THE UNIVERSITY OF TEXAS AT AUSTIN
RADIONAVIGATION LABORATORY

Advances in GNSS Equipment

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With Input From:

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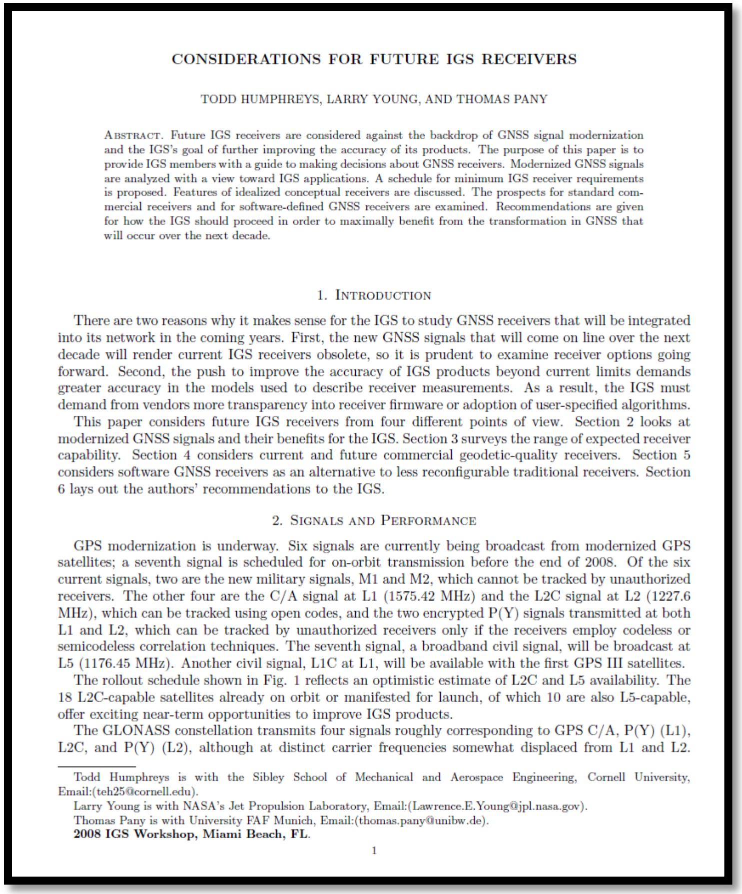
2010 IGS Workshop, Newcastle Upon Tyne

Q: What advances in GNSS receiver technology can the IGS exploit to improve its network and products?

Outline

- Review conclusions from Miami 2008
- A look at commercial receiver state-of-the-art
- Advances in software receiver technology
  - DFE: The final front-end
  - The CASES receiver
  - The IFEN/UFAF SX-NSR receiver: Performance evaluation
- Not all observables are created equal
- Summary

Conclusions from Miami 2008



CONSIDERATIONS FOR FUTURE IGS RECEIVERS

TODD HUMPHREYS, LARRY YOUNG, AND THOMAS PANY

ABSTRACT. Future IGS receivers are considered against the backdrop of GNSS signal modernization and the IGS's goal of further improving the accuracy of its products. The purpose of this paper is to provide IGS members with a guide to making decisions about GNSS receivers. Modernized GNSS signals are analyzed with a view toward IGS applications. A schedule for minimum IGS receiver requirements is proposed. Features of idealized conceptual receivers are discussed. The prospects for standard commercial receivers and for software-defined GNSS receivers are examined. Recommendations are given for how the IGS should proceed in order to maximally benefit from the transformation in GNSS that will occur over the next decade.

1. INTRODUCTION

There are two reasons why it makes sense for the IGS to study GNSS receivers that will be integrated into its network in the coming years. First, the new GNSS signals that will come on line over the next decade will render current IGS receivers obsolete, so it is prudent to examine receiver options going forward. Second, the push to improve the accuracy of IGS products beyond current limits demands greater accuracy in the models used to describe receiver measurements. As a result, the IGS must demand from vendors more transparency into receiver firmware or adoption of user-specified algorithms.

This paper considers future IGS receivers from four different points of view. Section 2 looks at modernized GNSS signals and their benefits for the IGS. Section 3 surveys the range of expected receiver capability. Section 4 considers current and future commercial geodetic-quality receivers. Section 5 considers software GNSS receivers as an alternative to less reconfigurable traditional receivers. Section 6 lays out the authors' recommendations to the IGS.

2. SIGNALS AND PERFORMANCE

GPS modernization is underway. Six signals are currently being broadcast from modernized GPS satellites; a seventh signal is scheduled for on-orbit transmission before the end of 2008. Of the six current signals, two are the new military signals, M1 and M2, which cannot be tracked by unauthorized receivers. The other four are the C/A signal at L1 (1575.42 MHz) and the L2C signal at L2 (1227.6 MHz), which can be tracked using open codes, and the two encrypted P(Y) signals transmitted at both L1 and L2, which can be tracked by unauthorized receivers only if the receivers employ codeless or semicodeless correlation techniques. The seventh signal, a broadband civil signal, will be broadcast at L5 (1176.45 MHz). Another civil signal, L1C at L1, will be available with the first GPS III satellites.

The rollout schedule shown in Fig. 1 reflects an optimistic estimate of L2C and L5 availability. The 18 L2C-capable satellites already on orbit or manifested for launch, of which 10 are also L5-capable, offer exciting near-term opportunities to improve IGS products.

The GLONASS constellation transmits four signals roughly corresponding to GPS C/A, P(Y) (L1), L2C, and P(Y) (L2), although at distinct carrier frequencies somewhat displaced from L1 and L2.

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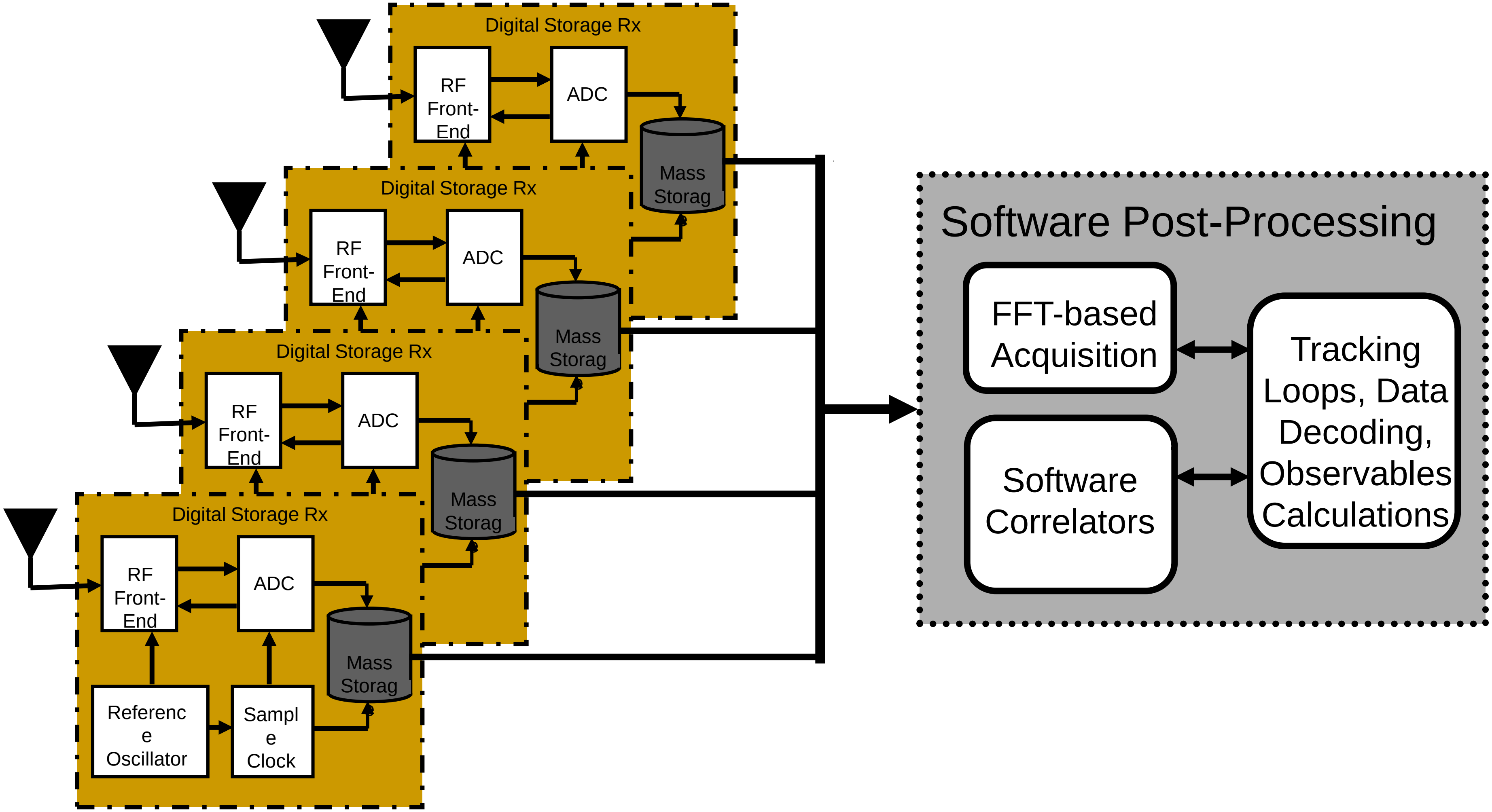
2008 IGS Workshop, Miami Beach, FL.

- Many excellent commercial RXs to choose from
- All major manufacturers have road maps toward all-in-view capability
- Pseudorange and phase measurement error statistics are heterogeneous and ill-defined, impairing IGS products
- Software receivers show promise but have not been vetted

The Super Receiver

- Tracks all open signals, all satellites
- Tracks encrypted signals where possible
- Well-defined, publicly disclosed measurement characteristics (phase, pseudorange, C/No)
- RINEX 3.00 compliant
- Completely user reconfigurable, from correlations to tracking loops to navigation solution
- Internal cycle slip mitigation/detection
- Up to 50 Hz measurements
- Internet ready; signal processing strategy reconfigurable via internet
- Low cost

The Ultra Receiver



Commercial Receiver Offerings (2008)

Septentrio PolaRx3

Trimble NetRS/NetR5

Leica GRX1200

Topcon NET-G3

Commercial Receiver Offerings (2010)

Septentrio GeNeRx1

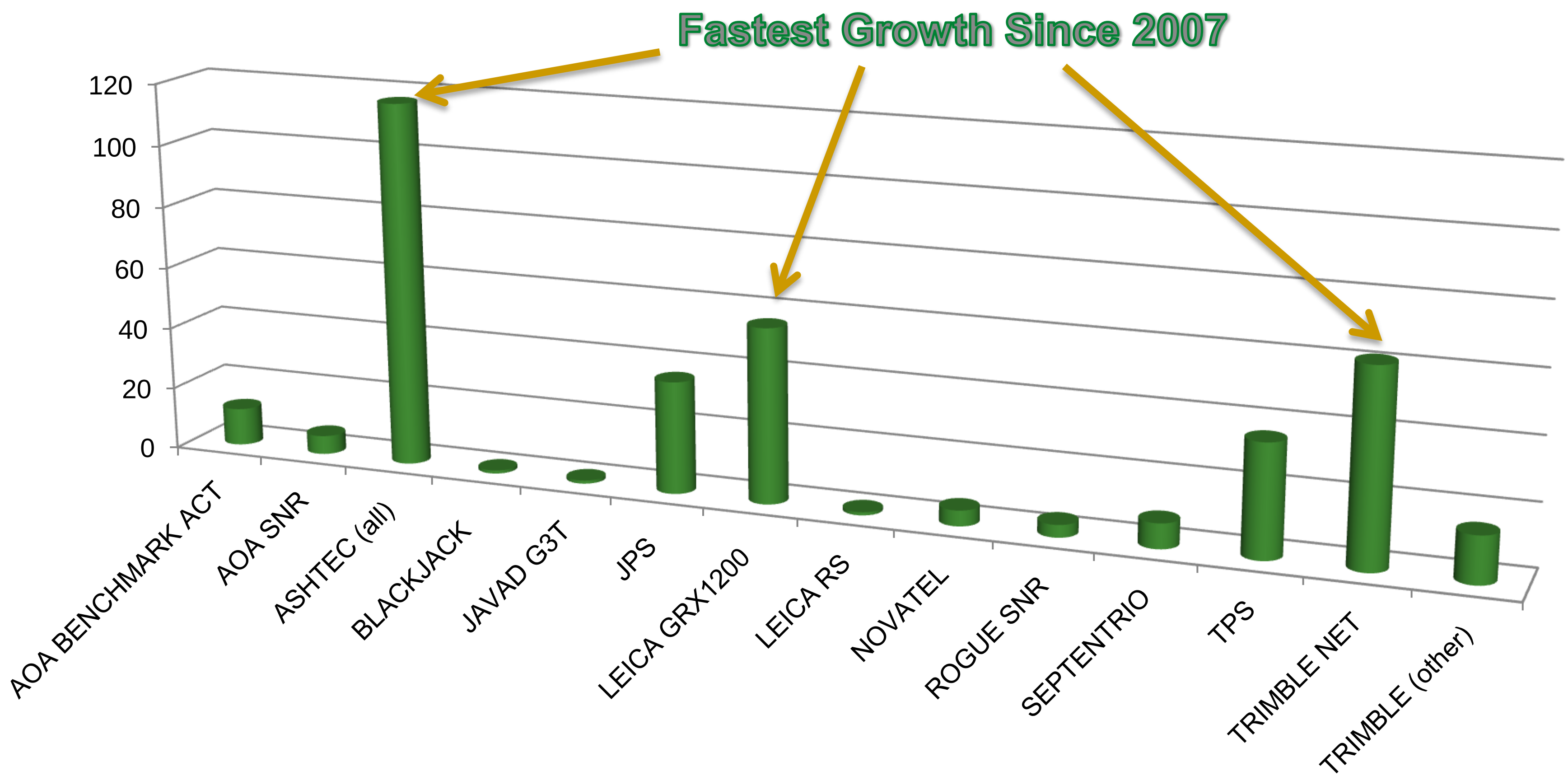
Trimble NetRS/NetR5/NetR8

Javad G3T

Leica GRX1200+GNSS

Topcon NET-G3

Receiver Type Distribution (June 2010)



Approaching the Super Receiver

Example Commercial Reciver: Javad G3T

Except E5B, 216 channels

- Tracks all open signals, all satellites
- Tracks encrypted signals where possible
- ...fined, publicly disclosed measurement ...ristics (phase, pseudorange, C/No)
- ... 3.00 compliant
- Completely user reconfigurable, from correlations to tracking loops to navigation solution
- Internal cycle slip mitigation/detection
- Up to 50 H...
- ...ternet re... ...configur...
- Low cost

Loop BW, update rate configurable

~$8k

Only one G3T in IGS network (BOGI, Poland)
Performance appears good

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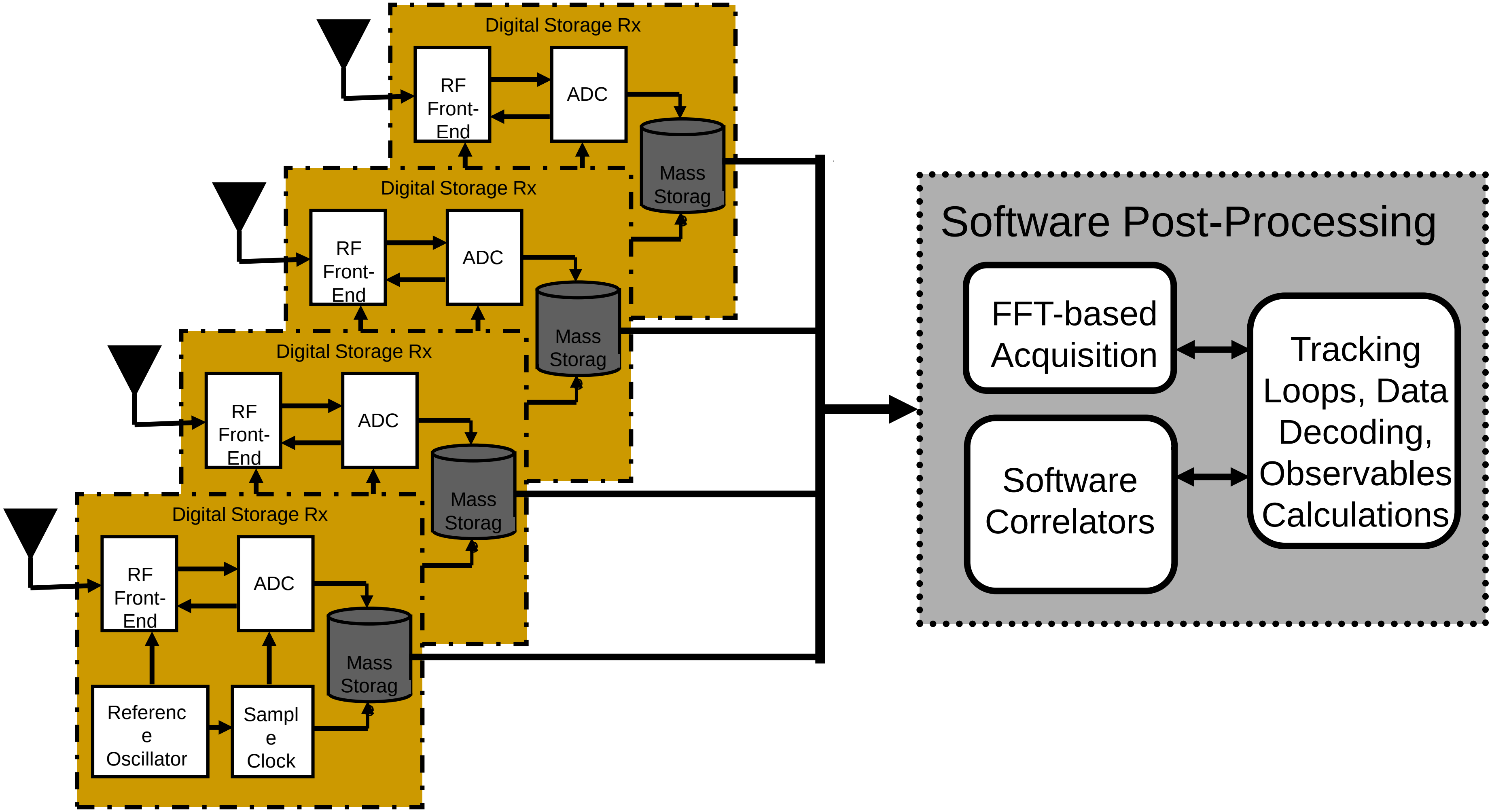
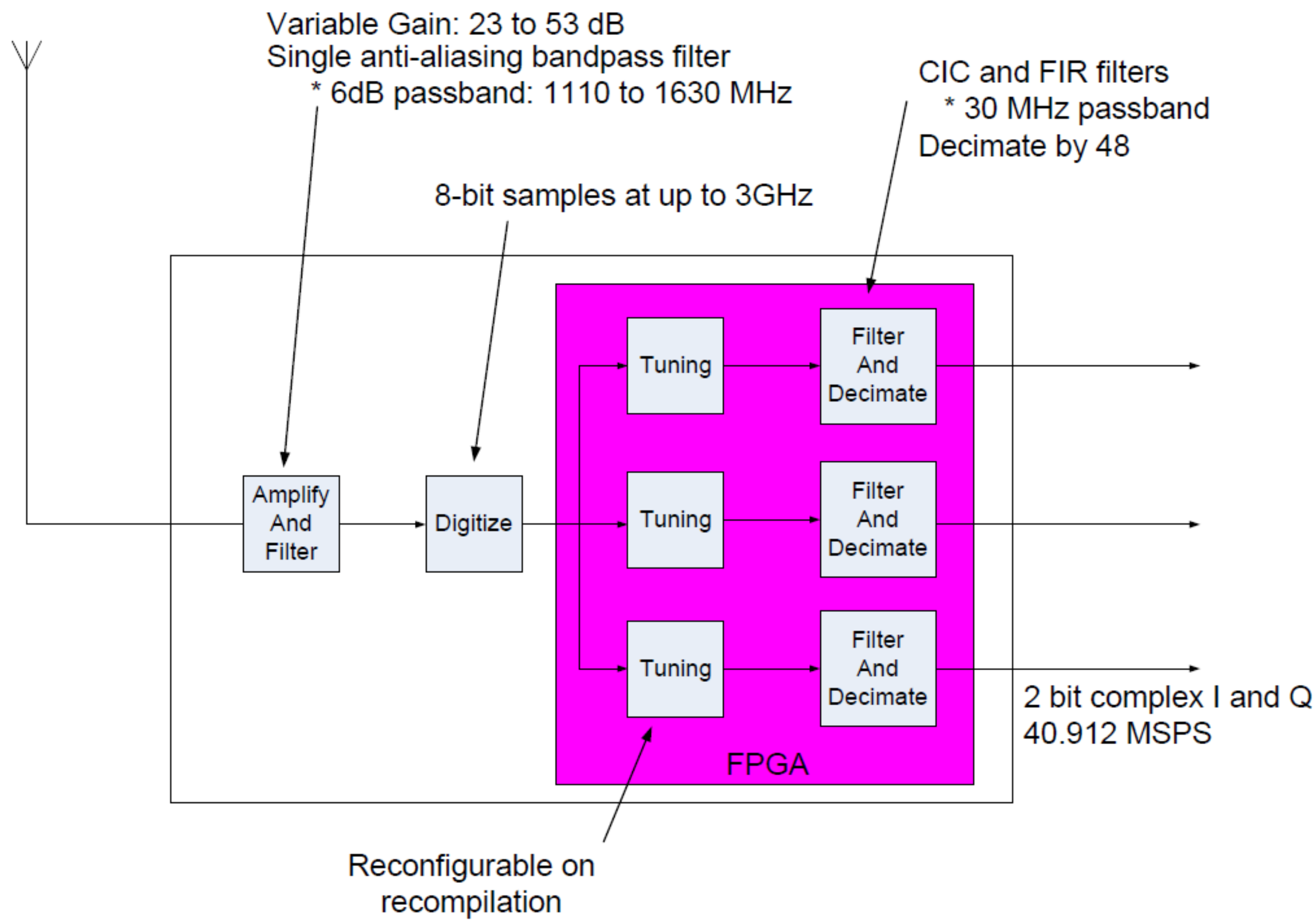
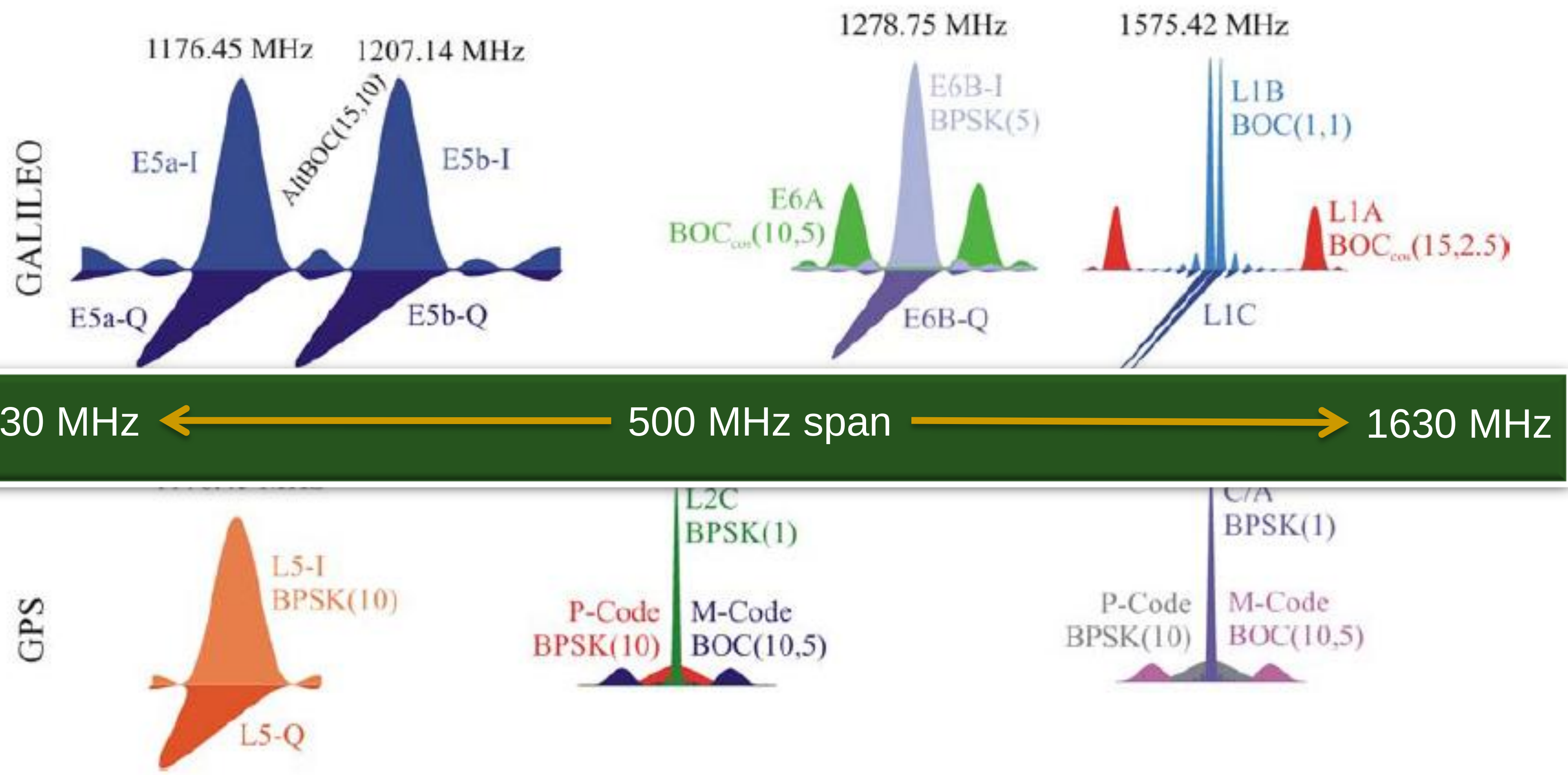
Recall: The Ultra Receiver



The ARL:UT Digitizing Front End

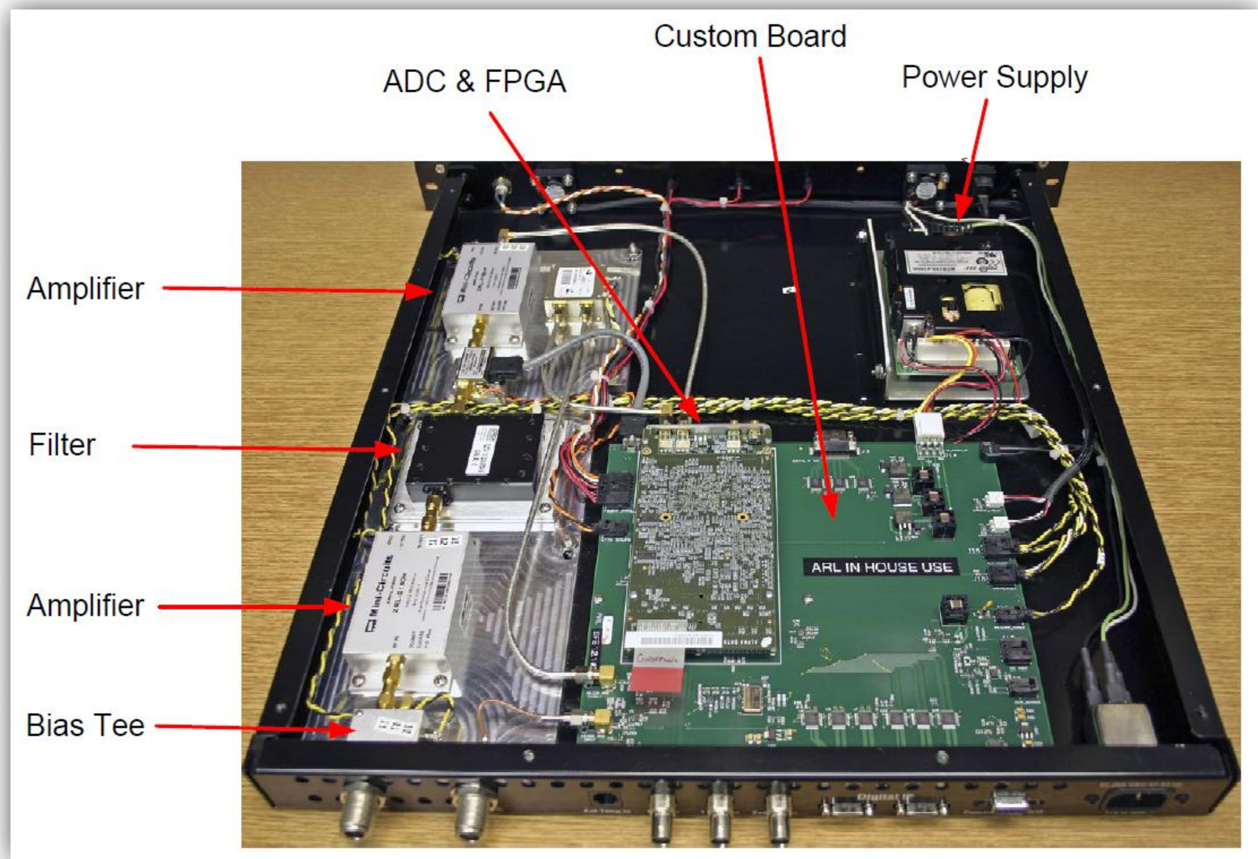


The ARL:UT Digitizing Front End



(Fig. 1 of Wallner et al., "Interference Computations Between GPS and Galileo," Proc. ION GNSS 2005)

The ARL:UT Digitizing Front End



- 500 MHz bandwidth
- Single RF signal path and ADC substantially eliminates inter-signal instrument biases
- Temperature-stabilized signal conditioning chain
- Open-source design, as with GPSTk
- Debut at ION GNSS 2010

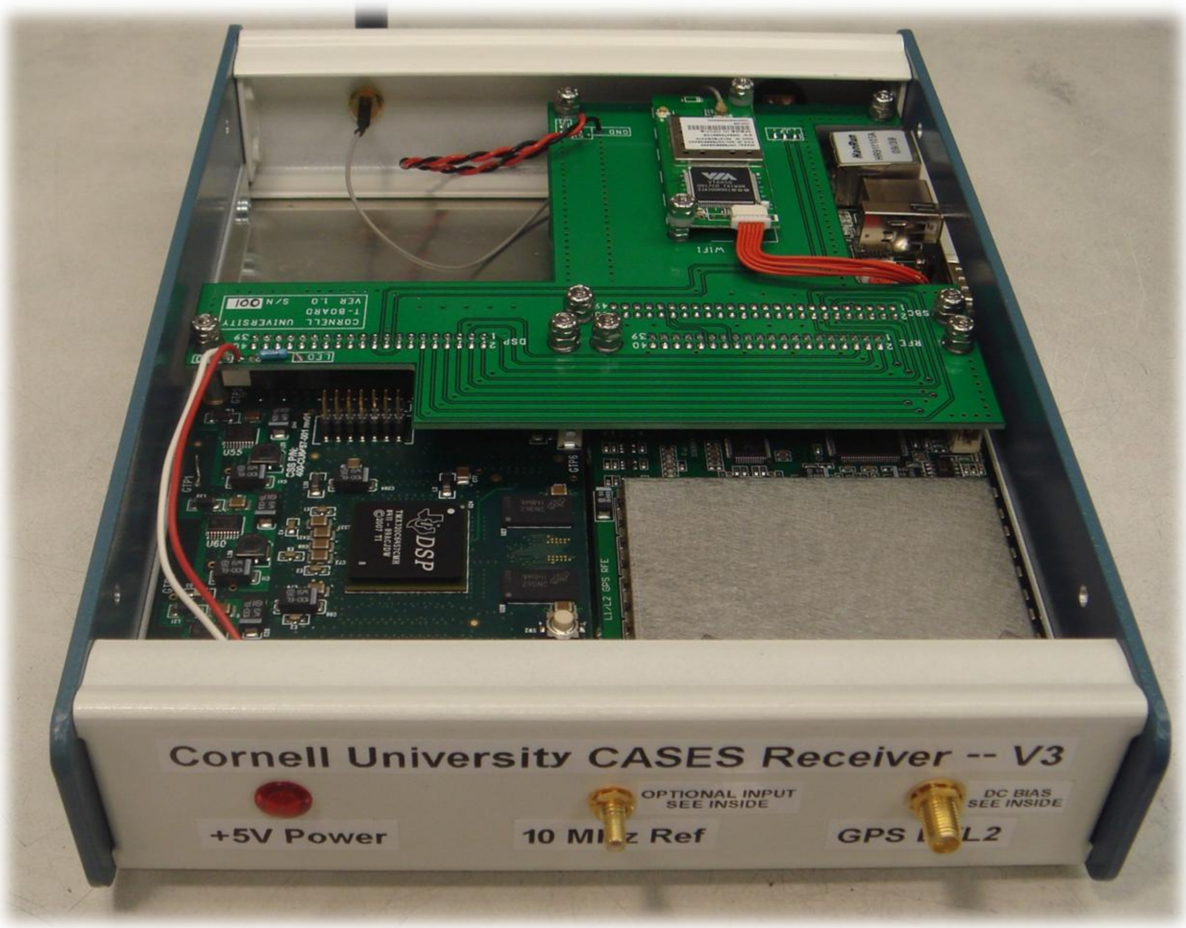
UT/Cornell/ASTRA CASES SwRx

V0

V1

V2

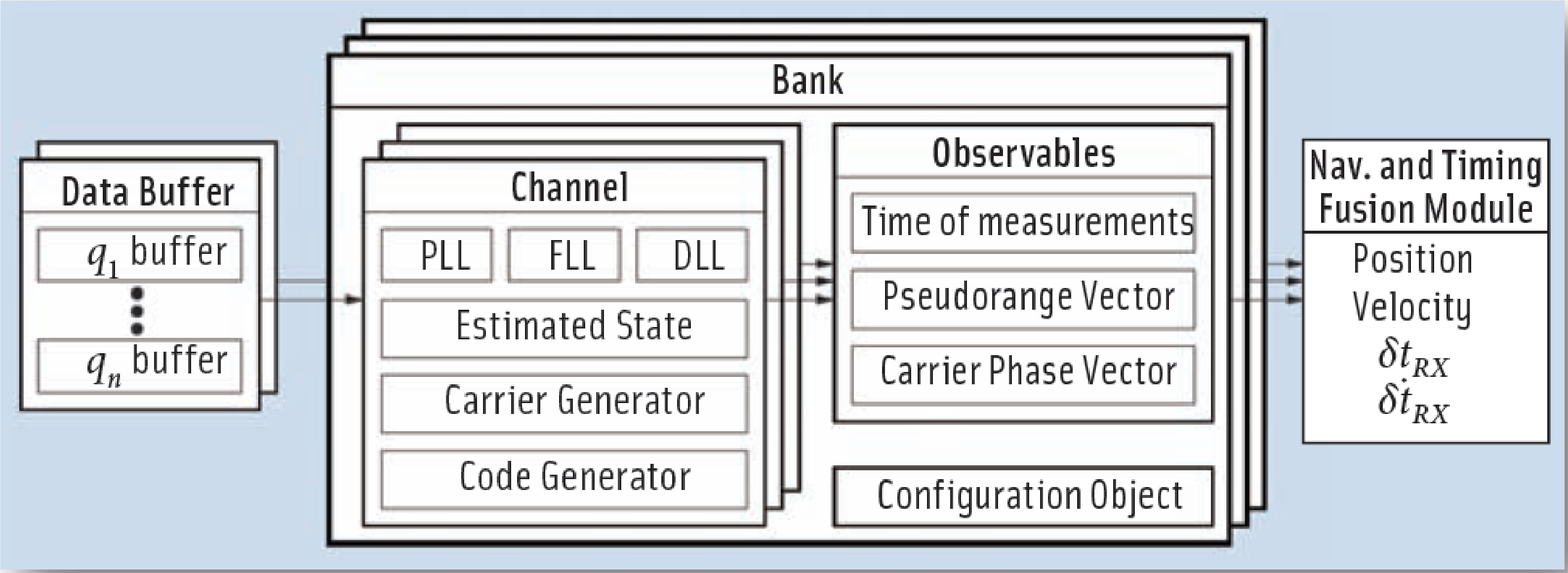
UT/Cornell/ASTRA CASES SwRx



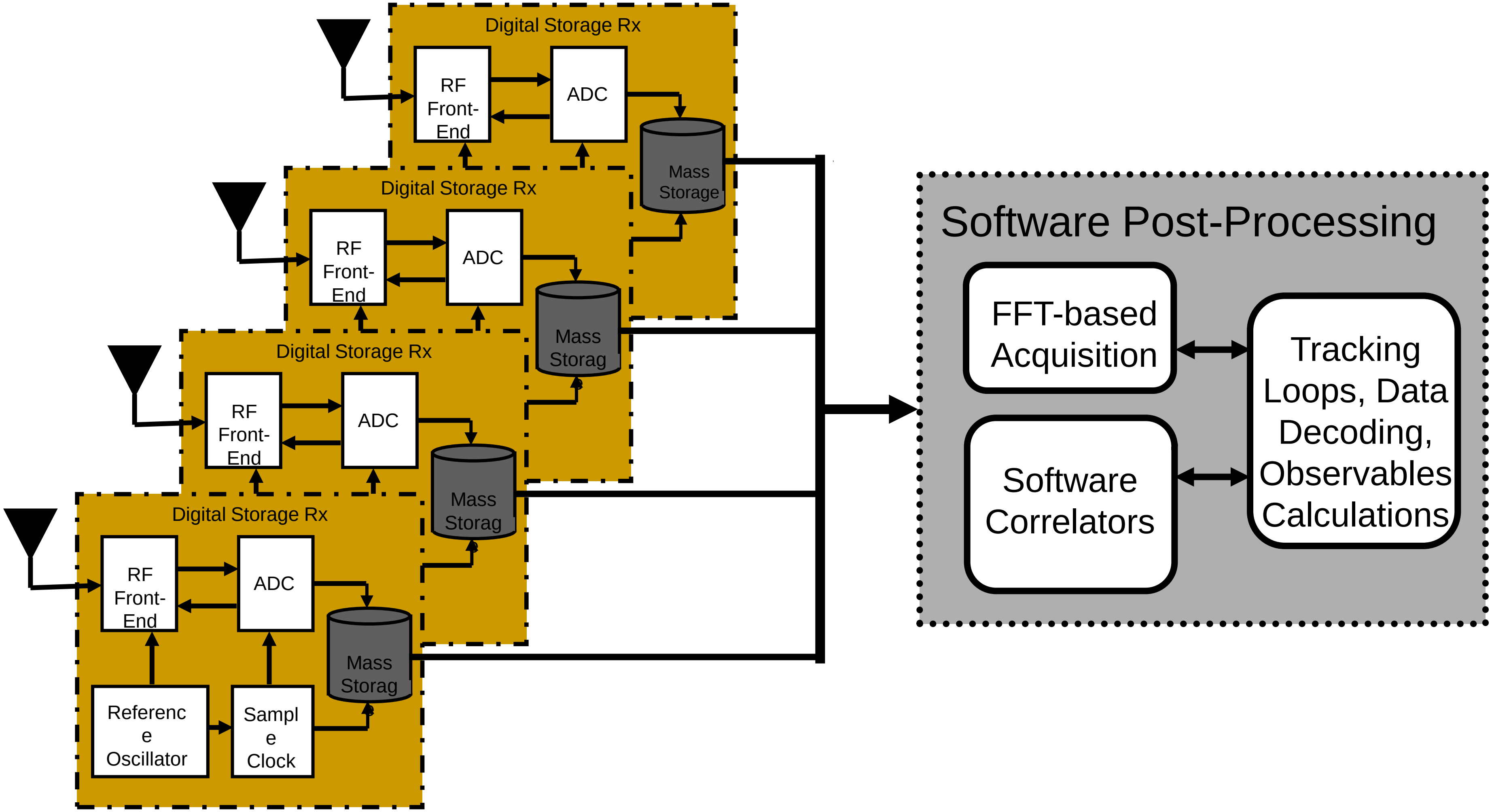
- Dual-frequency narrowband
- Completely software reconfigurable
- Antarctic deployment 2010
- Space deployment 2012 (as occultation sensor)

V3

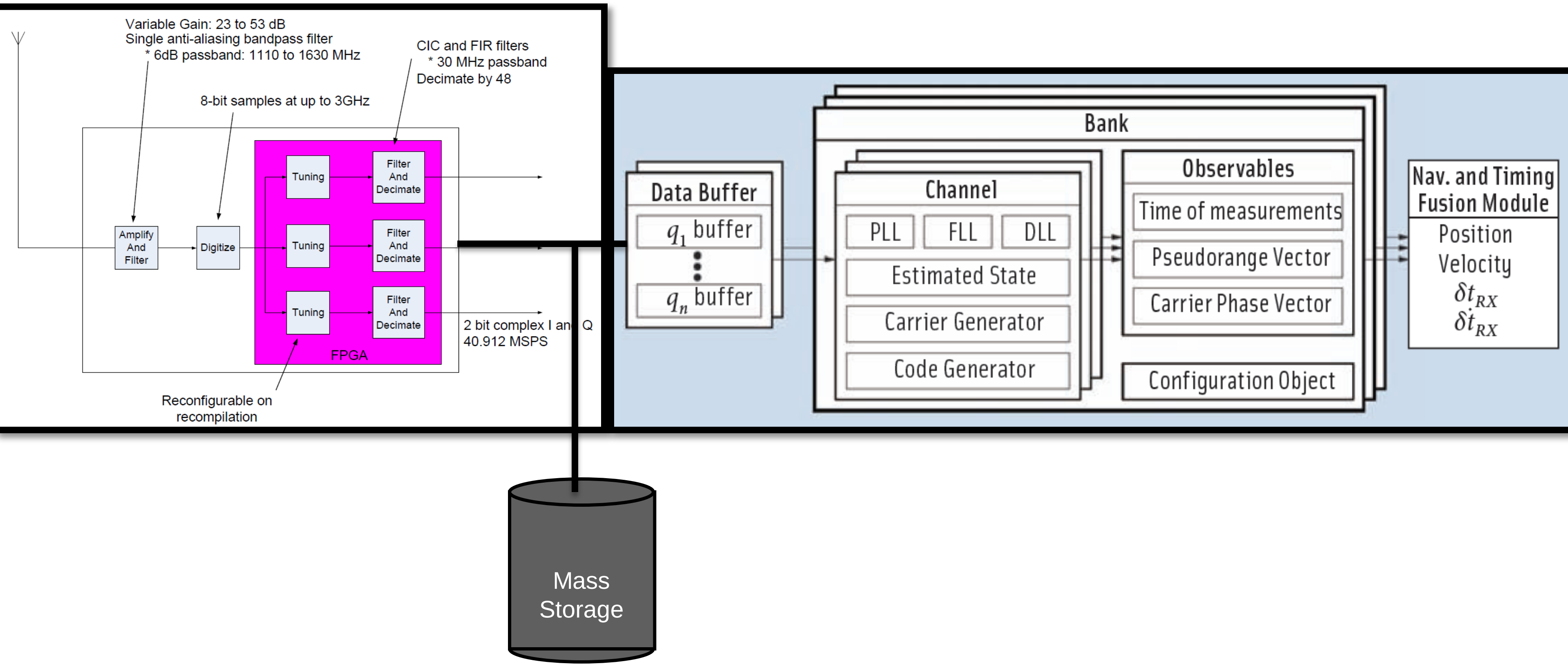
CASES Multi-System Receiver Bank



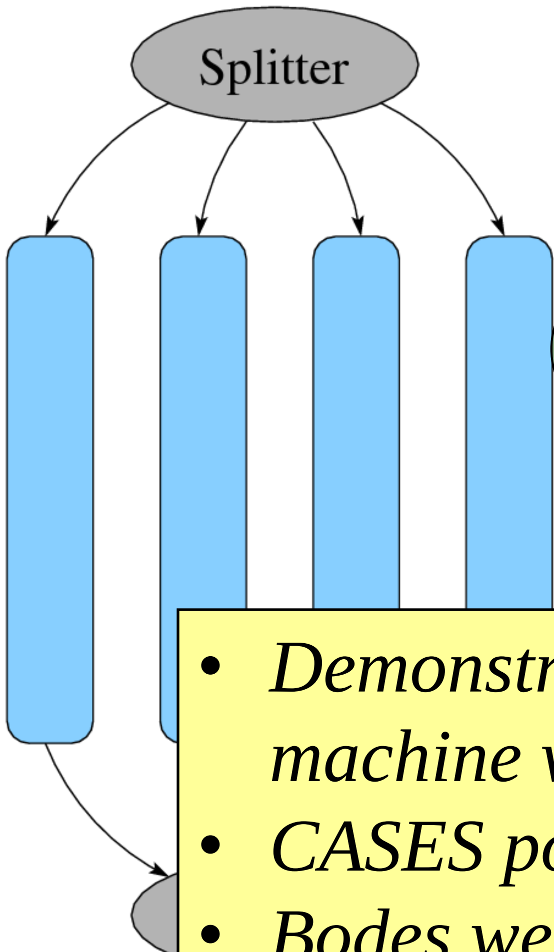
Approaching the Ultra Receiver



Approaching the Ultra Receiver



Multicore GNSS Processing



- Signal-type level
  - Low comm/sync overhead
  - Poor load balancing
- Channel level
  - Low comm/sync overhead
  - Good load balancing
  - Favors shared memory architecture
- Correlation level

- *Demonstrated 3.4x speedup on 4-core machine with OpenMP*
- *CASES post-processing now 25x real-time*
- *Bodes well for reanalysis*

UFAF SwRx Evaluation (Carsten Stroeber)

Running since	**End 2007**
Current Signals	**GPS L1 C/A, L2C (CM+CL), L5 Giove A+B SBAS**
Frontend	**Fraunhofer, (IFEN possible)**
Longest running time without external reset	**>10 days**
Longest running time with external reset	**>1 month**

http://www.unibw.de/lrt9_3

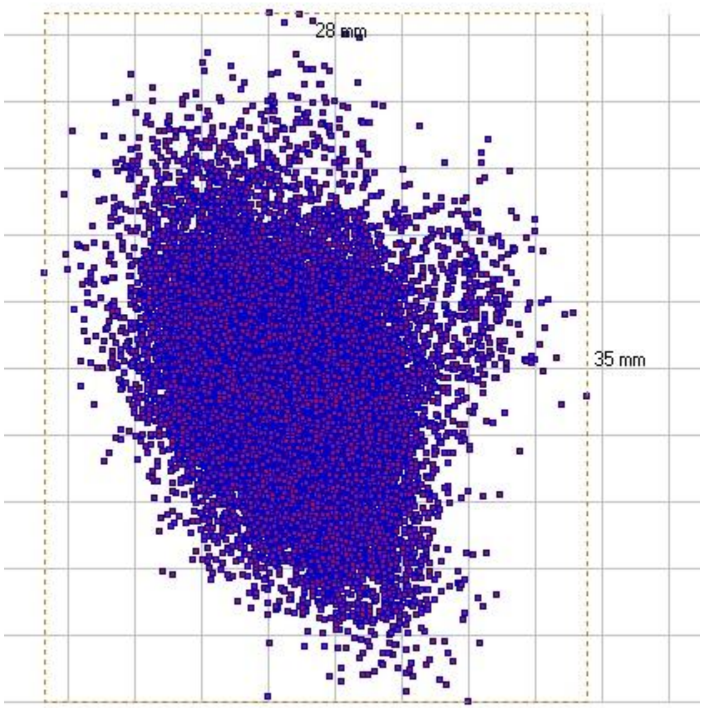
Annotations:

- External reset denotes automatic restart of the receiver via script program
- Reference station was on a productive system simultaneously employing monitoring algorithms -> priority was not only given to long time stability
- Currently Glonass is in test mode
- Dedicated software receiver reference station (GPS L1, L2 only) intended for long run stability is in test phase

Advantages

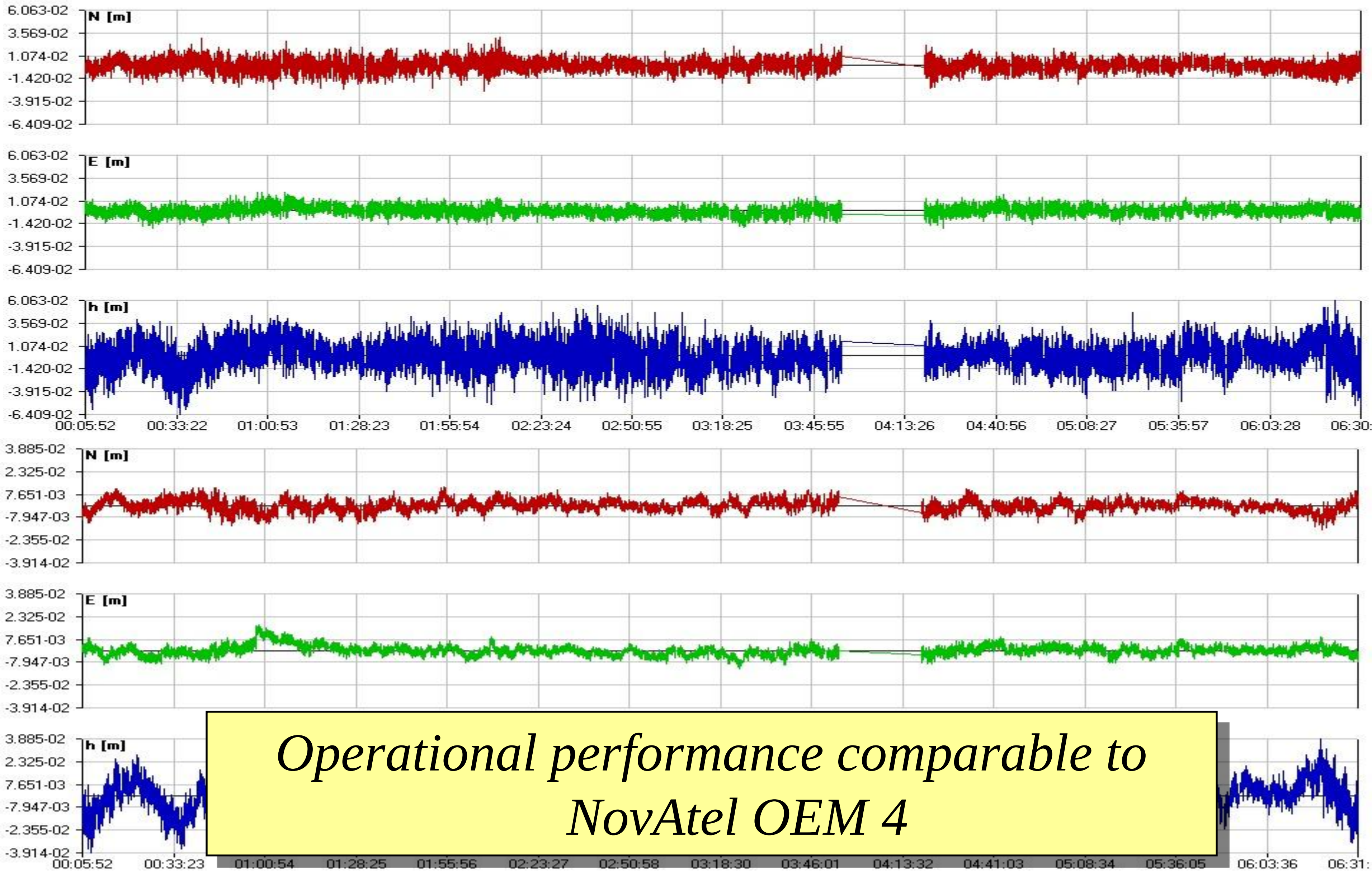
- Extensive data analysis possible at measurement time
  - e.g. instantaneous monitoring for signal distortions with access to “low” level measurements i.e. signal sample data
- Software receiver is “independent” from utilized hardware

UFAF SwRx Evaluation



Horizontal scatter plot of final PDGPS adjustment at highest temporal resolution with bounding box (upward: north; right: eastward).

Date	**DoY 170, Year 2007**
Analysis Software	**PrePos GNSS Suite**
Measurements	**GPS L1**
Number observations (double differences)	**128614**
Duration	**405 min**
Data deleted due to cycle slips	**2% (for OEM 4 receiver 1%)**
Standard deviation position	**X 5.2mm Y 3.7mm Z 6.1mm**



Operational performance comparable to NovAtel OEM 4

Coordinate time series of final PDGPS adjustment. Software receiver at top, OEM IV at bottom.

UFAF SwRx Evaluation

Drawbacks, suggested directions

- Complex interaction between PC hardware, working system, additional applications and software receiver e.g.:
  - USB access is controlled by working system (drivers …) -> buffering needed
  - Additional applications starts unmeant, process time consuming action e.g. disk defrag -> additional applications must be deleted or configured too
- Short-time internal processing load peaks due to frequently simultaneous execution of extensive tasks -> 2 strategies:
  - For reference station no “real” real-time needed -> use already existing buffering
  - Adapt configuration to PC hardware and use high power hardware
- Free configurability leads to a big error source given by non optimal or wrong configuration -> in reference station mode this is relaxed due to fixed configuration

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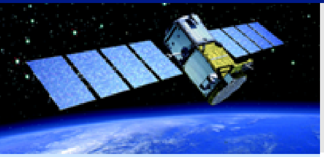
IGS Workshop



Implementing a Pseudorange Reading Standard with the SX-NSR

Thomas Pany, Bernhard Riedl

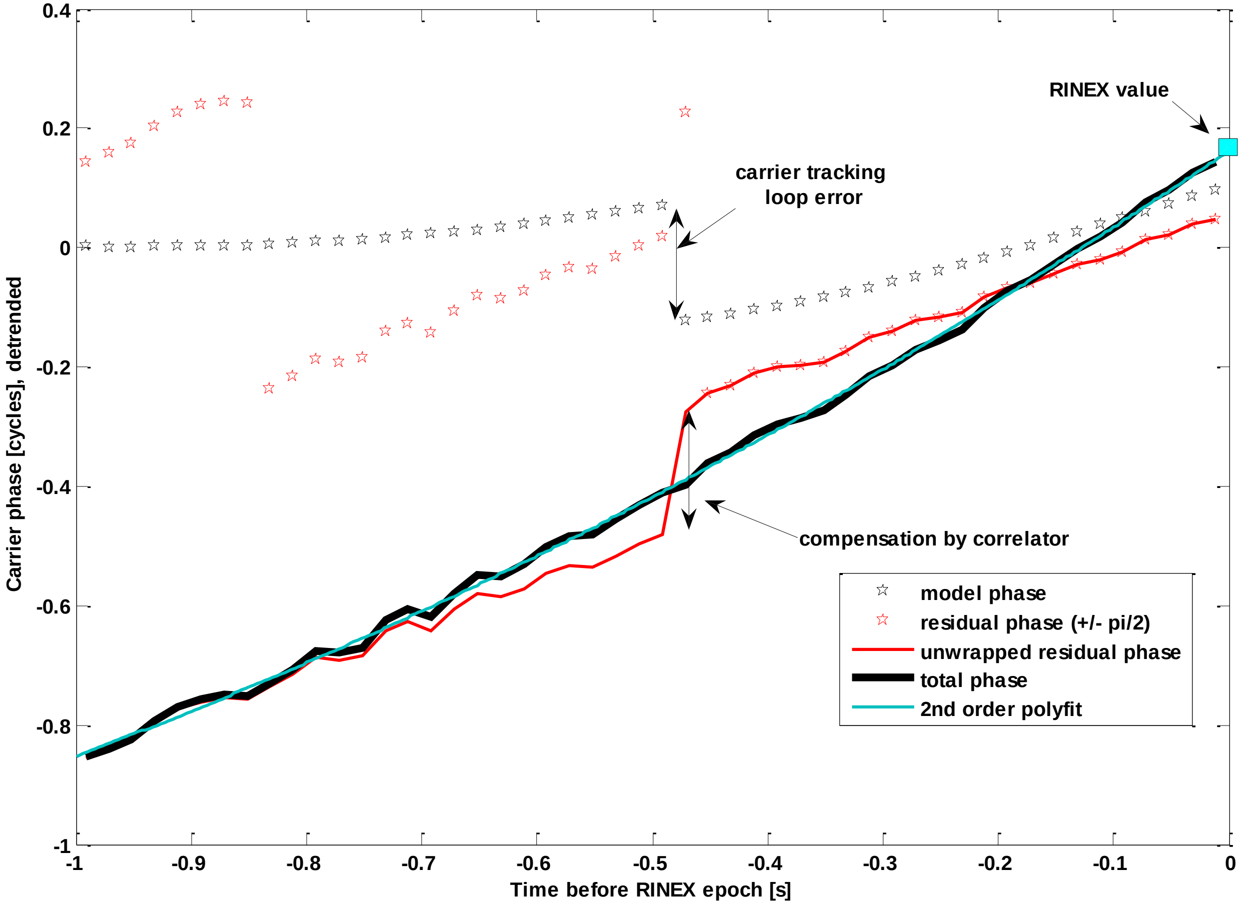
IFEN GmbH

Toward a Standardized Carrier Phase and Pseudorange Measurement Technique

- Different receiver manufacturers use proprietary (code/carrier) measurement definitions
- Standard proposed by L. Young at last IGS workshop based on the US patent no. 4,821,294 (Thomas, Jr., Caltech)
- Goal: to have stochastically independent code/carrier observations with a well understood observation principle
- Use SX-NSR software receivers API for a prototype implementation

Illustration (Carrier Phase)

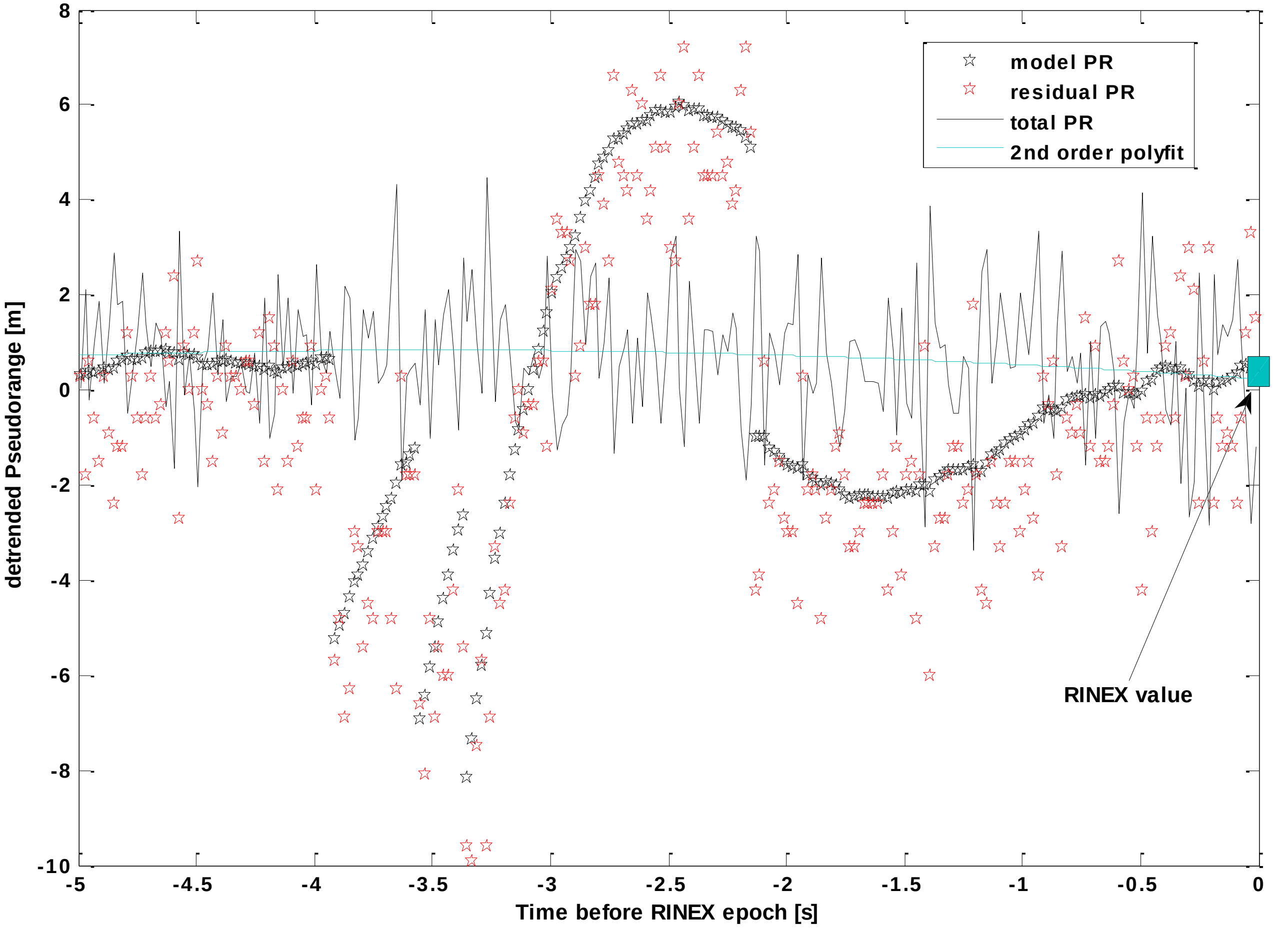
GPS C/A PRN13
Week 1570, sec ~
234179, NavPort-2
Frontend with OCXO



- ‘Verification’ that correlator based observations are truly independent
- Download: C++ source code and exemplary data (GPS L1, Galileo E1/E5a) at www.ifen.com

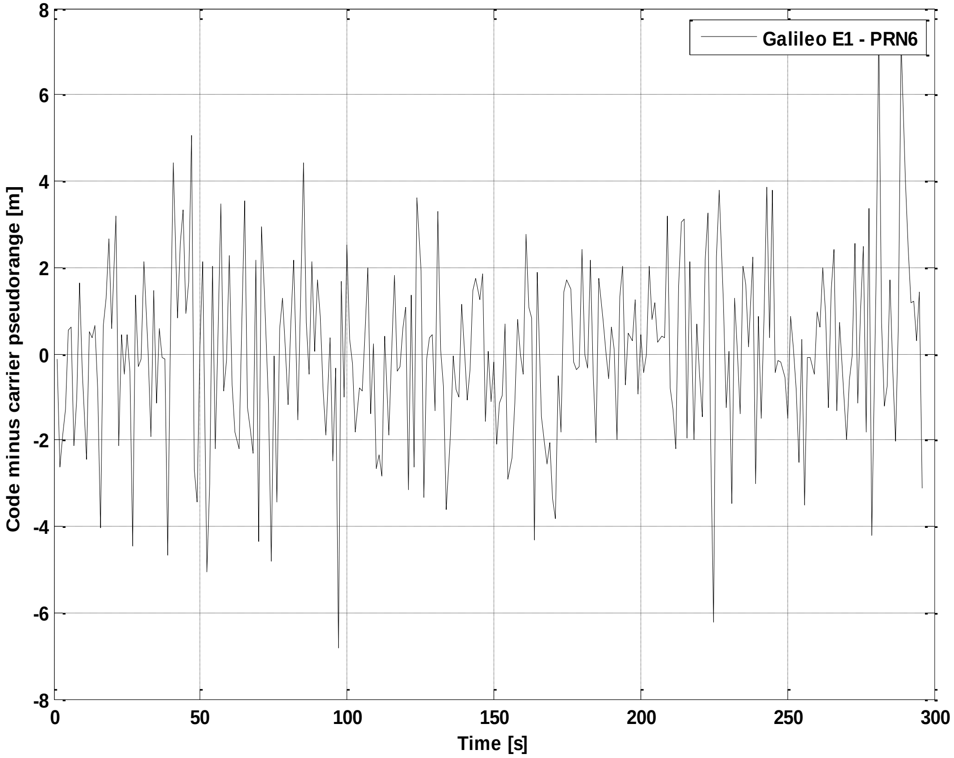
Illustration (Pseudorange)

GPS C/A PRN13
Week 1570, sec ~ 234179, NavPort-2 Frontend with OCXO



Evaluating the Example

- Code minus carrier analysis shows that data is statistically independent
- Discriminators cancel time correlation caused by the low bandwidth (0.1 -0.25 Hz) tracking loops
- Phase discriminiator unwrapping together with FLL tracking gives valid carrier ranges



Summary

Q: What advances in GNSS receiver technology can the IGS exploit to improve its network and products?

A1: Commercial receivers are approaching the "Super Receiver": nearing all-GNSS-signals tracking, reconfigurable, low-cost

A2: 500-MHz digitizing open-design front-end captures all current and planned GNSS signals, substantially eliminates inter-signal RX biases

A3: 500-MHz front-end + Multi-system SwRx + Multi-core processing + data buffering → Ultra Receiver

A4: SwRx performance comparable to commercial geodetic RXs (but not yet as reliable)

A5: Receiver APIs offer path for measurement standardization (e.g., IFEN SX-NSR)