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Atmospheric Multipath Tests

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Atmospheric Multipath Tests

Content:

- Background
- AMP GO Model
- Simulating AMP with GSS

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AMP Test Background

- OL retrieval algorithms, like e.g. FSI, needs to be tuned and validated with representative measurement data.
- Direct WOP simulations and Instrument models can be used to approximate real measurement data
- Measurement data should include the full GRAS Instrument response

- SE propose here to use a GRAS BB can be used in lab environment to simulate realistic AMP measurements.
- Resolving a propagated signal as multiple carriers that can be simulated by a GNSS simulator.
- GO supported by PO integration sufficient to characterise the sub-carriers

Derivation of AMP Sub-Carriers

1.Refractivity profile, N(h), is selected

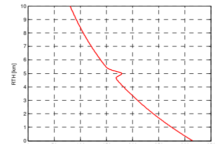
2.Bending angle, α, from inverse Abel transform vs impact parameter, a.

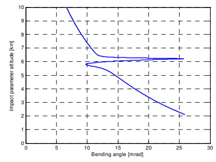
3.Time from α, a and geomtry

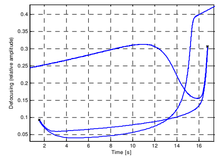
4.Amplitude from bending angle derivative, dα/da (except caustic regions)

5.Amplitude in caustic directions derived from PO

6.Multiple rays are identified and sub-carriers are disentangled







The purpose of the chosen method is not to simulate AMP accurately, but to generate a well defined instrument input signal, that is representative for a multipath signal.

Method inspired by Gorbunov and DMI team's work on Canonical Transform and FSI and agree reasonably well with WOP methods.

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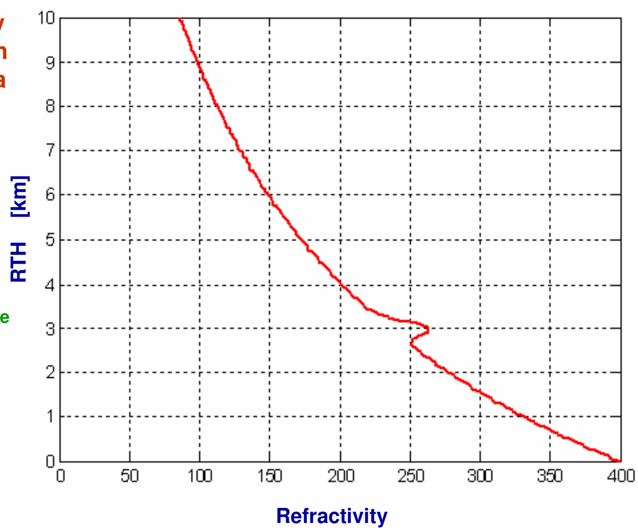
AMP Refractivity Profile

Atmosphere with a refractivity profile composed by a smooth background exponential and a "bump";

$$N(h) = N_0 \exp(-h/H_0) + N_W \exp(-h/H_W) + N_b \exp[-(h-h_b)^2/w_b^2]$$

N0 = 300; % Refractivity at surface
H0 = 7.9; % [km] Scale height
Nw = 100; % Wet refractivity at surface
Hw = 2.5; % [km] Wet scale height
Nb = 28; % Bump strength
hb = 3; % [km] Bump height
wb = 0.2236;% [km] Bump width



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Critical Refractivity

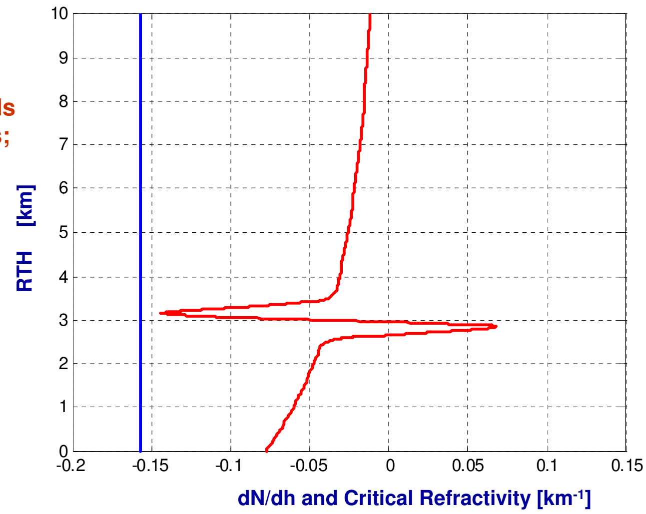
Critical refractivity, i.e. for which the ray bends towards the earth, can be derived as;

$d\ln(\mu)/dr < -1/r$

$\Downarrow$

$dN/dh < -10^6/r \sim -0.16\ m^{-1}$

N refractivity
$\mu = 1+10^{-6}$ N refractive index
r radius of curvature



Bending Angle

The bending angle is obtained by the inverse Abel transform:

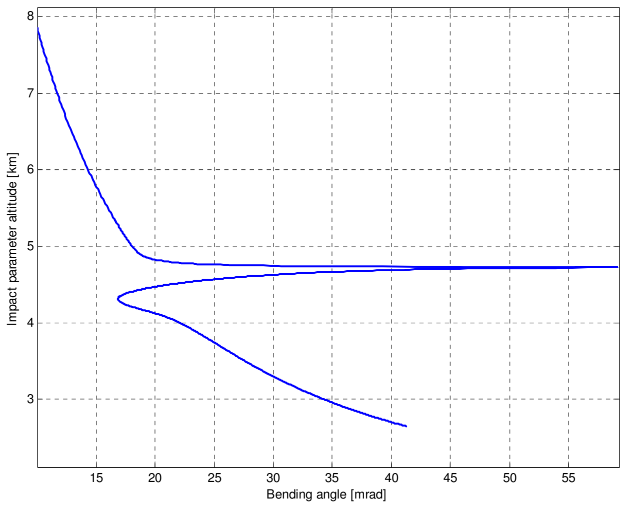
$$\alpha(a) = -2a\int_a^\infty \frac{\frac{d}{da'}(\ln\mu)da'}{\sqrt{a'^2 - a^2}}$$

or by partial integration;

$$\alpha(a) = 10^{-6}\, 2\int_a^\infty \sqrt{a'^2 - a^2}\ \frac{d^2N}{da'^2}da'$$

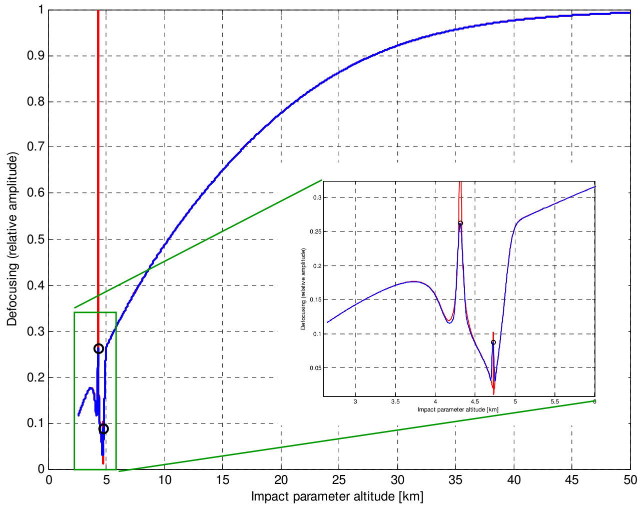
better suited for numerical integration

$\mu = 1+10^{-6}$ N refractive index



Amplitude vs. Impact Parameter

1. The caustics directions are identified.
2. Singular in the simple GO picture
3. Needs special attention



Defocusing

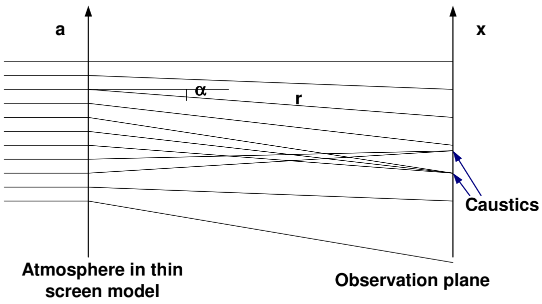
The signal amplitude can be obtained by the PO integral, solved using MSP:

$$A = \int_0^{\infty} \exp\left[-j\Phi(a) - jkr(a)\right] da$$

$$A = \sqrt{D\lambda} \begin{cases} \left[1 - D \left.\dfrac{d\alpha}{da}\right|_{as}\right]^{-1/2} & \text{(1)} \\ 2.154\, D^{-1/2}\, \lambda^{-1/6} \left[\left.\dfrac{d^2\alpha}{da^2}\right|_{as}\right]^{-1/3} & \text{(2)} \end{cases}$$

(1) valid outside caustic regions
(2) valid in caustic regions

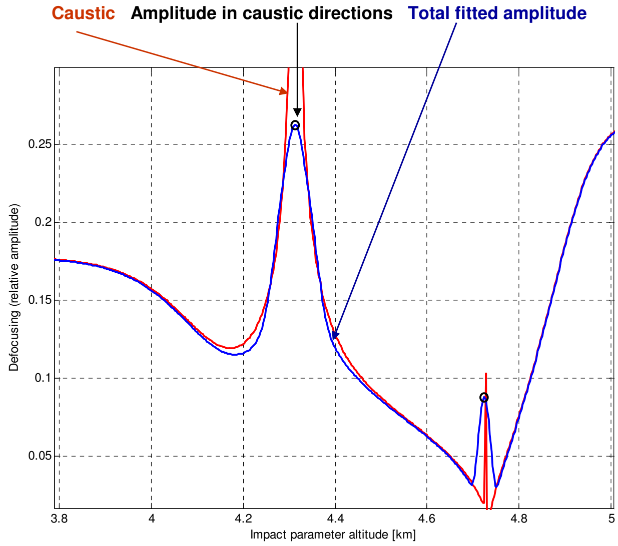
Distance dependent amplitude variations can be neglected.



PO Physical Optics
MSP Method of Stationary Phase
Φ atmospheric phase delay
$D = (1/S_G + 1/S_L)^{-1}$
S_G distance GPS to atmosphere
S_L distance LEO to atmosphere

Amplitude; Caustic Handling

1. The caustics directions are identified.
2. Caustic direction amplitude is calculated with MSP
3. Approximate caustic “beamwidth” is calculated from Fresnel zone size
4. A Gaussian shape is fitted to the non-caustic amplitude



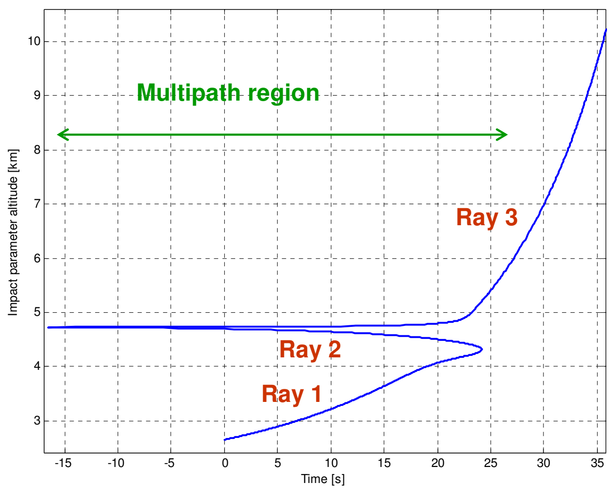
Time

Impact parameter and bending angle is related to time by the orbit geometry:

$$\theta = \alpha(a) + \arccos\left(\frac{a}{R_L}\right) + \arccos\left(\frac{a}{R_G}\right)$$

Ray 1 starts just above the horizon, while ray 2 and 3 appear well before this time.

a	impact parameter
θ	angular separation between S/Cs
R_G	GPS radius
R_L	LEO radius

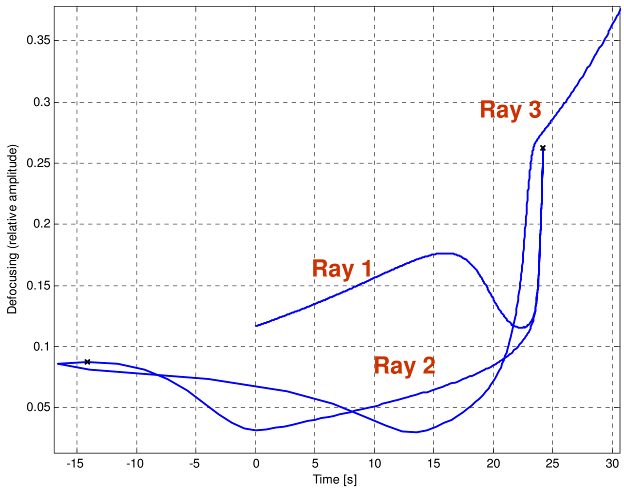


Time [s]

Sub-Carrier Amplitude

The three sub-carriers show a smooth behaviour, well suited for GSS modelling.

Amplitude range:
~20 dB



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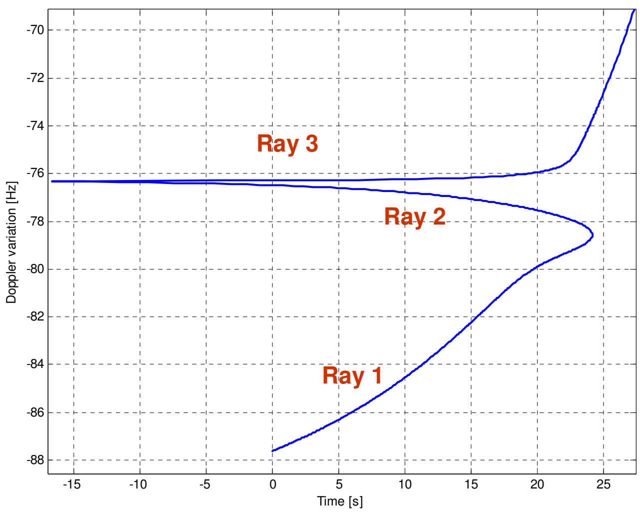
Sub-Carrier Doppler

Doppler range:
< 4 m/s
< 20 Hz



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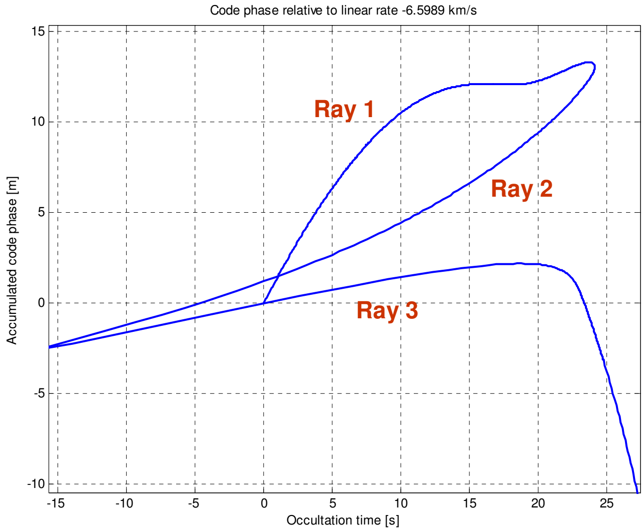
Sub-Carrier Code Phase

The three sub-carriers exhibit modest differences in code phase

Relative code phase range:

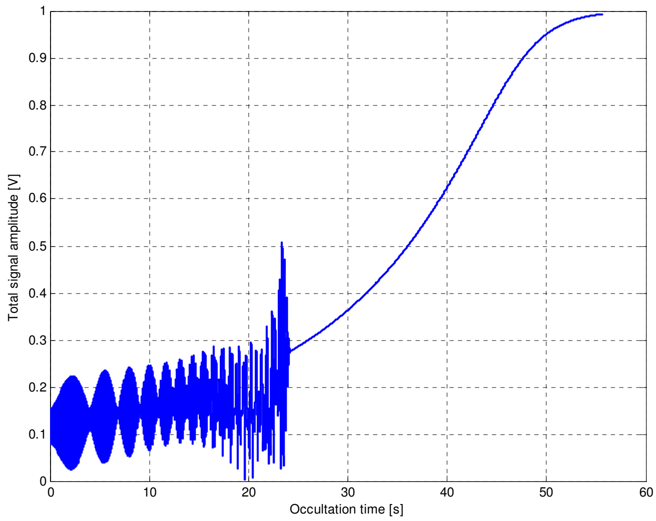
~ 10 m

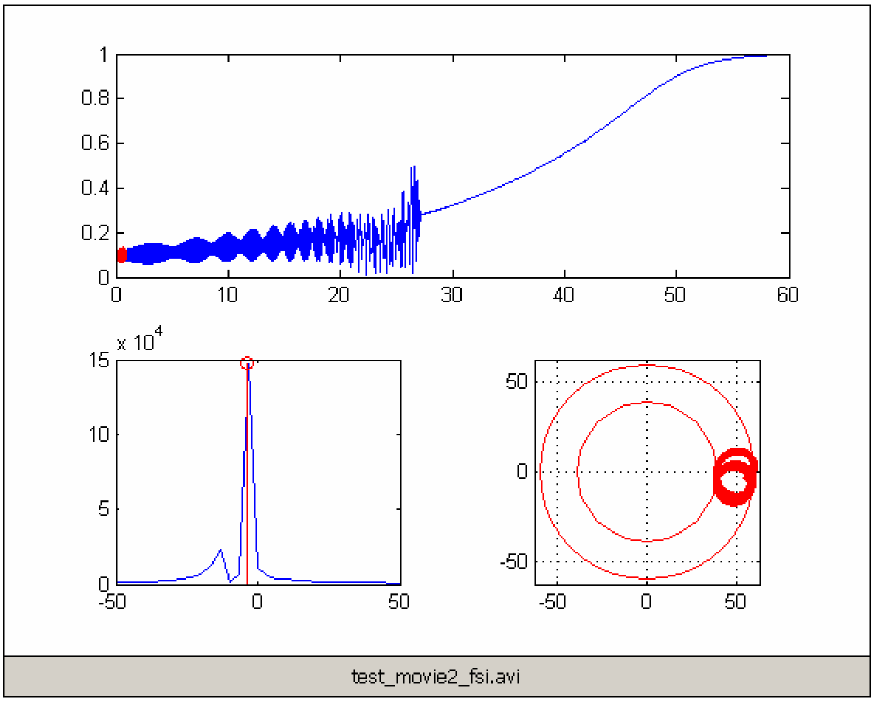
⇒ Negligible impact on code tracking



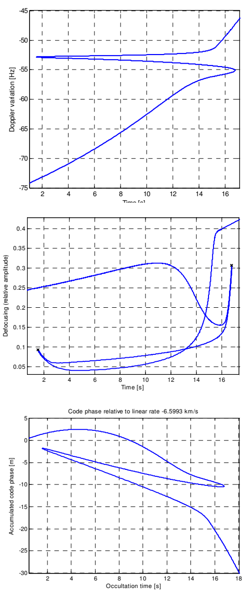
Combined Signal

The three sub-carriers are up-sampled and combined to form the rapidly varying total signal





Test Implementation



A recent upgrade of the Spirent STR4760 GPS simulator assigns each signal to a channel, rather than to an SVID.

The simulator can then be set up as follows:

•Define an almanac with a scenario containing at least 4 SVs for navigation and one occultation SV

•AMP can be simulated by adding a number of sub-carriers, e.g. 3 for a single bump or 5 for a differential bump.

•The occulting SV (SVID) is also assigned to two additional channels with the same orbit position and SVID.

•The 3 occ signals are modulated in 10 Hz, in Amplitude, Carrier phase and Code phase to represent the 3 sub-carriers.

•The combined simulated signal is measured by the Instrument