Are there possibilities to observe GNSS-signals with VLBI2010?

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1) Importance of observing GNSS satellites by VLBI for geodetic purposes.

2) Is it possible to receive the strong GNSS signal with present S-band systems?
   - Link-budget calculation for GNSS-satellites: signal strength, examples of L-band observations at Onsala
   - Some details on the current S-band system at Italian stations and at Onsala
   - How can all the data acquisition system in S-band see an artificial signal at 1575 MHz? -> Onsala spectra

3) Other problems to be considered

4) Conclusions and outlook
Importance of observing GNSS satellites by VLBI for geodetic purposes (1)

- Opportunity to make "co-location in space": to combine kinematic and dynamical reference frames
- to express GPS-satellite positions with respect to the background radio sources
- to establish and improve the link of the VLBI reference system to the geocenter
Importance of observing GNSS satellites by VLBI for geodetic purposes (2)

- At present to combine different spatial techniques ‘Local Ties’ (LT) are used: three-dimensional coordinate differences between the reference points of each technique derived from local terrestrial surveys carried out at the stations.

- But many problems on LT reduce the potential of a multi-technique combination.
Problems concerning many LT

- Some LT values are missing completely.
- Some values are very dubious and do not fit to the space-geodetic results by far.
- Statistical information, particularly the variance-covariance matrix, is sometimes not available.
- A detailed documentation is often missing.
- There is no complete central archive where all actual LT including their documentation are available and accessible to all users.
How strong are GNSS signals? (1)

- **EIRP of GPS-satellites**
  - (Equivalent Isotropically Radiated Power)
    - L1 (1575 MHz) C/A-code (2 MHz) EIRP = 26 dBW
    - L1 P-code (20 MHz) EIRP = 23 dBW
    - L2 (1227.6 MHz) P-code (20 MHz) EIRP = 19 dBW

- **Path loss**
  - Elevation 5°: d=25150 km => L = 184 dB
  - Elevation 90°: d=20180 km => L = 182 dB
How strong are GNSS signals? (2)

- **Flux density (worst case)**
  - L1 C/A-code \( F = -158 \text{ dBW/m}^2 \)
  - L1 P-code \( F = -161 \text{ dBW/m}^2 \)
  - L2 P-code \( F = -165 \text{ dBW/m}^2 \)

- **Expressed in Jansky**
  - L1 C/A-code \( S = 8000 \text{ Jy} \)
  - L1 P-code \( S = 400 \text{ Jy} \)
  - L2 P-code \( S = 160 \text{ Jy} \)
How strong are GNSS signals? (3)

- Assume 10m telescope with aperture efficiency 0.8 at L-band => $G_r=44$ dBi
- Received power (worst case):
  - L1 C/A-code $P_r = -84$ dBm
  - L1 P-code $P_r = -86$ dBm
  - L2 P-code $P_r = -90$ dBm
- Really strong signals! Easily detectable with L-band receivers.
Examples of observed GNSS signals

Example: L-band observations with the Onsala 25m radio telescope: a) Galileo Giove-A and b) GLONASS.
IVS VLBI Workshop on FRFF
Wettzell/Höllenstein, Germany, March 18 – 20, 2009

Medicina and Noto S/X Receivers

Coaxial Feed Horn
RHCP

X-Band

LNA
8180…8980 MHz
7 sections

100…900 MHz
5 sections

IF Out
100…900 MHz

S-Band

LNA
2193…2373 MHz
7 sections

178…348 MHz
5 sections

IF Out
178…348 MHz

2020 MHz

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Medicina and Noto S Receiver (1)

- HORN coaxial, poor in attenuation, it is plausible observation of L-band signal with attenuation of about 20 dB
- LNA (narrow band) it could receive leaking the signal instead of amplify it
- FILTER: it needs to be removed to observe signal in L-band (primary focus)
- IF-AMPLIFIER: has a large band but the hardware needs to be modified to observe in L
- LOCAL OSCILLATOR (constrained to 2020 MHz.)
Medicina and Noto S Receiver (3)

Answer of the filter

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The Onsala S-X system
The Onsala S-band filter

- Centered around 2330 MHz
- About 60 dB attenuation below LO frequency
- Could be replaced by other filters that also let pass GPS L1 (1575 MHz)
The Onsala S-band horn

Transition from circular to the rectangular waveguide has a cut-off frequency 1690 MHz (!). Everything below is suppressed.
Testing the Onsala S-band system with an artificial signal

- Sending in a signal at 1575 MHz (GPS L1) with -80 dBm into the S-band receiver system.
- A peak at 445 MHz is clearly visible in the spectrum of the IF-signal in the Onsala control room (!).
General comments:

- To reveal GNSS signals with S receivers is site dependent.
- With present receivers it is necessary to make several changes, it is difficult, but it is not impossible.
- It is much easier to insert such requests in the proposals of new receivers like for the VLBI2010 or for SRT (Sardinia Radio telescope).
Other problems to be considered (1)

- Include SatTack (Moya Espinosa and Haas, 2007) in the next official FS-distribution
- SatTrack allows tracking of satellites with known NORAD elements directly from the FS
- GNSS satellites move by only 0.5 degrees/minute, => no big problem
Other problems to be evaluated (2)

- **Observing VLBI mode**: geodetic, differential, astronomical?
- Precision of the orbits?
- To implement the phase delay model for finite distant GNSS satellites
- Data processing for GNSS orbit determination by VLBI
Conclusions and outlook (1)

- GNSS-signals could in principle be observed with the current S-band systems already today
- However, some modifications would be necessary, e.g. filters, waveguides
- But observation of strong L-band signals could be included in the plans for the future VLBI2010 system
Conclusions and outlook

- SatTRACK needs to be incorporated in official FS release
- Correlator models need to be extended to allow finite distance radio sources
- Special observing schemes need to be developed