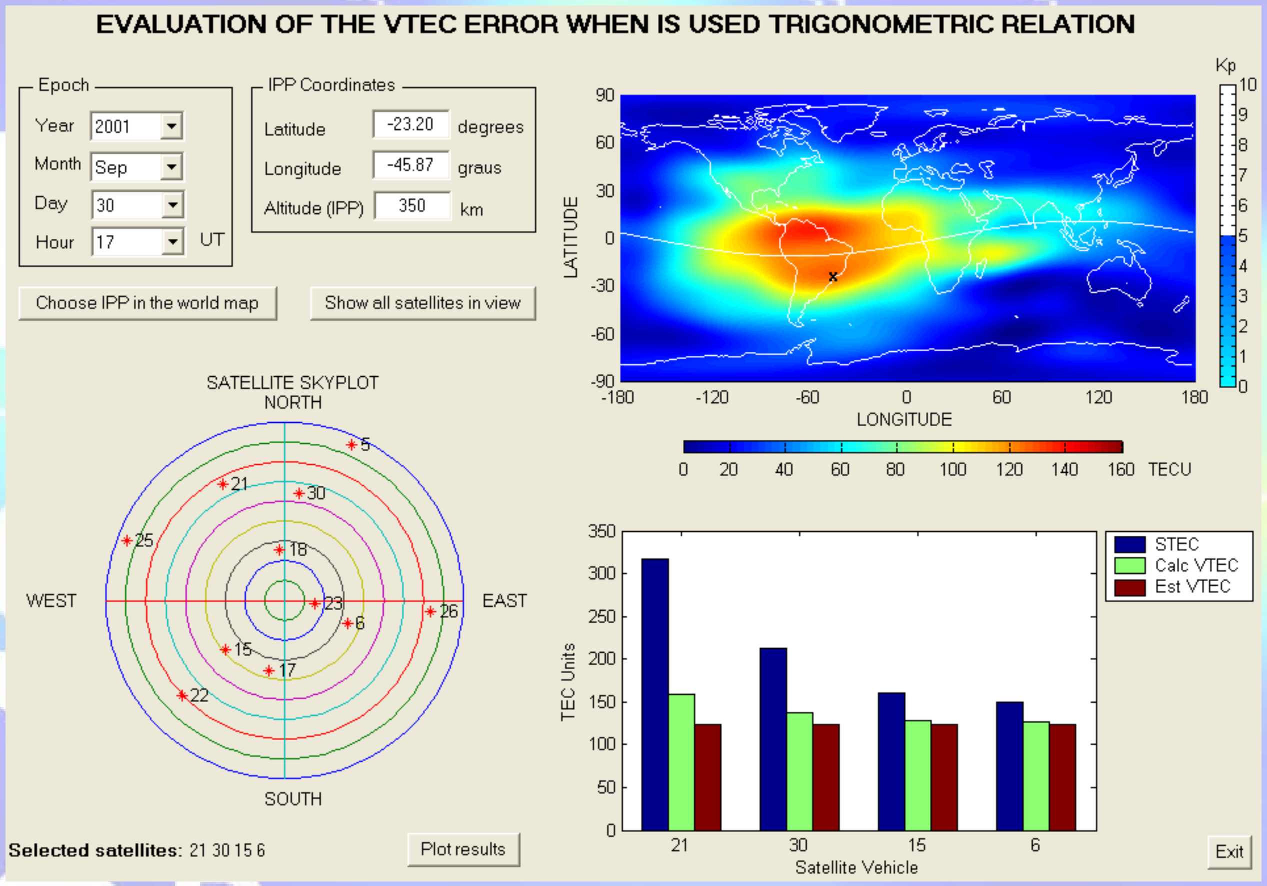
- **PL Prototype**

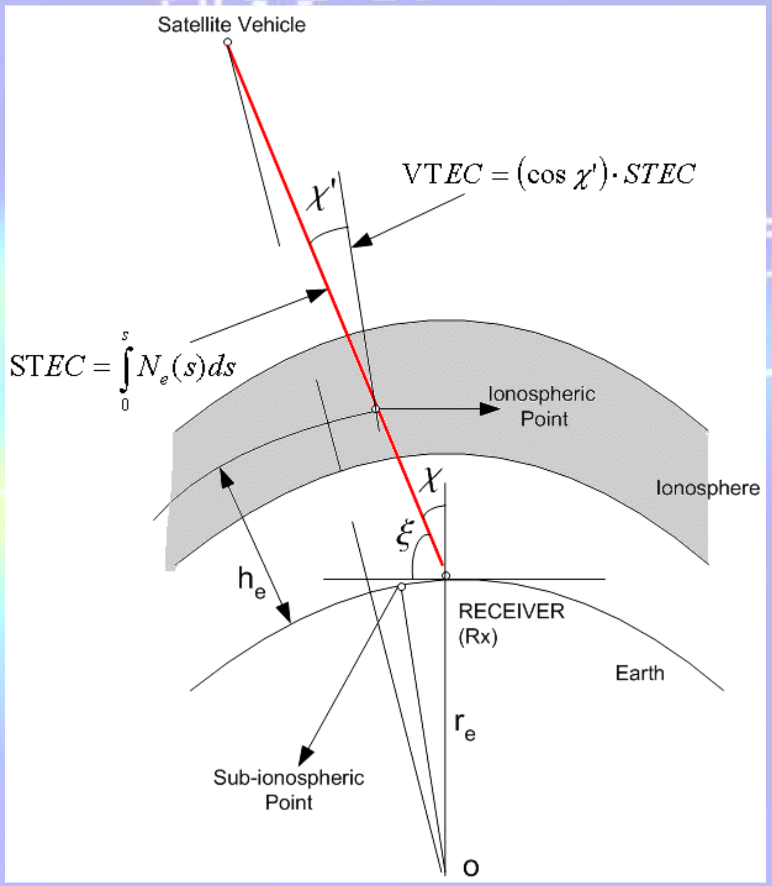


Effects on the Signal Path

3-D RT

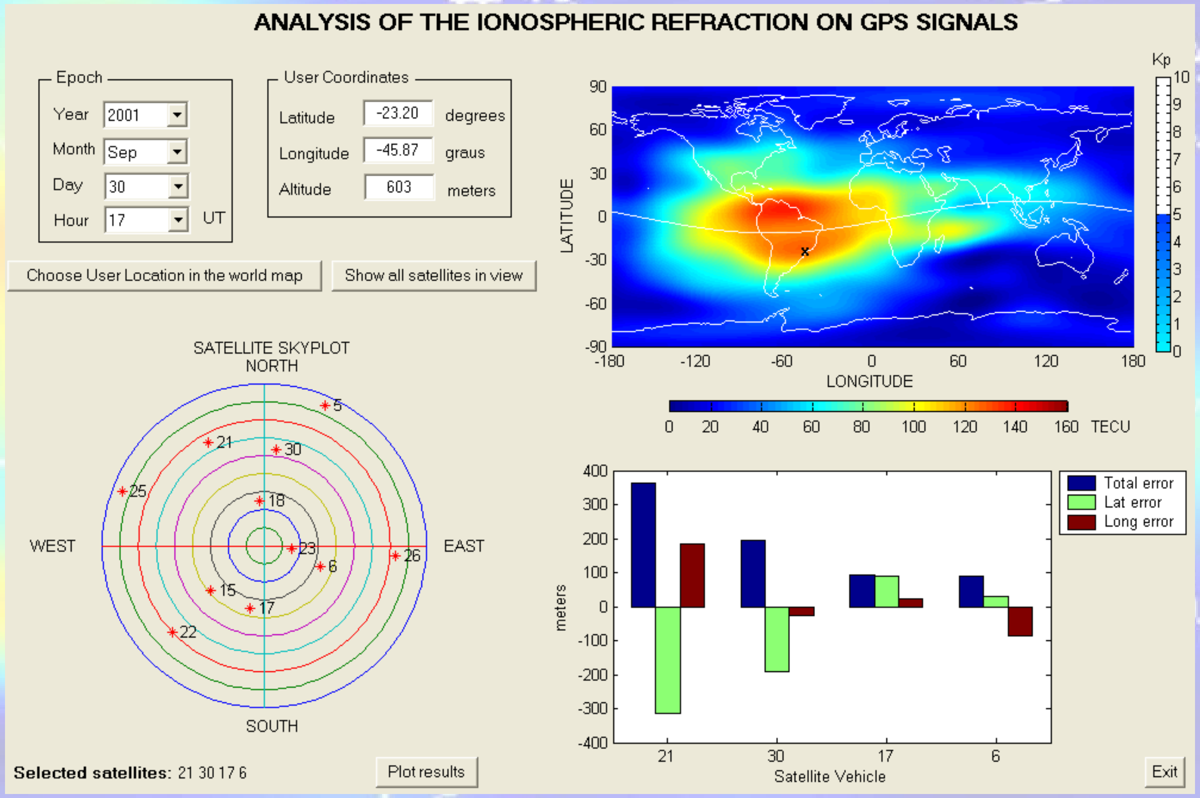

SV
PRINCIPAIS FONTES DE ERRO
Altitude
Erro de efemérides
Erro de relógio
21000 km
1000 km
50 km
10 km
IONOSFERA
ESTRATOSFERA
TROPOSFERA
Caminho real
Caminho direto
Multicaminho
Ruído do receptor
Usuário





$$VTEC = \cos(\chi')STEC$$

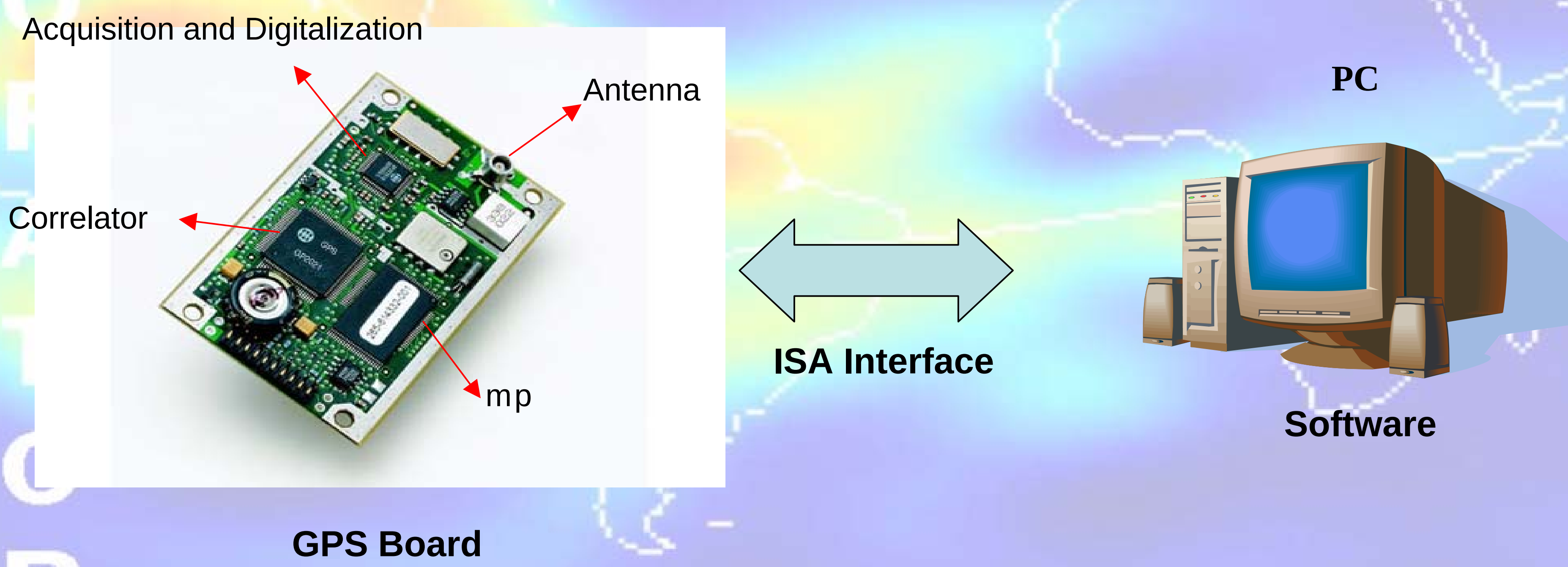
$$\sin\chi' = \frac{r_e}{r_e + h_e}\sin\chi$$

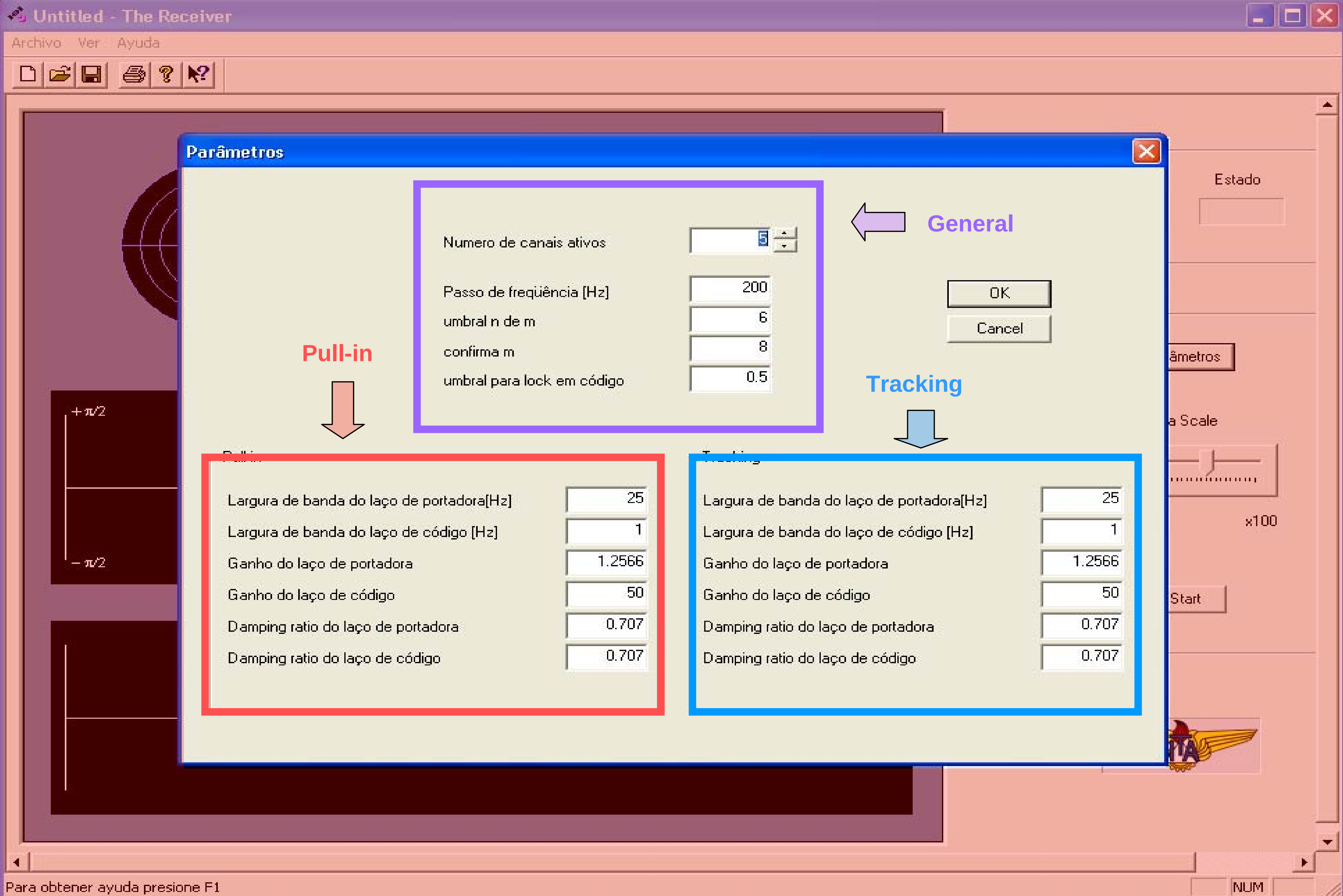


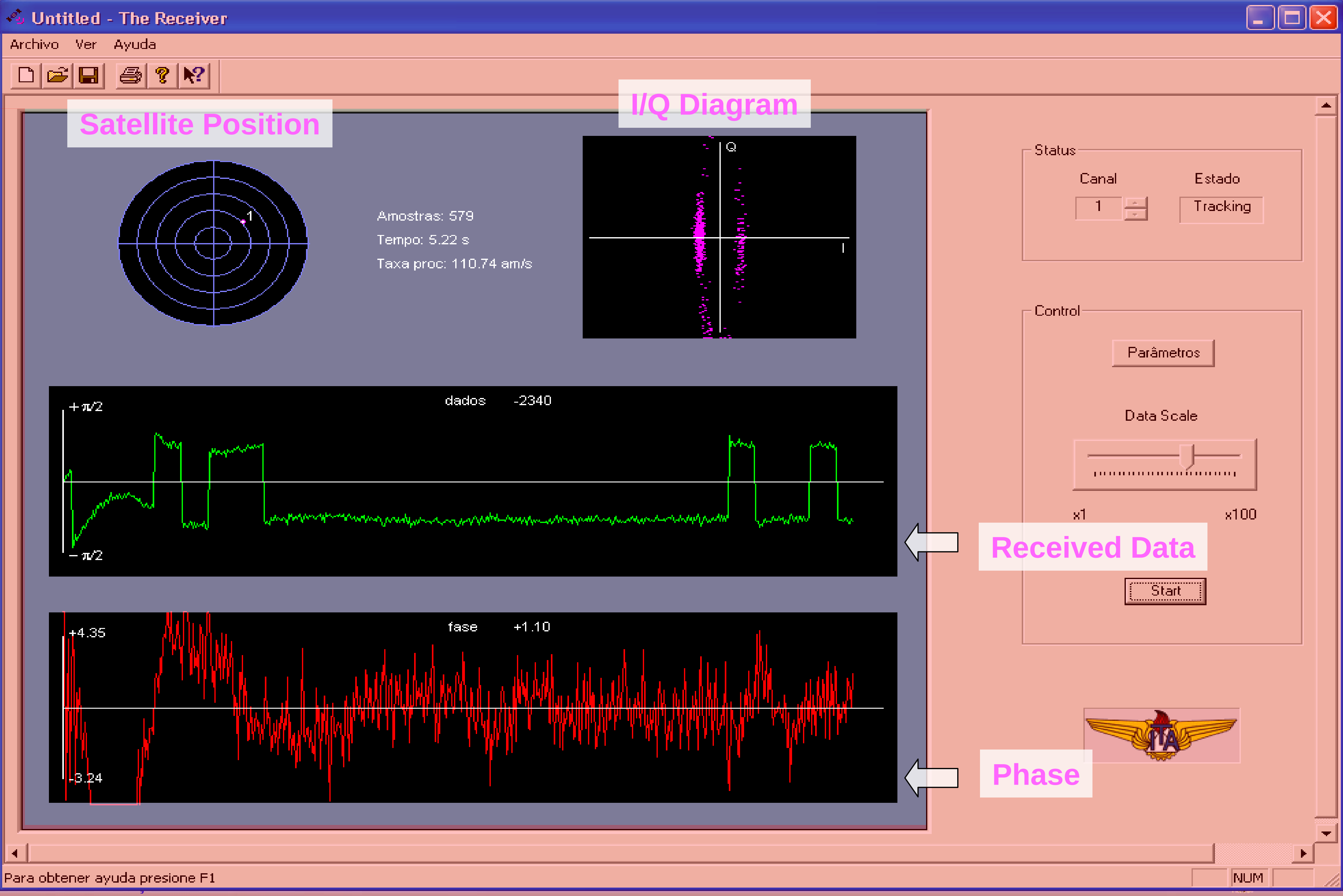
GLOBAL NAVIGATION SATELLITE SYSTEMS LABORATORY

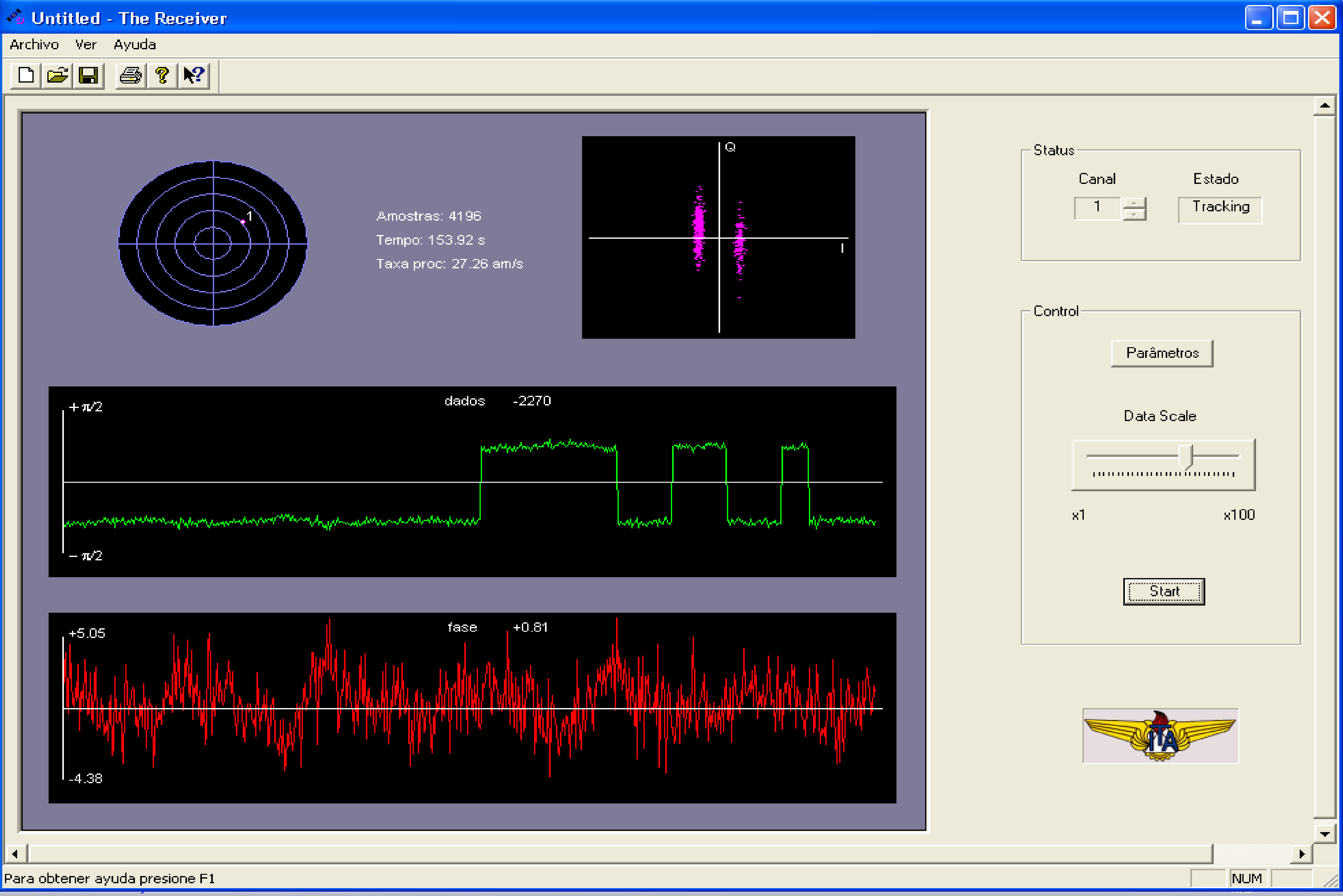
GPS SOFTWARE RECEIVER

GPS Software Receiver

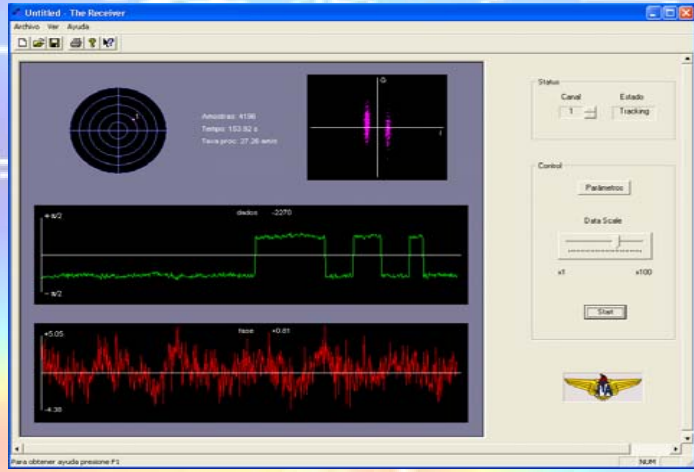


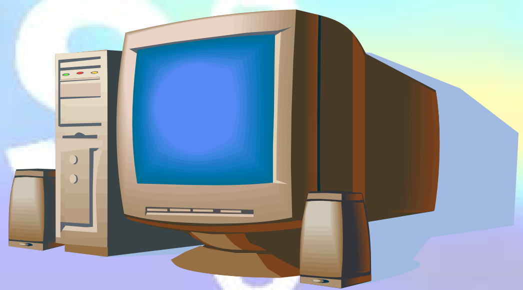

Untitled - The Receiver
Archivo Ver Ayuda
Parâmetros
Numero de canais ativos 5
Passo de freqüência [Hz] 200
umbral n de m 6
confirma m 8
umbral para lock em código 0.5
General
OK
Cancel
Pull-in
Tracking
Largura de banda do laço de portadora[Hz] 25
Largura de banda do laço de código [Hz] 1
Ganho do laço de portadora 1.2566
Ganho do laço de código 50
Damping ratio do laço de portadora 0.707
Damping ratio do laço de código 0.707
Largura de banda do laço de portadora[Hz] 25
Largura de banda do laço de código [Hz] 1
Ganho do laço de portadora 1.2566
Ganho do laço de código 50
Damping ratio do laço de portadora 0.707
Damping ratio do laço de código 0.707
Estado
x100
Start
+π/2
−π/2
Para obtener ayuda presione F1
NUM


Untitled - The Receiver
Archivo
Ver
Ayuda
Satellite Position
I/Q Diagram
Q
I
1
Amostras: 579
Tempo: 5.22 s
Taxa proc: 110.74 am/s
dados -2340
+π/2
−π/2
fase +1.10
+4.35
-3.24
Received Data
Phase
Status
Canal
Estado
1
Tracking
Control
Parâmetros
Data Scale
x1
x100
Start
Para obtener ayuda presione F1
NUM

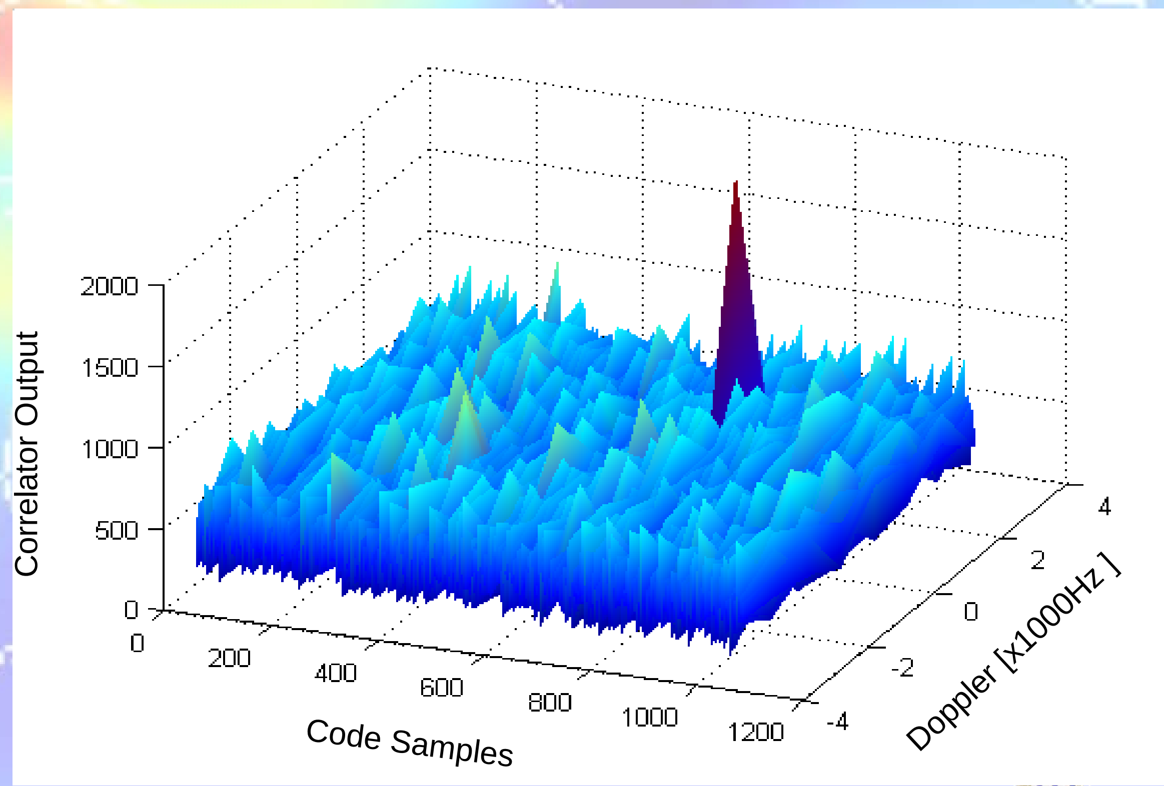

Untitled - The Receiver
Archivo
Ver
Ayuda
Amostras: 4196
Tempo: 153.92 s
Taxa proc: 27.26 am/s
Q
I
1
Status
Canal
Estado
1
Tracking
Control
Parâmetros
Data Scale
x1
x100
Start
dados
-2270
+ π/2
− π/2
fase
+0.81
+5.05
-4.38
Para obtener ayuda presione F1
NUM

Software





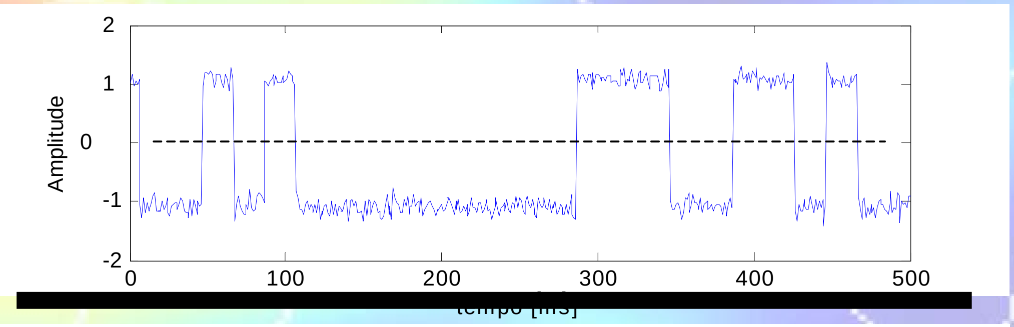
Research & Development tool



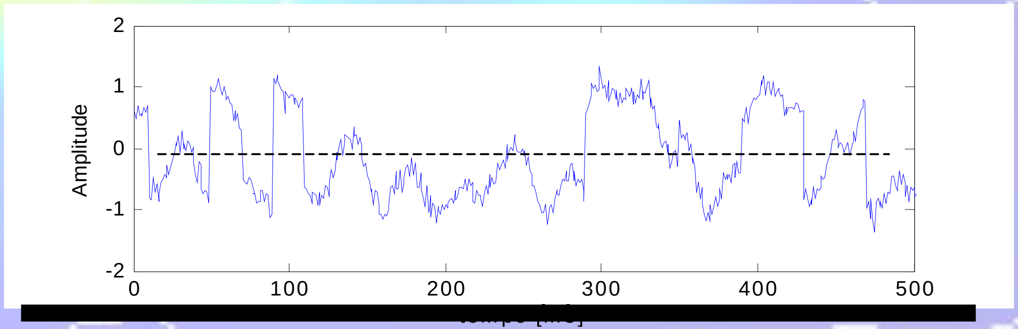
Doppler Frequency change

- The Doppler change depends of the satellite-user relative motion. For vehicle of high dynamic with acceleration of a lot of times the gravitational acceleration, the Doppler change increase strongly. One user with the half of the gravitational acceleration (4,9 m/s^2) have a ratio of 25,7 Hz/s.

without Doppler

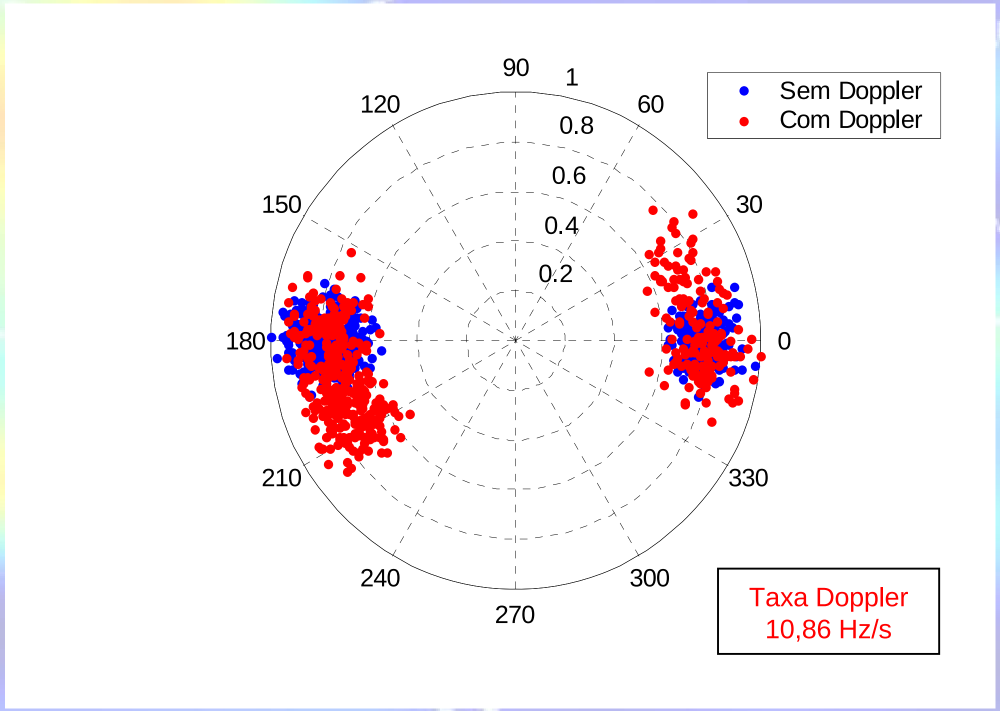


With Doppler (ratio of 25,7 Hz/s)



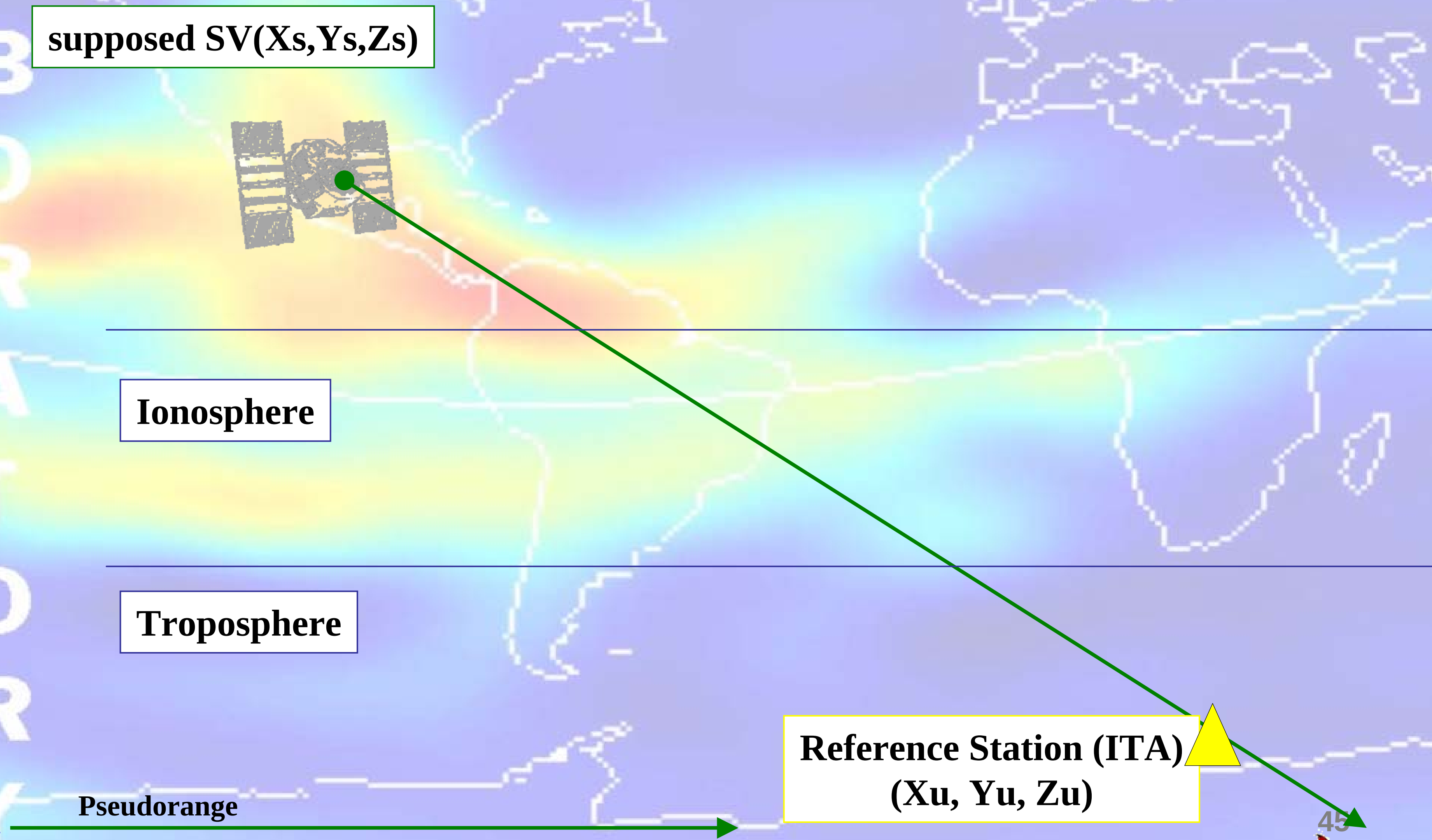
Doppler Frequency change

- The degradation can be seen in the constellation diagram.

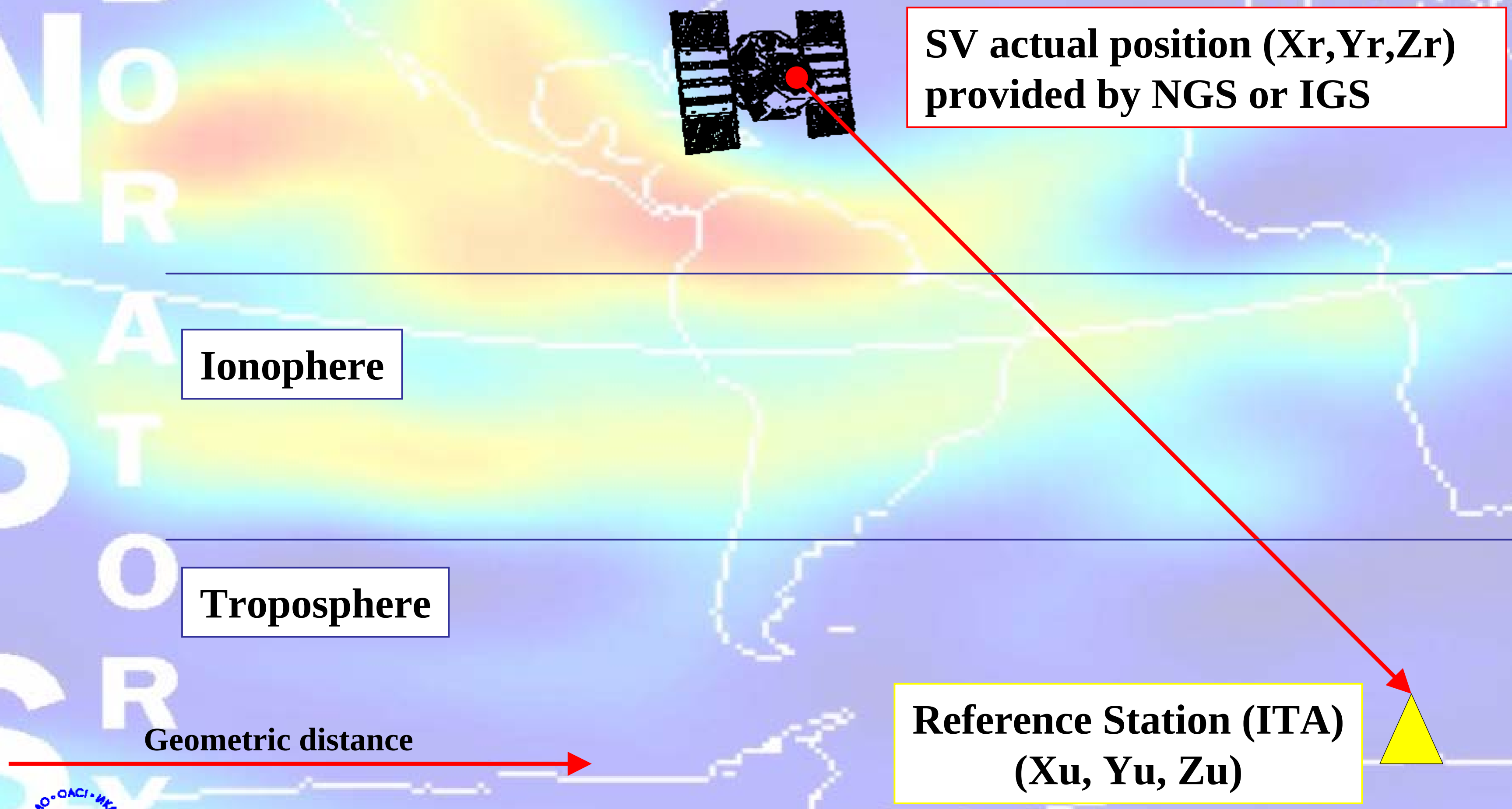


Pseudorange Statistics

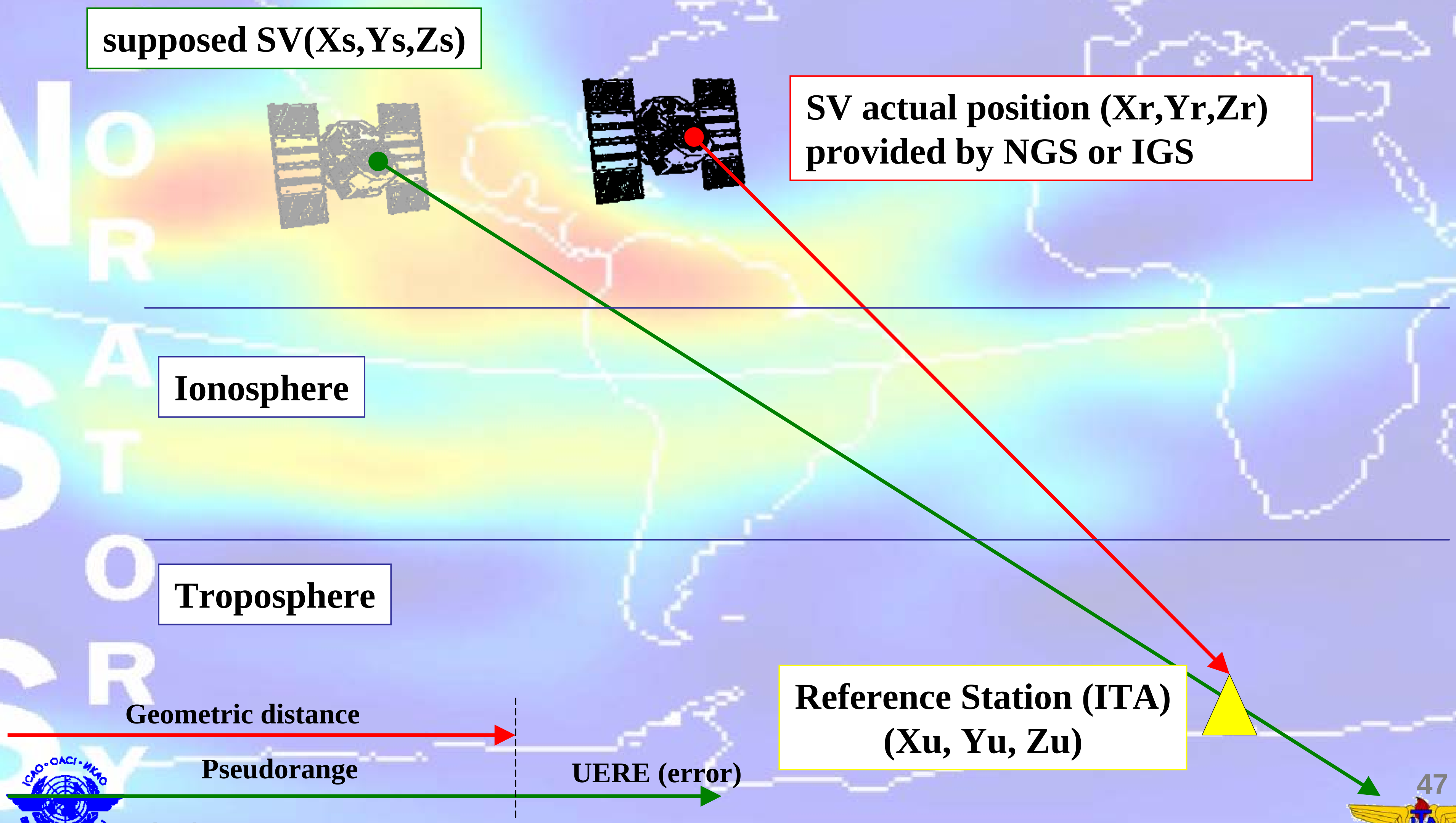
CURRENT PROCEDURE



CURRENT PROCEDURE

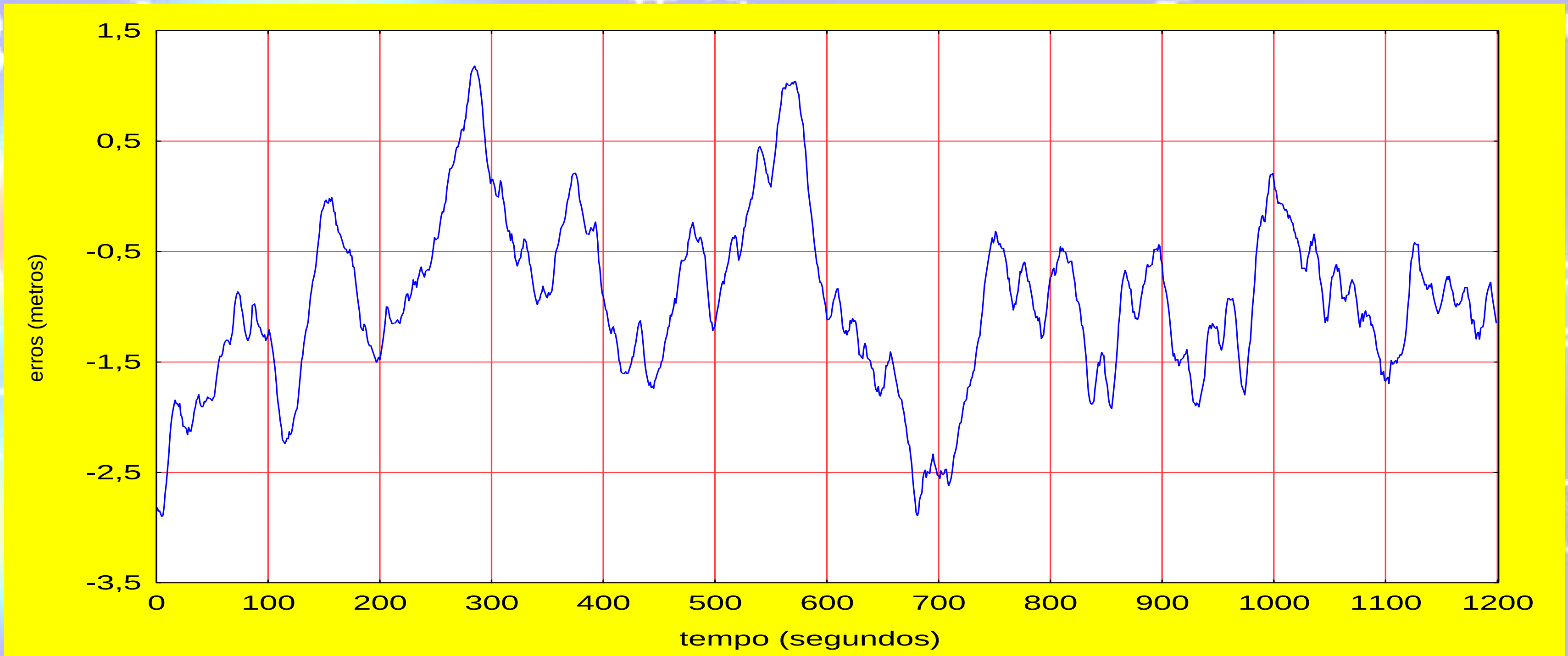


CURRENT PROCEDURE



Final Error

Satellite 02

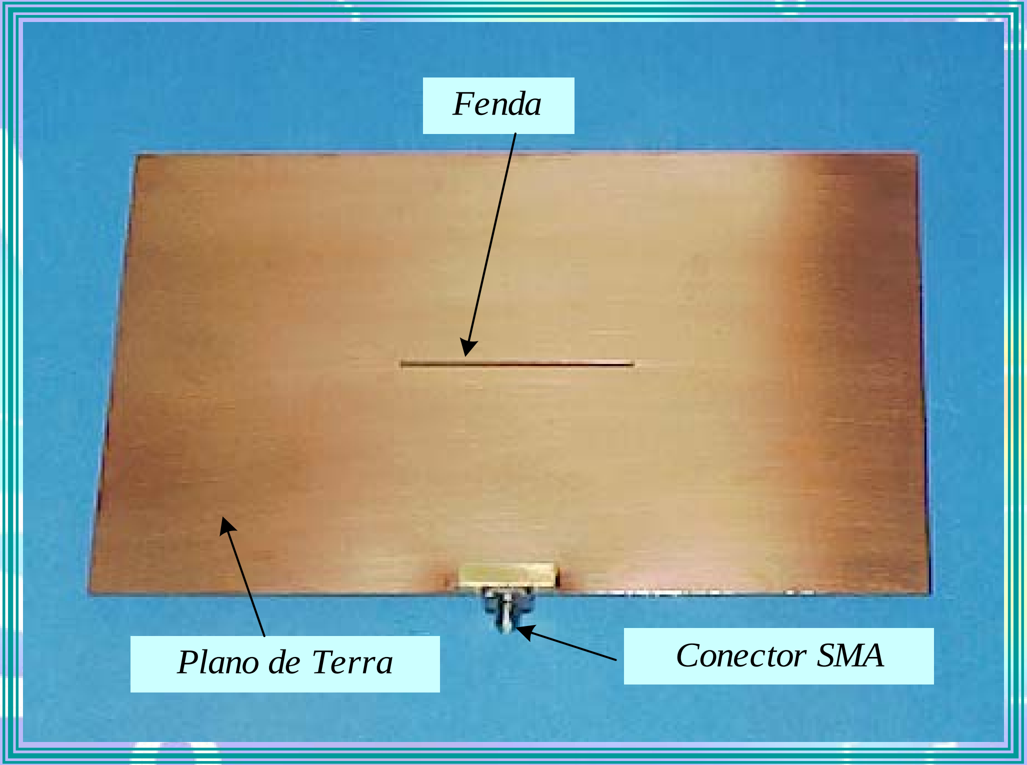


N	*Média (m)*	*(m)*	*Mínimo (m)*	*Máximo (m)*
1200	-0,95	0,76	-2,89	1,81

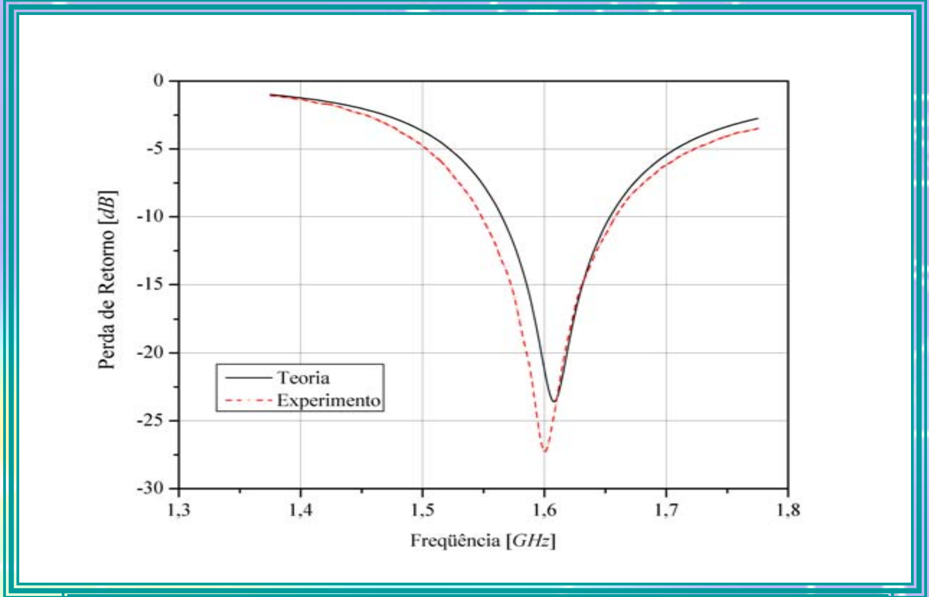
Antennas
Multipath Mitigation

Electromagnetic Aperture

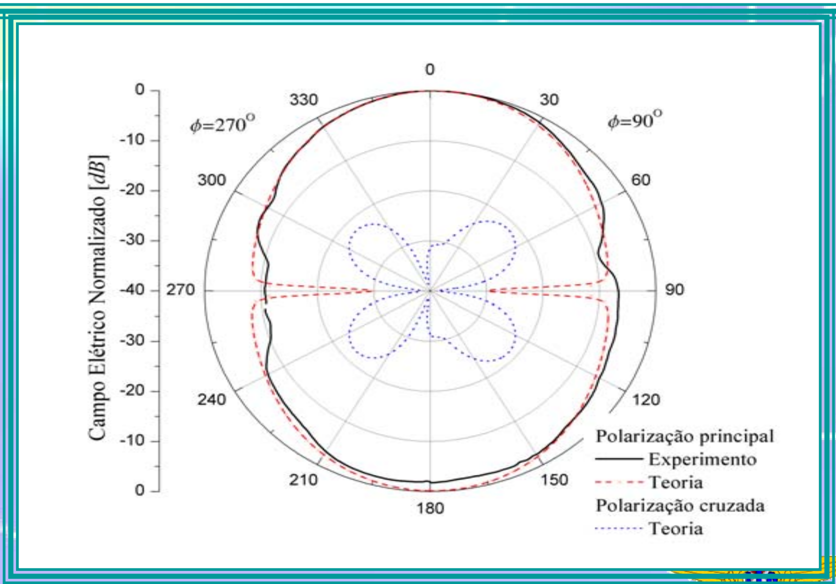
Aperture Prototype



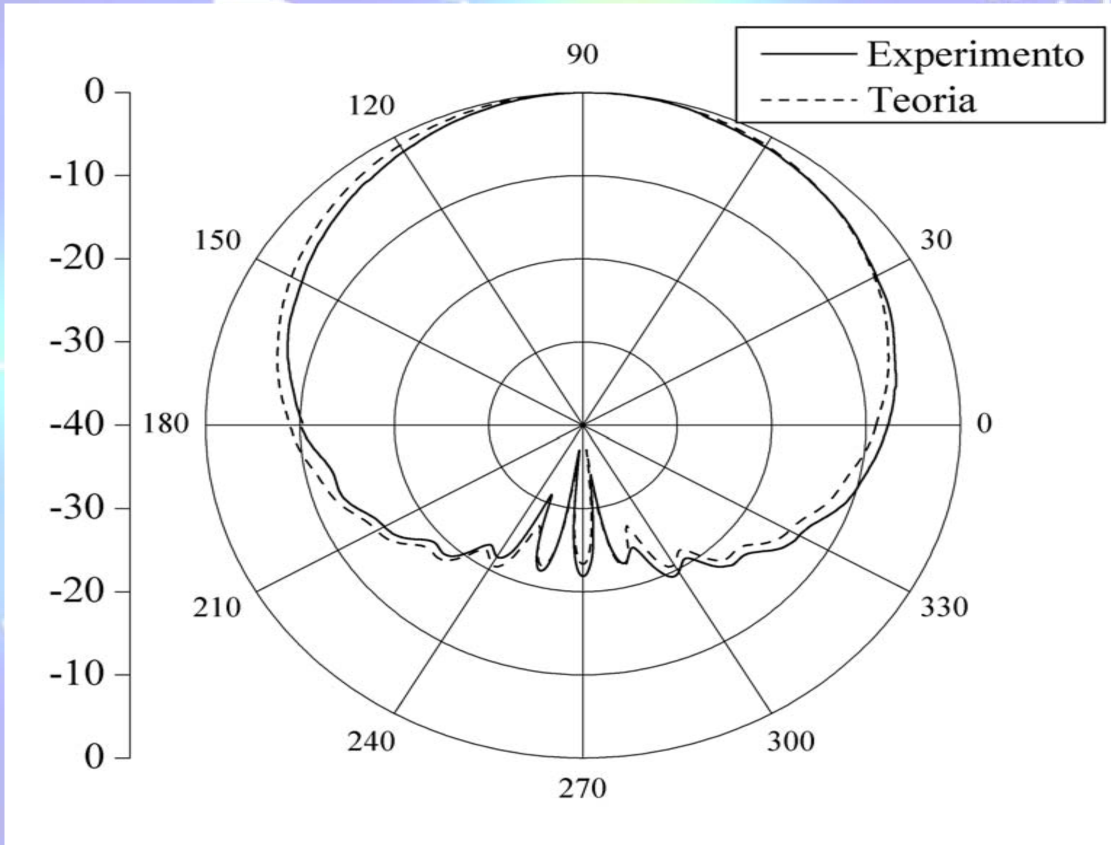
Return Loss



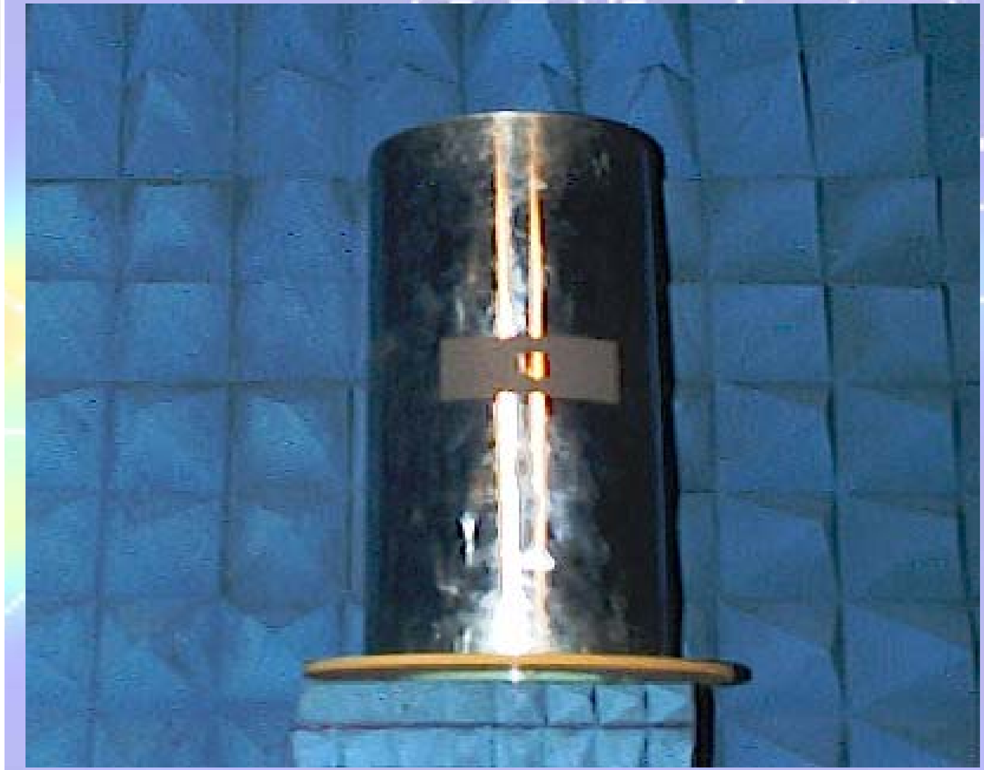
Radiation Pattern



EXPERIMENTAL RESULTS – 2nd PROTOTYPE

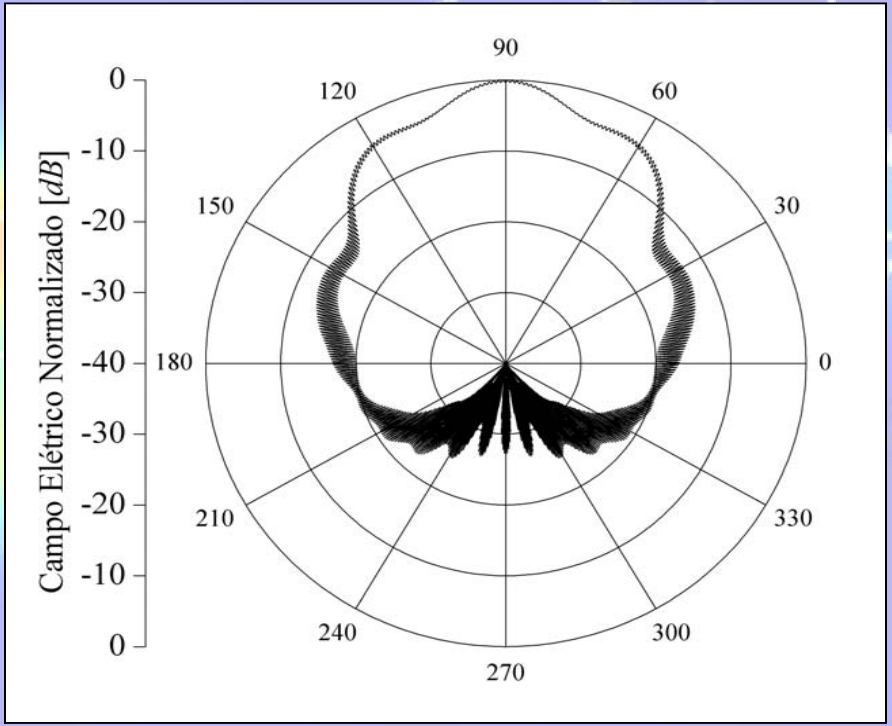


Radiation Pattern ($\theta = 90^o$)

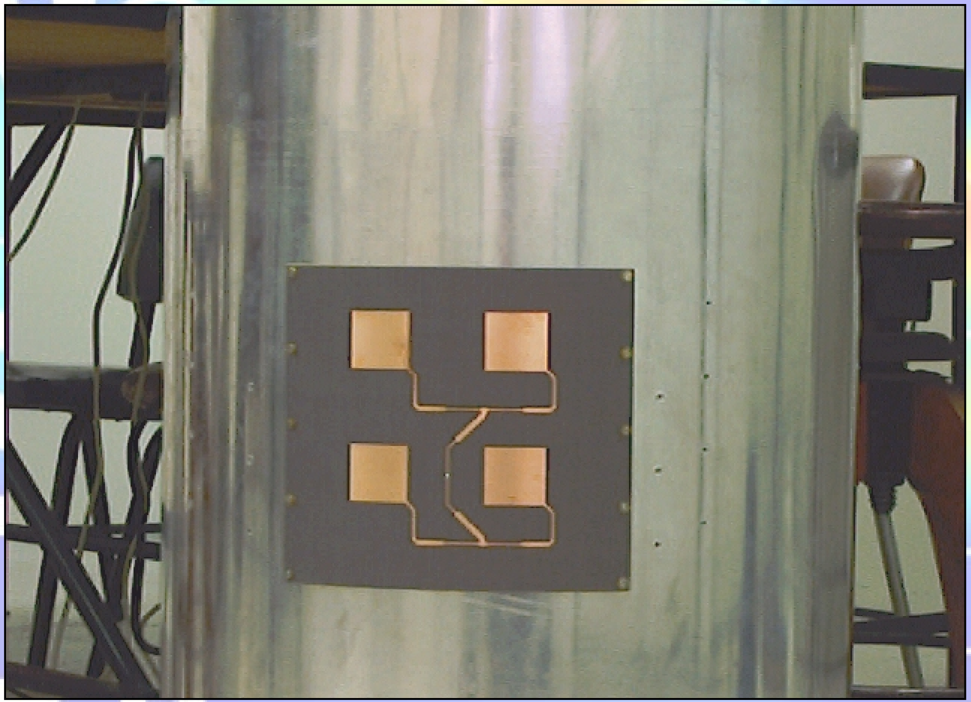


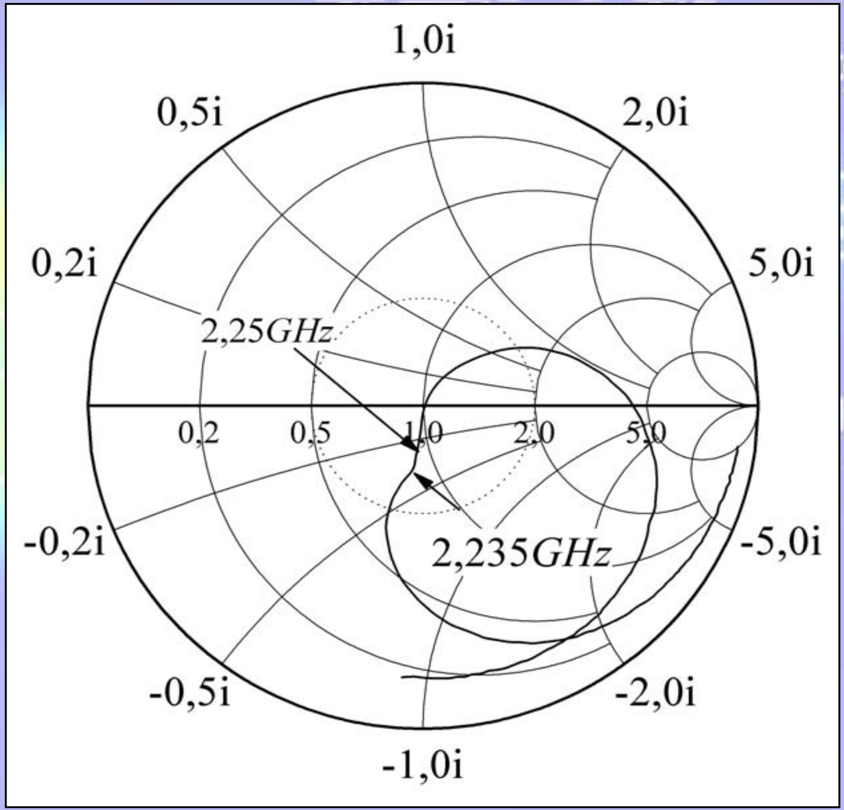
Set up for measurement of the radiation pattern.

CONFORMAL ARRAY

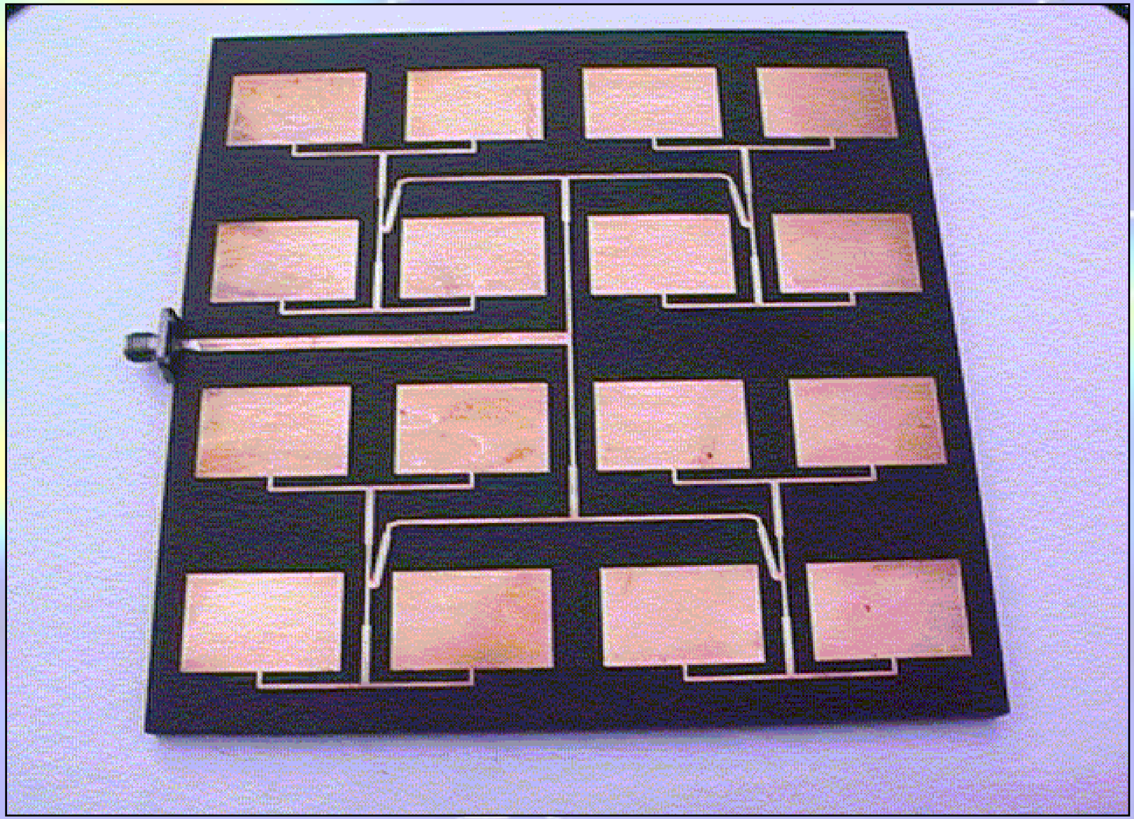


Array 2 x 2




1,0i
0,5i
2,0i
0,2i
5,0i
2,25GHz
0,2
0,5
1,0
2,0
5,0
-0,2i
2,235GHz
-5,0i
-0,5i
-2,0i
-1,0i

4 x 4 Planar array



CONCLUSIONS

- The medium and long-term goals of the GNSS Laboratory are to implement GBAS and SBAS test beds at the São José dos Campos, SP.
- GPS as a interdisciplinary laboratory in Telecommunications theory. GLONASS and Galileo will be included on curricular program.
- The best way to train qualified people to work with CNS/ATM, ADS and GBAS (SBAS).

ACKNOWLEDGMENTS

To Kevin T. Fitzgibbon who introduced me the GPS, back 1987. To UNPD and ICAO to had sponsored the GPS project at ITA. To the Brazilian Government to support the work through Financial Agencies. To Professor B. Parkinson (91) and to Dr. A. Van Dierendonck (93) for the seminars given at ITA. To my graduate students that did the real work.

The only way to strength the
DEMOCRACY
is through
EDUCATION

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