GRAS SAF Open Loop Workshop
Helsingør, Denmark
June 6-8, 2005

DMI Technical Report 05-11
ISSN: 1399-1388
Kent B. Lauritsen and Frans Rubek, editors

GRAS Open Loop Tracking

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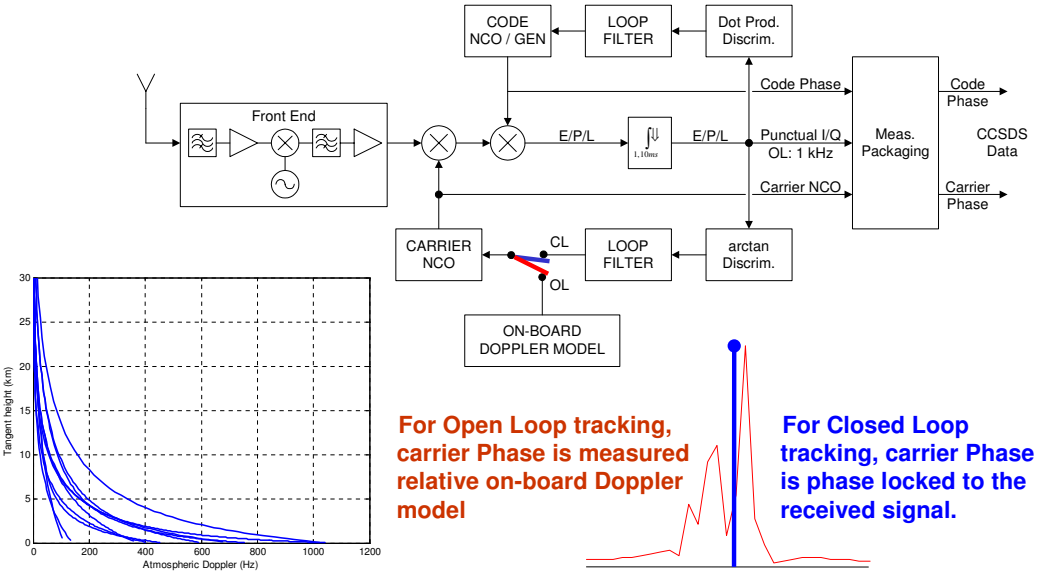
GRAS Open Loop Tracking

Content:

- **Justification for Open Loop Tracking**
- **Open Loop Tracking & Doppler Model**
- **Open Loop Data Format & Usage**
- **Questions / Answers**

Jacob Christensen (jacob.christensen@space.se)

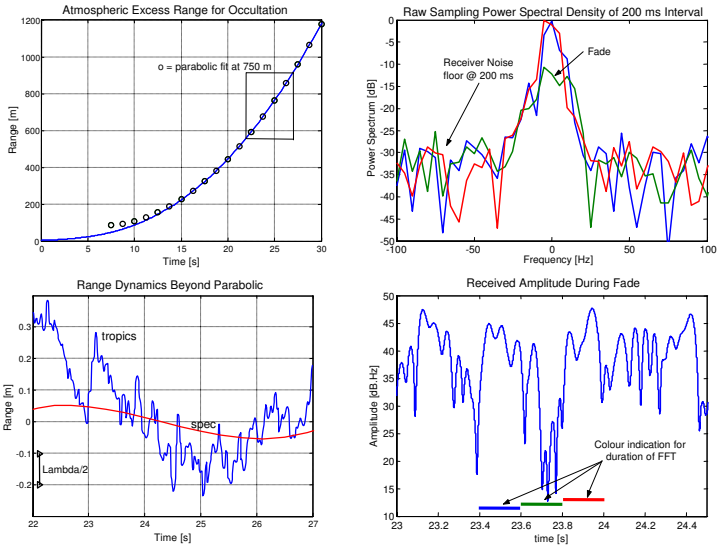
Open Loop Trackning



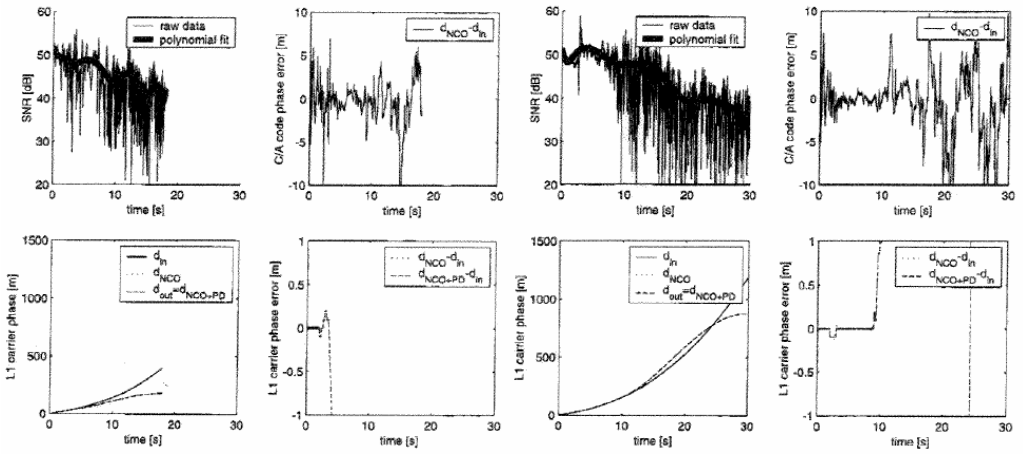
For Open Loop tracking, carrier Phase is measured relative on-board Doppler model

For Closed Loop tracking, carrier Phase is phase locked to the received signal.

Atmospheric Multipath Path Signal Sample



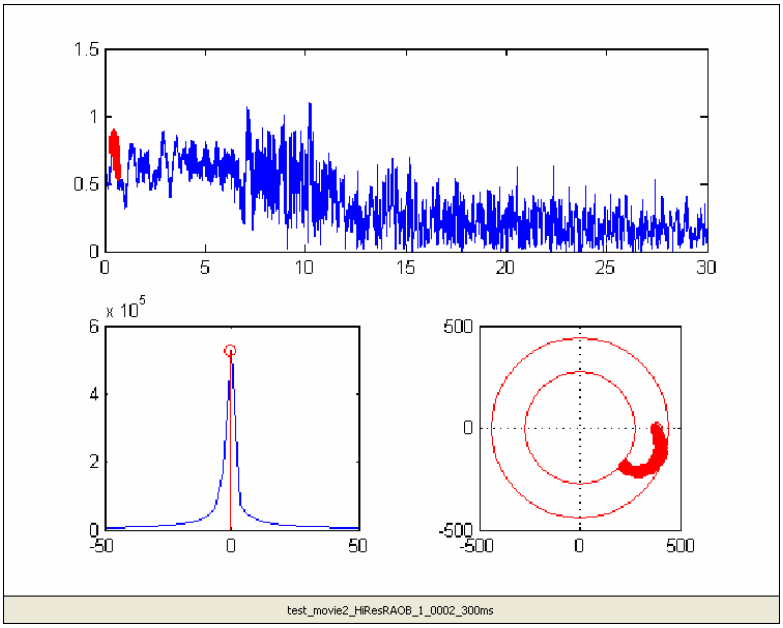
Code and Carrier Closed Loop Tracking Simulation



- Code Tracking is maintained
- Carrier Tracking is lost
- Carrier Measurements Supported by Open Loop Tracking

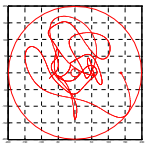
Data: High resolution Radiosonde data forward modeled by UCAR

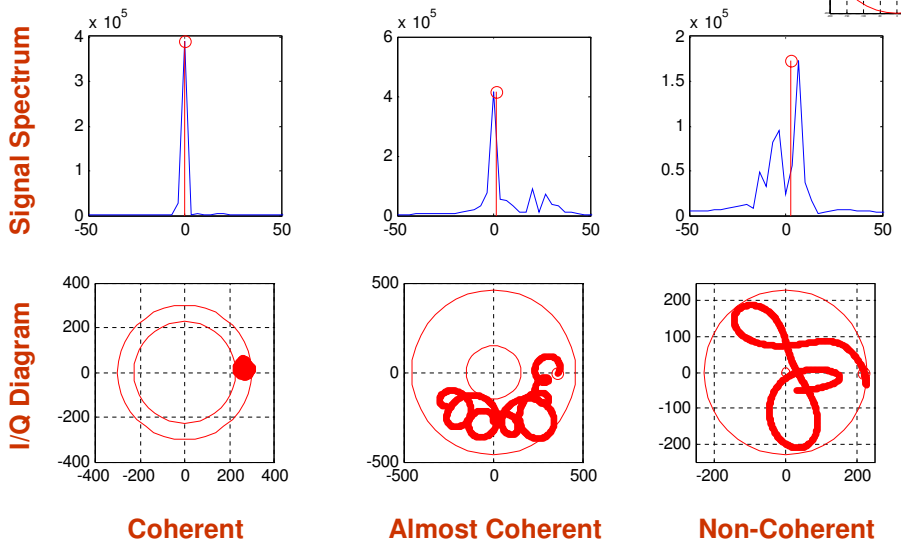
300 ms Spectrum & Residual I/Q simulation



Coherency

(From hi resolution radiosonde data)



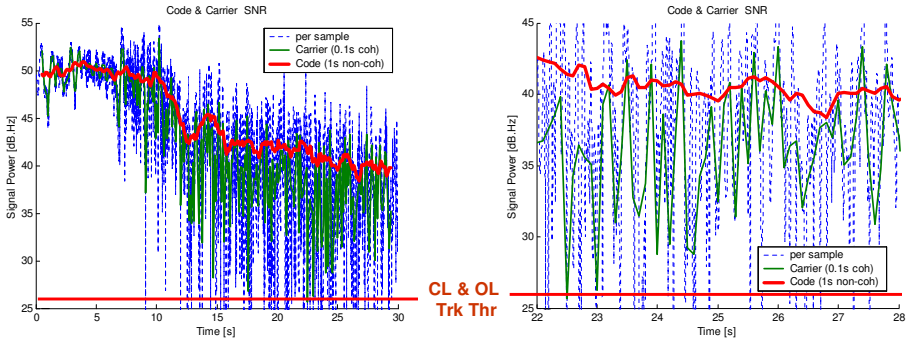


Coherent **Almost Coherent** **Non-Coherent**

Code & Carrier SNR

For severe atmospheric conditions:

- Carrier tracking will be lost due to lack of coherency (low SNR & dynamics)
- Code tracking is non-coherent and more resistant to “atmospheric dynamics”
- Open loop tracking rely only on code tracking and measures the carrier relative an onboard Doppler model.



Data: HI-resolution Radiosonde data (UCAR)

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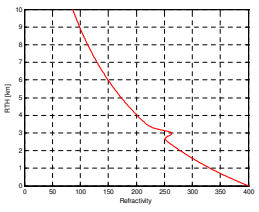
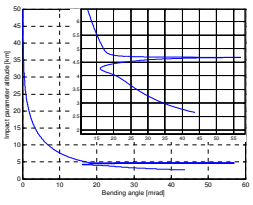
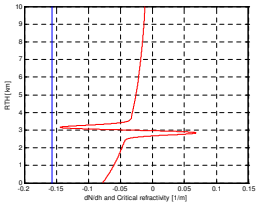
Refractivity Bump Simulation

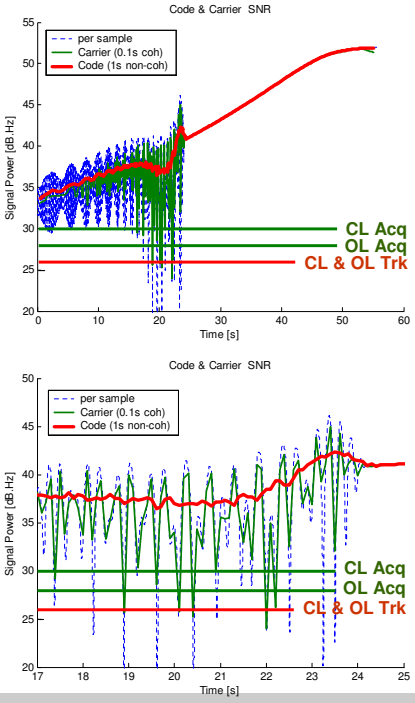
In “Dense Wet” Atmosphere







Refractivity at surface:	N0 = 300
Scale height:	H0 = 7.9 km
Wet refract. at surface:	Nw = 100
Wet scale height:	Hw = 2.5 km
Bump strength:	Nb = 28
Bump height:	hb = 3 km
Bump width:	wb = 0.2236 km



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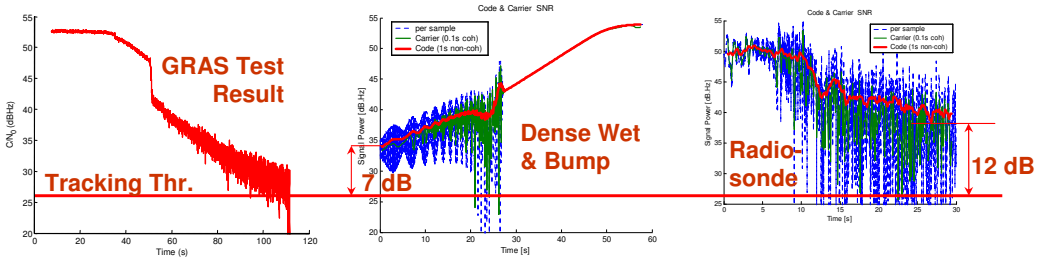
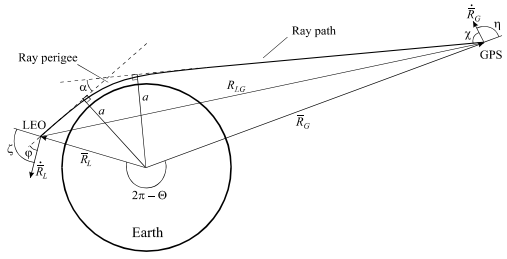
Signal tracking conditions

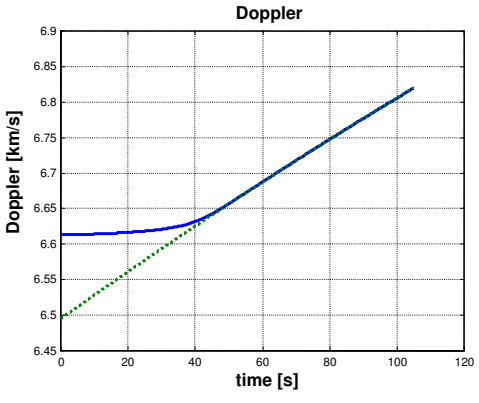


Real life versus GRAS Spec/Test:

- Closed Loop Tracking will be more intermittent.
- Open Loop Tracking will have more margin and be very robust.
- Open Loop Data will be more significant for real signals
- Retune instrument parameters to optimize open loop tracking for rising occultations. (SLTA_L2 & SLTA_A)

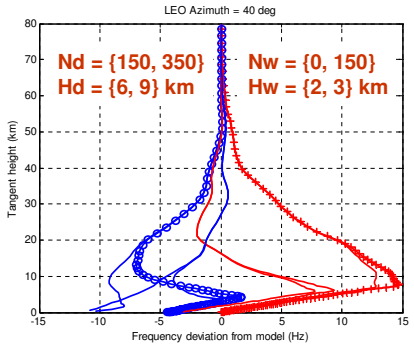
Doppler Model
(Patented)

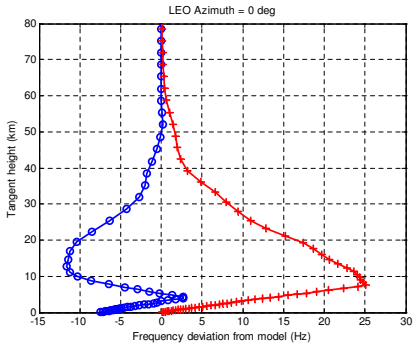




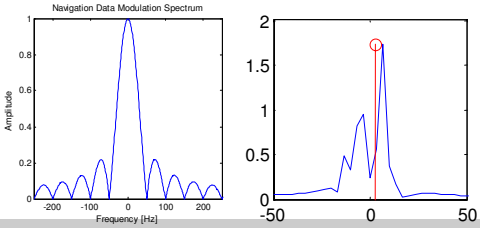
- Measured Doppler approximated as:
  - **Line of sight at high altitude**
  - **Constant impact parameter altitude above WGS 84 at low altitudes.**
- Nominal Ray Impact Points (NRIP) modeled on-board based on Straight Line Tangent Altitude (SLTA)

Doppler Model Accuracy



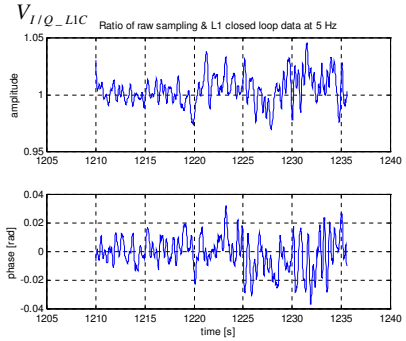


- Doppler Model residual: < ± 25 Hz
- Atmospheric modulation: up to ~ ± 25 Hz
- I/Q bandwidth: 50 - 100 Hz without nav data
- Nav. Data modulation: ± 150 Hz @ -20 dB

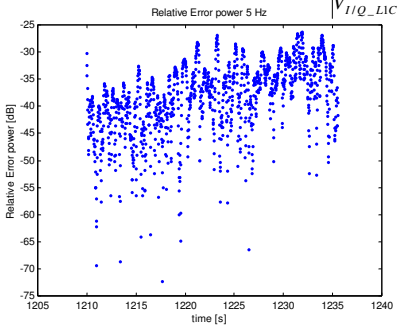


Open to Closed Loop Alignment

$$R_{I/Q} = \frac{V_{I/Q\_RS}}{V_{I/Q\_L1C}}$$



$$\varepsilon_R = \frac{\left|V_{I/Q\_RS} - V_{I/Q\_L1C}\right|}{\left|V_{I/Q\_L1C}\right|}$$



Measured OL & CL Data:

$$V_{Loop}^{RS} = \left(I_{RS} + j \cdot Q_{RS}\right) \cdot e^{j \cdot \phi_{RS\_NCO}}$$

$$V_{Loop}^{L1C} = \left(I_{L1C} + j \cdot Q_{L1C}\right) \cdot e^{j \cdot \phi_{L1C\_NCO}}$$

Evaluation Products:

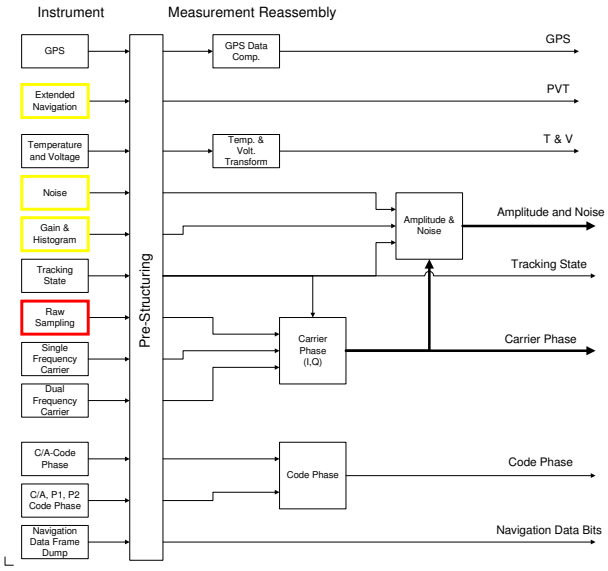
$$V_{I/Q\_RS} = \left(I_{RS} + j \cdot Q_{RS}\right) \cdot e^{j \cdot \left(\phi_{RS\_NCO} - \phi_{L1C\_NCO}\right)}$$

$$V_{I/Q\_L1C} = \left(I_{L1C} + j \cdot Q_{L1C}\right)$$

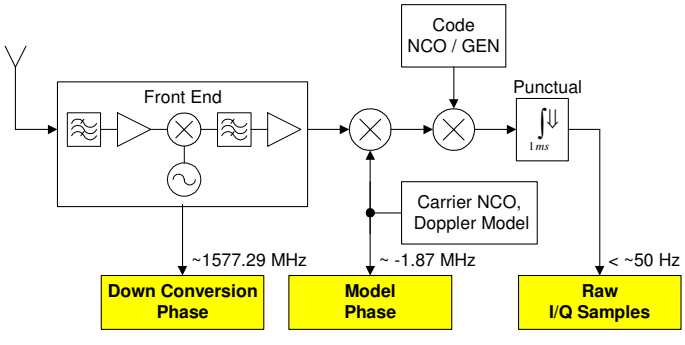
The relative error between open & closed loop measurement data is better than -20 dB.

GRAS Measurement Data

- "Raw Sampling" packet provide:
  - Doppler Model Phase
  - Raw I/Q samples at 1 kHz
  - Time tagged with IMT, (Instrument Measurement Time)
- Relation between IMT and UTC time from:
  - "Extended Navigation" packet
- Amplitude Scaling of raw I/Q data from:
  - "Gain and Histogram" packet
  - "Noise" packet



Open Loop Data Components



$$V_{Ant}(t) = \frac{1}{\sqrt{G_k}} \cdot \underbrace{e^{j\cdot\varphi_{DC}^{L1}(t)}}_{\text{Syst. Const.}} \cdot \underbrace{e^{j\cdot\varphi_{HP}^{L1}(t)} \cdot \left(I(t) + jQ(t)\right)}_{\text{Open Loop Measurement Data}}$$

$$\varphi_{DC}^{L1} = \frac{7571}{24} \cdot f_{USO} \cdot (t - t_0) + \varphi_{DC}^{L1}(t_0); \quad f_{USO} = 5.0MHz \pm 0.1Hz$$

The measured signal (V_{ant}), represent the GPS signal as received at the antenna and includes the GPS carrier at 1575.42 MHz (nom).

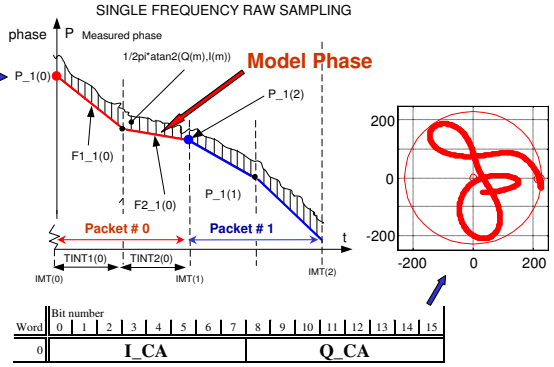
Open Loop Measurement Data

(Packet Type: 9 “Occultation Raw Sampling”)

“Raw Sampling” Data Packet:

Word	Bit number 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	LEN												TYP			
1	N/U				SAT								CHN			
2	IMT															
3																
4																
5	P_1															
6																
7																
8																
9	F1_1															
10																
11	TINT1															
12																
13	F2_1															
14																
15	TINT2															
16																
17	N/U												IQ_CA_EXP			
18	N/U															
19	Samples															
20																
...																
N																

Header



Word	Bit number 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	I_CA								Q_CA							

- Binary Data format described in: P-GRM-ICD-0008-SE
  - “Measurement Data Interface Control Document”
- Data Interpretation described in: P-GRM-SPC-0036-SE
  - “Measurement Data Interpretation and Description”

Open Loop Measurement Data (2)

SUB HEADER:

Label	Symbol	Size [bits]	Resolution [units]	Range [units]	Unit	Content
IMT	$T_{IMT}(n)$	64	1	$0\text{-}2^{64}$	Core_clk	IMT of first phase measurement in packet number n.
P_1	$\varphi_P^{L1}(n)$	64	2^{-12}	$\pm 2^{47}$	Cycles	L1 NCO phase at $T_{IMT}(n)$ in packet n in units of NCO phase resolution.
F_1	$F_{F1}^{L1}(n)$	32	1	$\pm 2^{31}$	f_{NCO_Res}	Reference frequency of L1 carrier for segment 1 and 2 of packet number n in units of NCO frequency resolution.
F_2	$F_{F2}^{L1}(n)$	32	1	$\pm 2^{31}$	f_{NCO_Res}	
IQ_CA_EXP	$E_{CA}(n)$	8	1	0-255	LSB	Exponent of L1 carrier I/Q samples in packet n.
TINT1	$T_{Int1}(n)$	32	1	$0\text{-}2^{32}$	Core_clk	Total integration time for all measurements in segment 1 and 2 of packet number n.
TINT2	$T_{Int2}(n)$	32	1	$0\text{-}2^{32}$	Core_clk	
CHN	Ch	4	1	8-11	LSB	Measurement channel id. GVA: 8,9; GAVA: 10,11
LEN	Len(n)	12	1	$0\text{-}2^{11}$	byte	Length of packet number n in bytes

BODY DATA:

Label	Symbol	Size [bits]	Resolution [units]	Range [units]	Unit	Content
I_CA	$I_{CA}(m)$	8	$2^{I/Q\_exponent}$	$\pm 2^{I/Q\_exponent+7}$	AGGA Integration Counts	m’th I and Q data of L1 carrier amplitude in terms of normalised counts of the C/A punctual integrate and dump.
Q_CA	$Q_{CA}(m)$	8	$2^{I/Q\_exponent}$	$\pm 2^{I/Q\_exponent+7}$		

Open Loop Data Interpretation

Complex signal at antenna:

$$V_{Ant}\left(t(n,m)\right)=\sqrt{G_k^{-1}(ch)}\cdot\left(I_{CA}(n,m)+jQ_{CA}(n,m)\right)\cdot e^{j\cdot\varphi_{DC}^{L1}(t)}\cdot e^{j\cdot\varphi_{HP}^{L1}(n,m)}$$

Receiver Gain (G_k):

From "Gain & Histogram" and "Noise" packets according to MDID.

Sample time (IMT):

$$t(n,m)\ =\ t_{IMT}(n)+\frac{\tau_{Int1}(n)+\tau_{Int2}(n)}{M_{samp}(n)}\cdot\left(\frac{1}{2}+m\right)\ \ [s]$$

where

$$t_{IMT}(n)=T_{IMT}(n).\tau_{Core}$$
$$\tau_{Int1}(n)=T_{Int1}(n).\tau_{Core}$$
$$\tau_{Int2}(n)=T_{Int2}(n).\tau_{Core}$$

Down conversion Phase:

$$\varphi_{DC}^{L1}(t)=\frac{7571}{24}\cdot f_{USO}\cdot(t-t_0)+\varphi_{DC}^{L1}(t_0)$$

Header Model Phase [cycles]:

First segment :

$$\varphi_{HP}^{L1}(n,m)=\varphi_{P}^{L1}(n)+f_{F1}^{L1}(n)\cdot\frac{\tau_{Int1}(n)+\tau_{Int2}(n)}{M_{samp}(n)}\cdot\left(\frac{1}{2}+m\right)$$

for $\quad m=\{0,1,2,\ldots,[M_1-1]\}$

Second segment :

$$\varphi_{HP}^{L1}(n,m)=\varphi_{P}^{L1}(n)+f_{F1}^{L1}(n)\cdot\tau_{Int1}(n)+f_{F2}^{L1}(n)\cdot\frac{\tau_{Int1}(n)+\tau_{Int2}(n)}{M_{samp}(n)}\cdot\left(\frac{1}{2}+m-M_1\right)$$

for $\quad m=\{M_1,\ldots,(M_{samp}-1)\}$

Where: $\quad M_1=Round\left(\frac{\tau_{Int1}\cdot M_{Samp}}{\tau_{Int1}+\tau_{Int2}}\right)$ and $f_{Fx}^{L1}(n)=F_{Fx}^{L1}(n)\cdot\frac{f_{Core}}{12\cdot 2^{28}},\ x=\{1,2\}$

n: Packet number;
m: Sample number;

$$\tau_{Core}=\frac{1}{f_{Core}};\ f_{Core}=\frac{113}{20}f_{USO};\ f_{USO}=5MHz\pm 0.1Hz;\ M_{samp}(n)=\frac{Len(n)-40}{2}$$

Open Loop Data Interpretation

Complex signal at antenna:

$$V_{Ant}\left(t(n,m)\right)=\sqrt{G_k^{-1}(ch)}\cdot\left(I_{CA}(n,m)+jQ_{CA}(n,m)\right)\cdot e^{j\cdot\varphi_{DC}^{L1}(t)}\cdot e^{j\cdot\varphi_{HP}^{L1}(n,m)}$$

I/Q — Phase

Keep Phase & I/Q as separate components

Receiver Gain (G_k):

Calculation described in MDID

Sample time (IMT):

$t(n,m)$ calculated from:

- IMT
- TINT1
- TINT2
- LEN

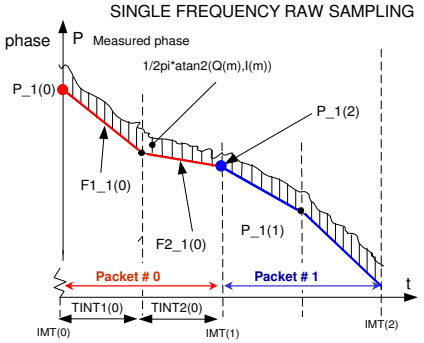
Down conversion Phase:

$$\varphi_{DC}^{L1}(t)=\frac{7571}{24}\cdot f_{USO}\cdot(t-t_0)+\varphi_{DC}^{L1}(t_0)$$

Header Model Phase [cycles]:

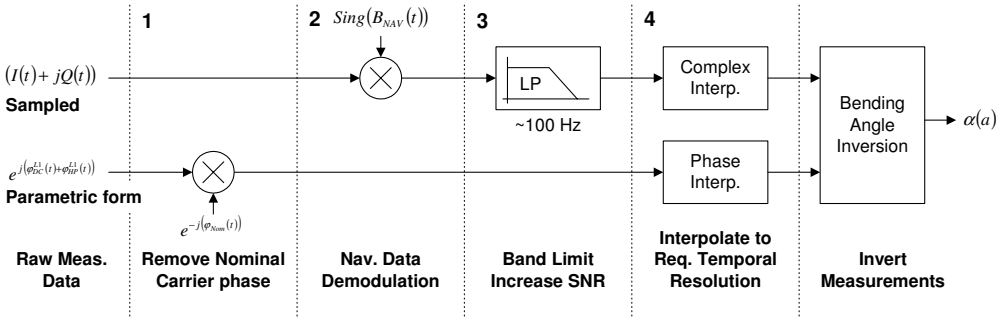
$\varphi_{HP}^{L1}(n,m)$ calculated from:

- P_1
- F1_1
- F2_1
- TINT1
- TINT2
- LEN



n: Packet number; $\quad m$: Sample number;

Using Open Loop Data



1:

- Remove nom GPS freq
  => f < ~50 kHz
- Remove mean/LOS Doppler
  => f < ~2 kHz
- Coordinate with clock corr.
- Coordinate with Inversion algorithm

2:

- Remove Nav. Data Mod. to eliminate π–ambiguities.

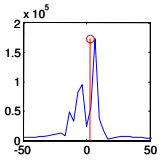
3:

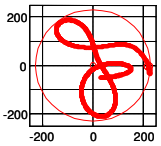
- Maximize SNR before any non-linear processing is applied.
  ~ -5dB @ Trk. Thr. & 1 kHz

4:

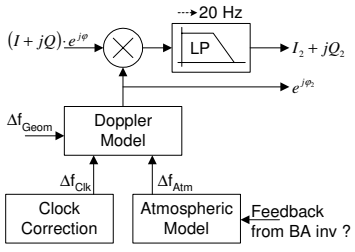
- I/Q data is over sampled after band limiting.
  => Low order interp OK
- Interpret phase to avoid aliasing.
  I.e. $\Delta\varphi > 2\pi$ per sample

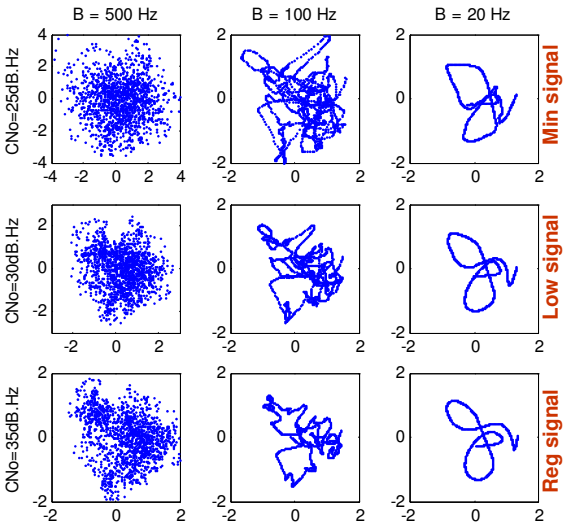
Band Limiting



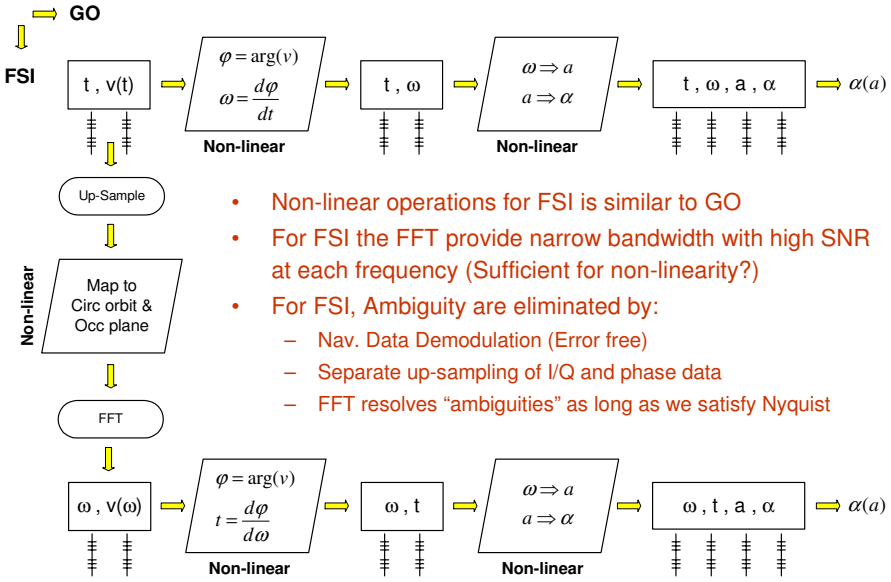


- Coordinate filtering with needs from and implementation of BA. Inversion
- Account for Noise Response of all non-linear operations





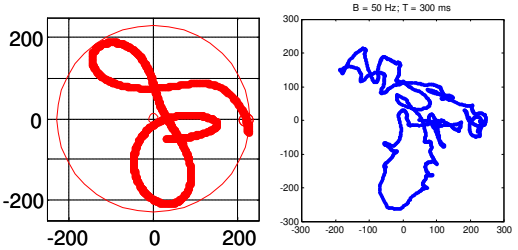
Non-linear operations for GO & FSI Inversions



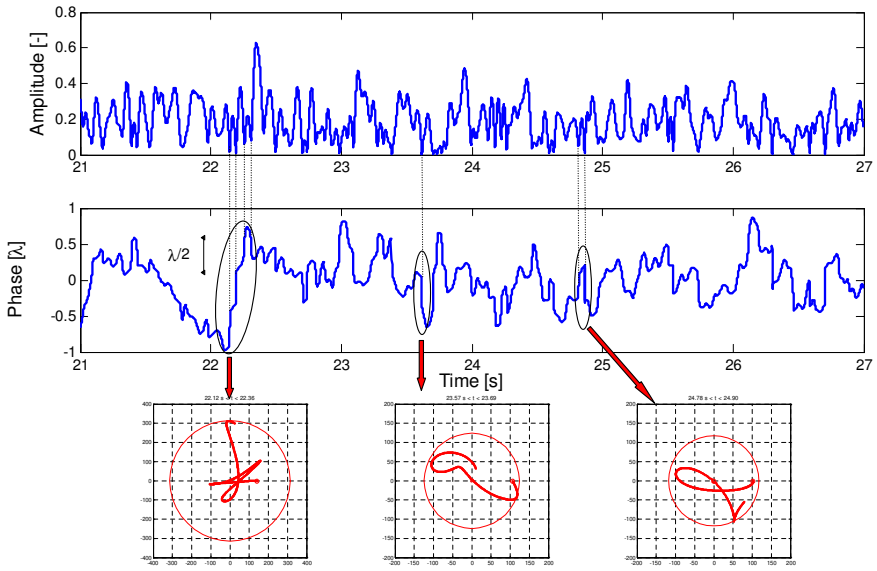
- Non-linear operations for FSI is similar to GO
- For FSI the FFT provide narrow bandwidth with high SNR at each frequency (Sufficient for non-linearity?)
- For FSI, Ambiguity are eliminated by:
  - Nav. Data Demodulation (Error free)
  - Separate up-sampling of I/Q and phase data
  - FFT resolves “ambiguities” as long as we satisfy Nyquist

Atmospheric or Navigation data modulation?

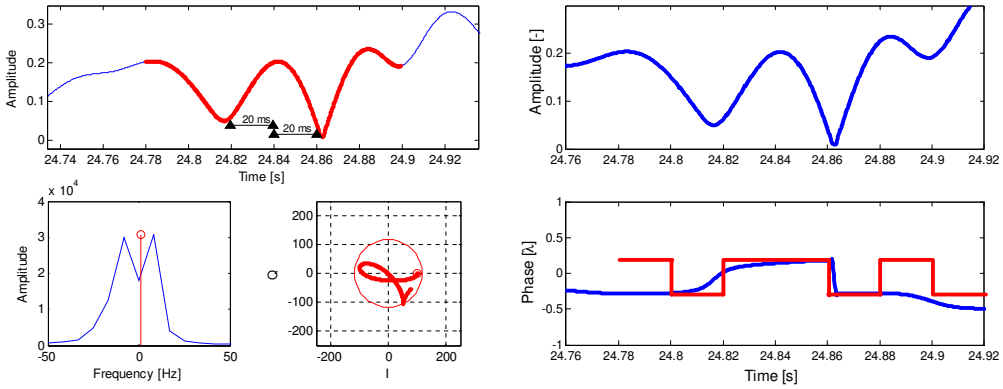
- Presence of Navigation Data Modulation introduce π–ambiguities in the measurement data that needs to be removed.
- The spectrum of the 50 Hz Nav. data modulation is often similar to the spectrum introduced by the “atmospheric modulation”
- Zero crossing from “atmospheric modulation” and navigation modulation looks similar.
- Navigation data modulation is not easily separated from the measured noise polluted signal.



Nav Data Demodulation



Nav Data Demodulation



- Atmospheric modulation or Navigation data modulation?

Navigation Data Demodulation

$$V_{Atm}(t) = (I_{RS}(t) + j \cdot Q_{RS}(t)) \cdot sign(NAV(t)) \cdot e^{j \cdot \varphi_{RS}(t)}$$

- Knowledge of Navigation Data Modulation (raw bits) are needed to retrieve atmospheric information from the measured signal.
- Option 1: Bring in navigation data from external source:
  - Retrieve from GPS control segment (availability?)
  - Retrieve from other measurements, e.g. fiducial stations etc.
- Option 2: Estimate navigation data from GRAS measurements:
  - Most of the information content is known from current ephemeris.
  - Use repeatability of navigation modulation and benefit from zenith data retrieved ~15 min before/after the occultation. (Turn on “Navigation Message Dump” by macro command)
  - Minimize dependency on navigation data bit estimations from occultation data.

Questions / Answers

- Frequency model used in OL: Climatic, NWP, fly-wheeling? What is the expected accuracy? There are comparisons between the model implemented and actual NWP models?
  - **Doppler model: Doppler towards NRIPA calculated. NRIPA from look-up table against SLTA.**
  - **Accuracy: ~±25 Hz**
- It is possible to use simultaneously two links with one occulting satellite and two different models? The second model could be the standard with a bias in delay or in frequency?
  - **No**
- Could we profit from the additional correlation sums obtained in the early and late arms?
  - **E/L products are not reported to ground**
- Integration times in CL and OL
  - **Clarify integration time.**
  - **For measurement reporting CL: 20 ms (50 Hz); OL: 1 ms (1 kHz)**
- Pre-detection bandwidth
  - **~20 MHz**

Questions / Answers (2)

- Expected SNR differences between OL and CL
  - **Identical C/No. I.e. SNR power difference = f_{CL}/f_{OL}**
- Removal of the navigation bit: wipe-off or sensitivity assistance
  - **Clarify / Discuss**
- Sampling rate of the observables in CL and in OL
  - **Default & recommended: CL: 50 Hz; OL: 1kHz.**
- Number of correlators used in the estimation of the peak amplitude
  - **Punctual correlation reported.**
- Process chain for the OL: from the RF signal to the level 1a products
  - **Answered or Discuss?**
- Switching from CL to OL: Does the OL model match the CL information?
  - **Yes.**
- Are expected other products in addition to those termed level 1a?
  - **Clarify / Discuss**