Starting tests for the observation of GNSS-Signals in view of the planned VLBI 2010 system

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- Link-budget calculation for GNSS-satellites: signal strength
- Examples of L-band observations at Onsala
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- Other problems to be considered and conclusions

Importance of observing GNSS satellites by VLBI for geodetic purposes

- Opportunity to make "co-location in space": to combine kinematic and dynamical reference frames
- to express GNSS-satellite positions with respect to the background radio sources
- to establish and improve the link of the VLBI reference system to the geocenter

Combination of different spatial technique at present

- 'Local Ties' (LT) are very important to combine different spatial techniques today.
- But some problems on LT reduce the potential of multi-technique combination:
  1. Difficulties to derive LT from local terrestrial surveys carried out at the stations.
  2. Statistical information, particularly the variance-covariance matrix, is sometimes not available
  3. Some values are very dubious and do not fit to the space-geodetic results by far

Opportunities offered by co-location in space :

Having GNSS signals sharing the same optics as the VLBI signals (including gravitational and thermal deformations)

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a direct comparison of the two techniques and of the different realizations of terrestrial reference system would become possible.

How strong GPS signals are ?

- 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 EIRP = 19 dBW**

- Path loss
  - Elevation 5°: d=25150 km => L = 184 dB

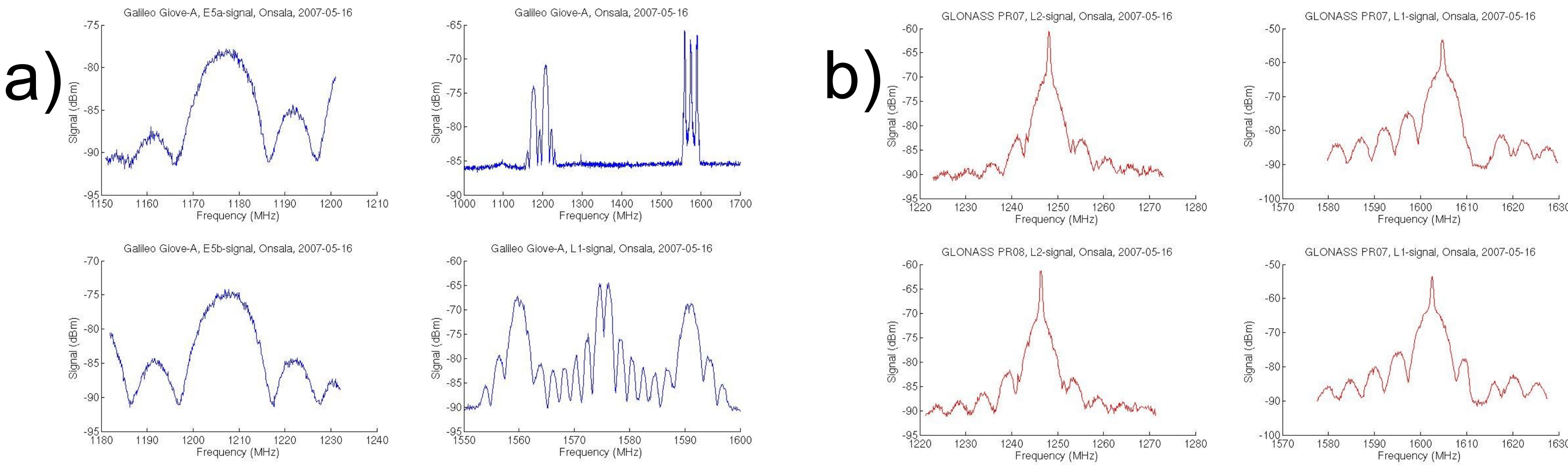
How strong GPS signals are ?

- Flux density (worst case)
  - L1 C/A-code $F = -158\ dBW/m^2$
  - L1 P-code $F = -161\ dBW/m^2$
  - L2 P-code $F = -165\ dBW/m^2$
- Expressed in Jansky
  - L1 C/A-code $S = 4 \cdot 10^6$ Jy
  - L1 P-code $S = 2 \cdot 10^6$ Jy
  - L2 P-code $S = 8 \cdot 10^4$ Jy

How strong GPS signals are ?

- 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 = –80 dBm
  - L1 P-code P_r = –83 dBm
  - L2 P-code P_r = –87 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.

Expected Precision on Bandwidth synthesized group delay

Considering: 10m telescope with aperture efficiency 0.8 at L-band

=> Gr = 44 dBi

T_S = 80° K

Digital recording rate = 16 Mb/s

Signal coherent integration time = 1 s

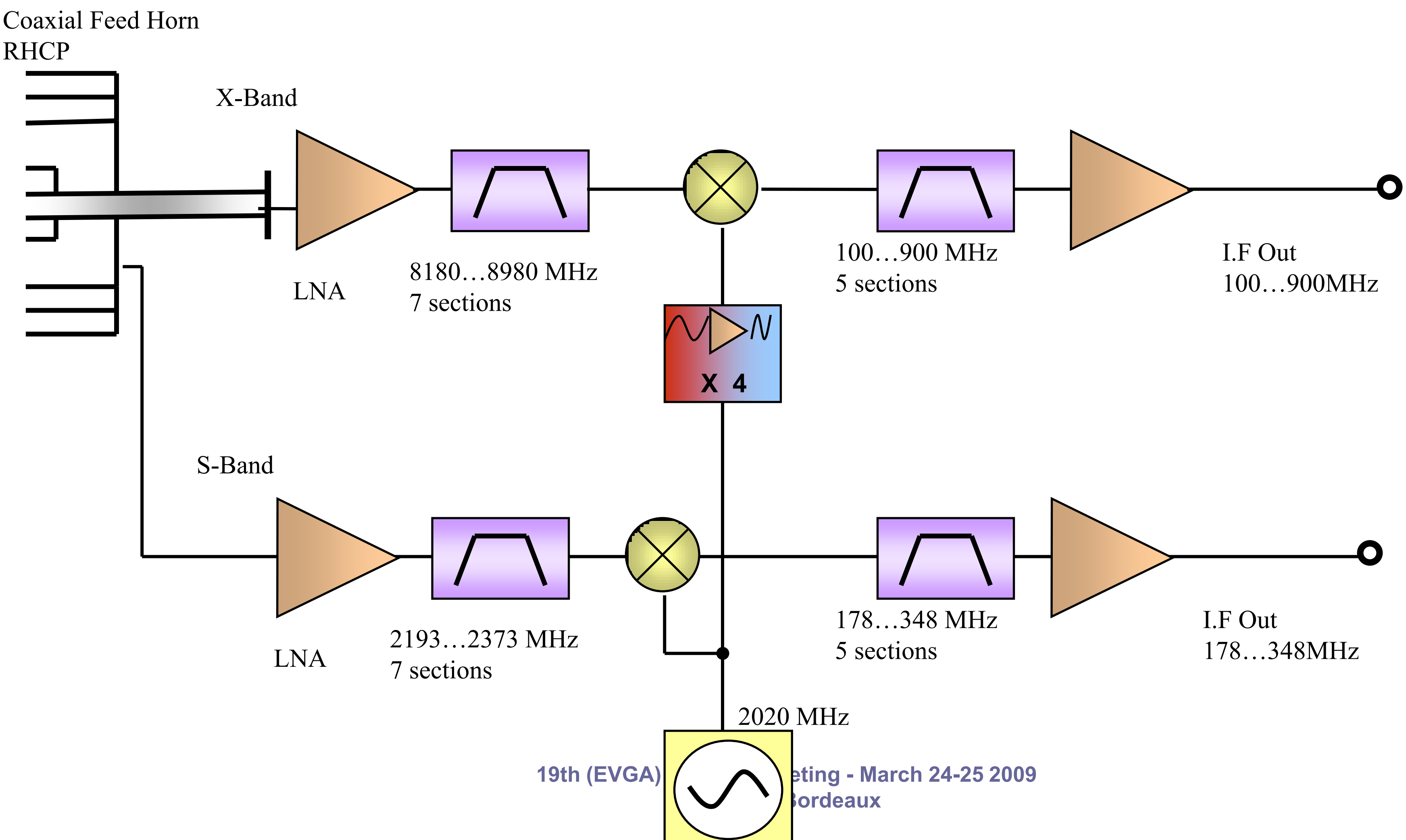
SNR(L1P) = $1.6 \cdot 10^6$

Considering: 2 channels, eachone with Δf = 10 MHz

Bandwidth synthesized group delay precision:

$$\sigma_\tau(L_{1P}) = \frac{1}{\sqrt{2\pi}(SNR)\Delta} \approx ps \rightarrow .3\,mm$$

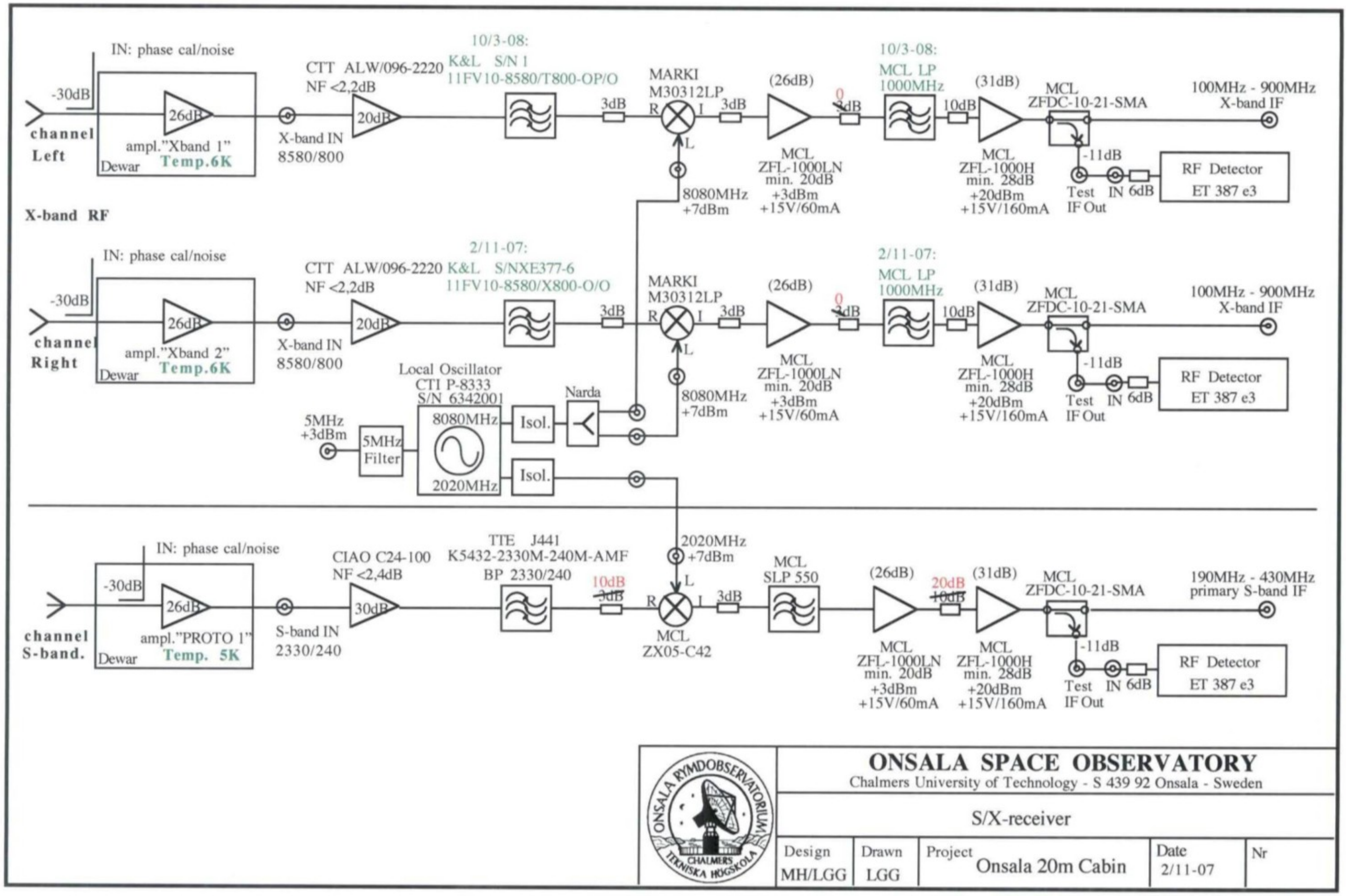
Medicina and Noto S/X Receivers



Medicina and Noto S Receivers

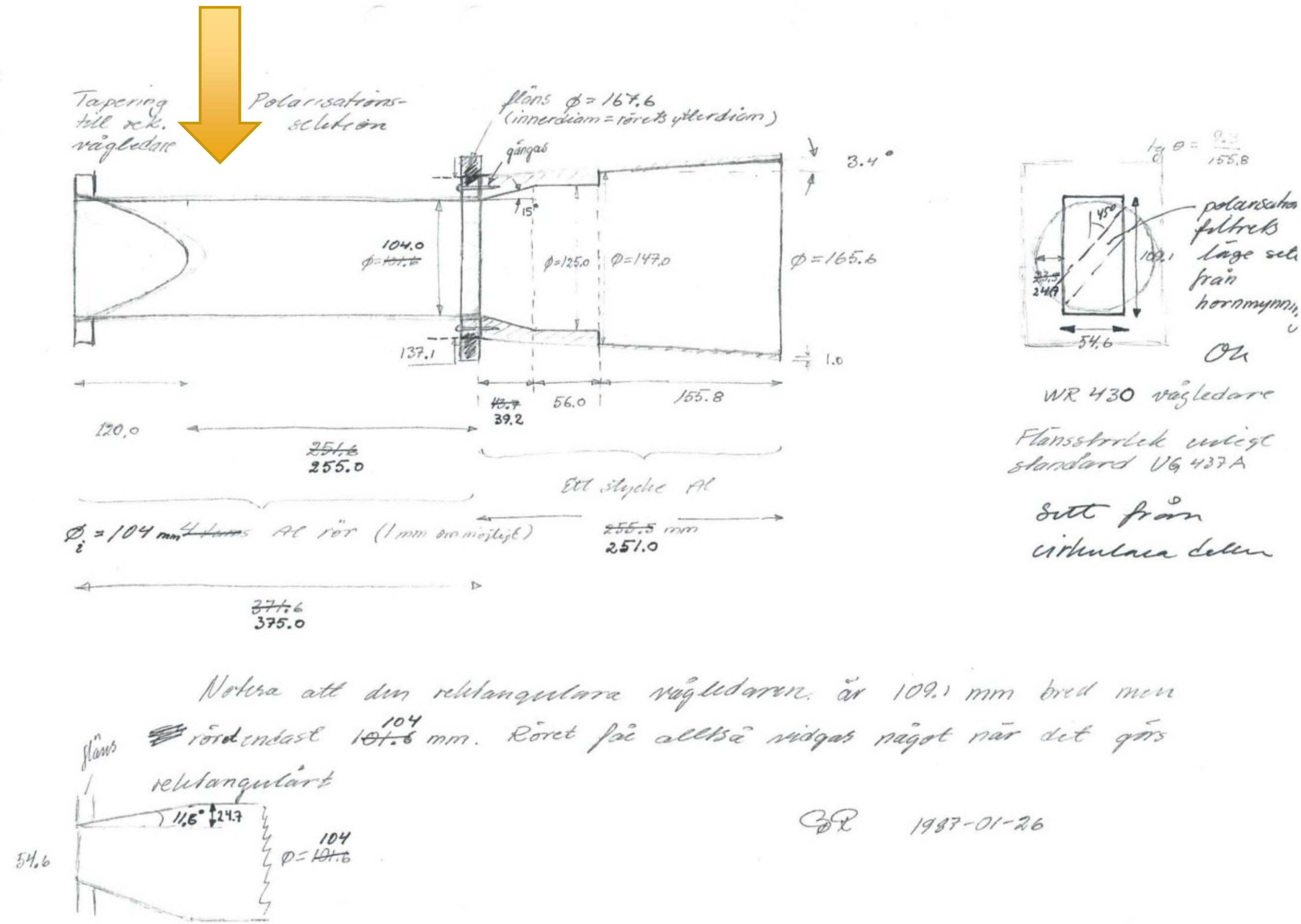
- HORN coaxial, poor in attenuation, it is plausible observation of L-band signal with attenuation of about 20 dB
- LNA (narrow band) it could receive leaking the signal instead of amplify it
- FILTER : it needs to be removed to observe signal in L-band (primary focus)
- IF-AMPLIFIER: has a large band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

The Onsala S-X system



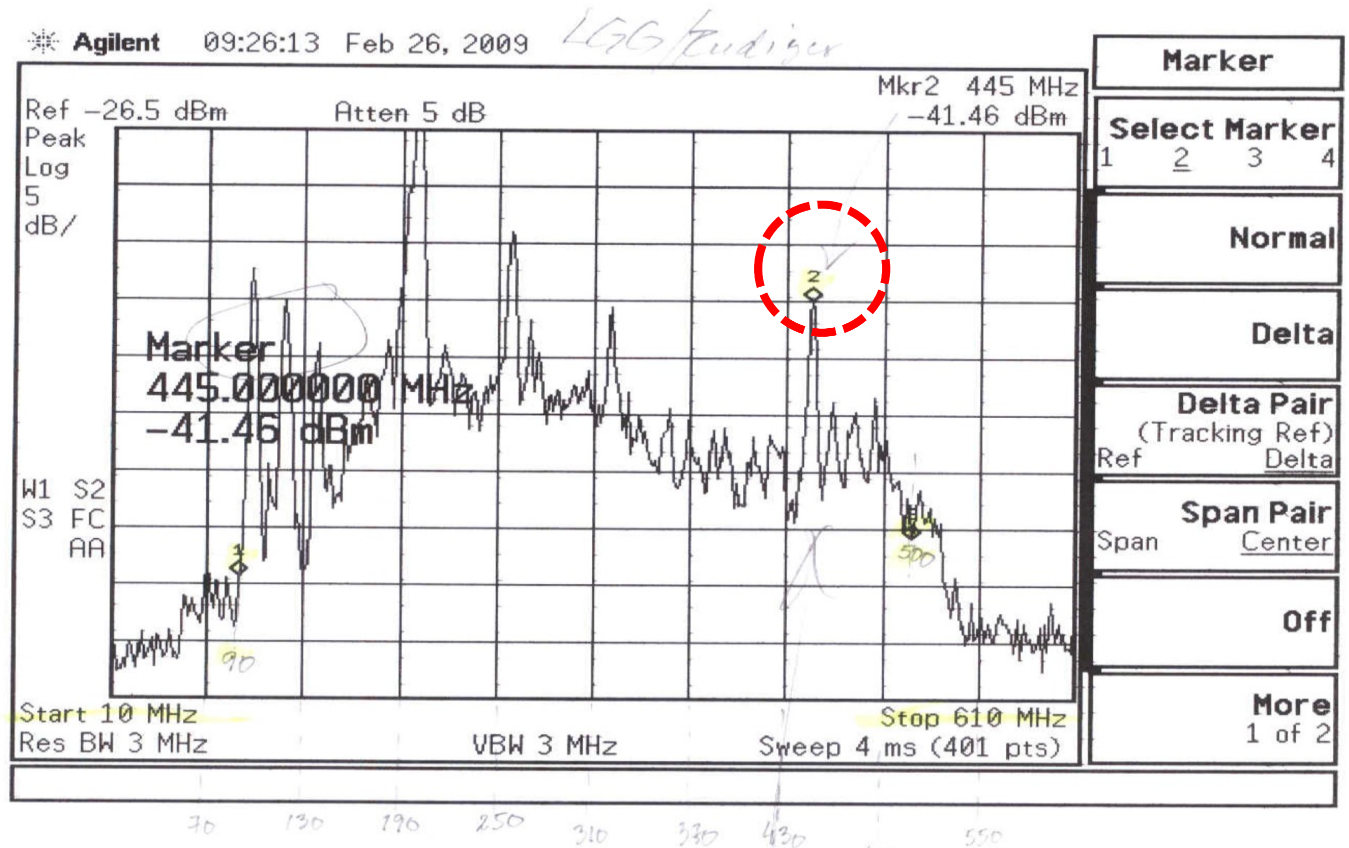
The Onsala S-band horn

Transition from circular to the rectangular waveguide has a cut-off frequency 1690 MHz (!). Everything below is suppressed.

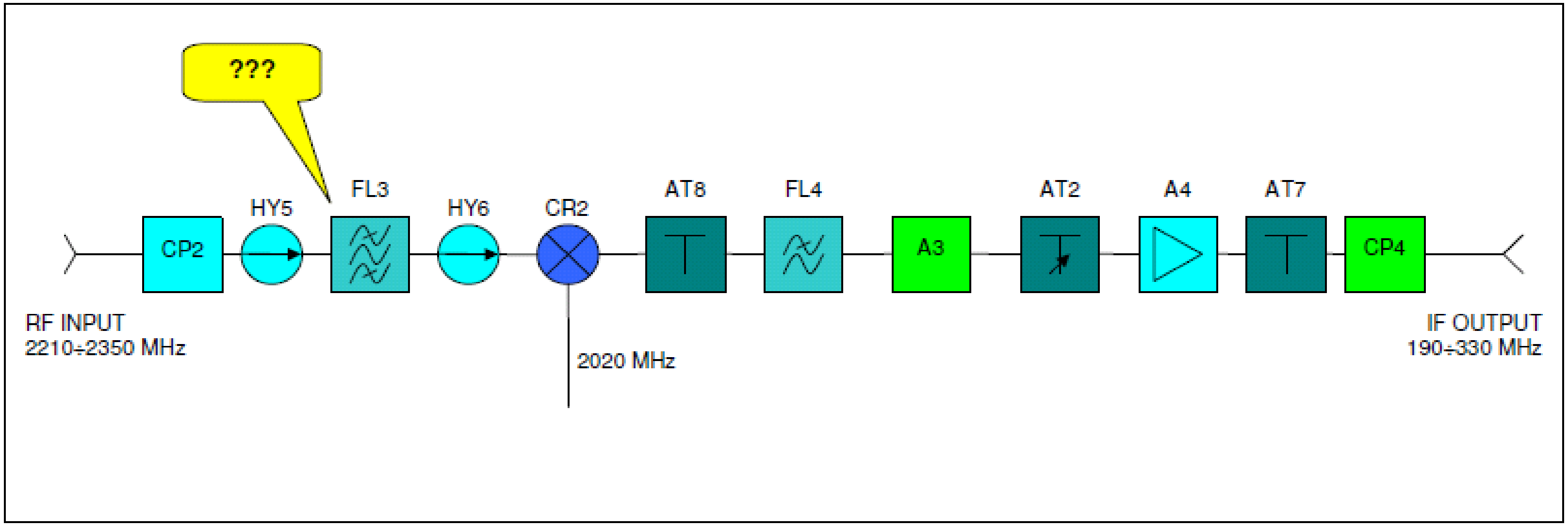


Testing the Onsala S-band system with an artificial signal

- 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 (!).



Matera S system



- CP2 Transizione N-SMA
- HY5 Isolatore
- FL3 Filtro per la reiezione della frequenza immagine
- HY6 Isolatore di adattamento
- CR2 Miscelatore a banda larga
- AT8 Attenuatore
- FL4 Filtro passa basso a 900 MHz: per l'eliminazione delle spurie ed armoniche ad alta frequenza
- A3 Amplificatore equalizzatore
- AT2 Attenuatore variabile
- A4 Amplificatore
- CP4 Transizione SMA-N

General comments:

- To reveal GNSS signals with S receivers is site dependent
- Our tests show that with present receivers it is necessary to make several changes, it is difficult but it is not impossible
- Perhaps it could be easier to consider such requests in the proposals of new receivers like for the VLBI2010 or for SRT (Sardinia Radio telescope) at least for experimental purposes.

Other problems to be considered

- Include SatTrack (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

- Observing VLBI mode: geodetic, phase referencing, astronomical ?
- Correlator models need to be extended to allow finite distance radio sources
- Data processing for GNSS orbit by VLBI
- Final precision of the GNSS orbits obtainable with VLBI observations
- Special observing schemes need to be developed

Conclusions and outlook

- GNSS-signals could in principle be observed with the current S-band systems already today but some modifications would be necessary
- Observation of strong L-band signals could be included in the plans for the VLBI2010 system:

  Adding a separate L-band system to avoid e.g. dispersion effect in waveguide and unpredictable phase-changes caused in the receiver

  Or new VLBI2010 feed might be suitable for L-band too.

Thanks for your attention !

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