GNSS Frequencies for VLBI2010

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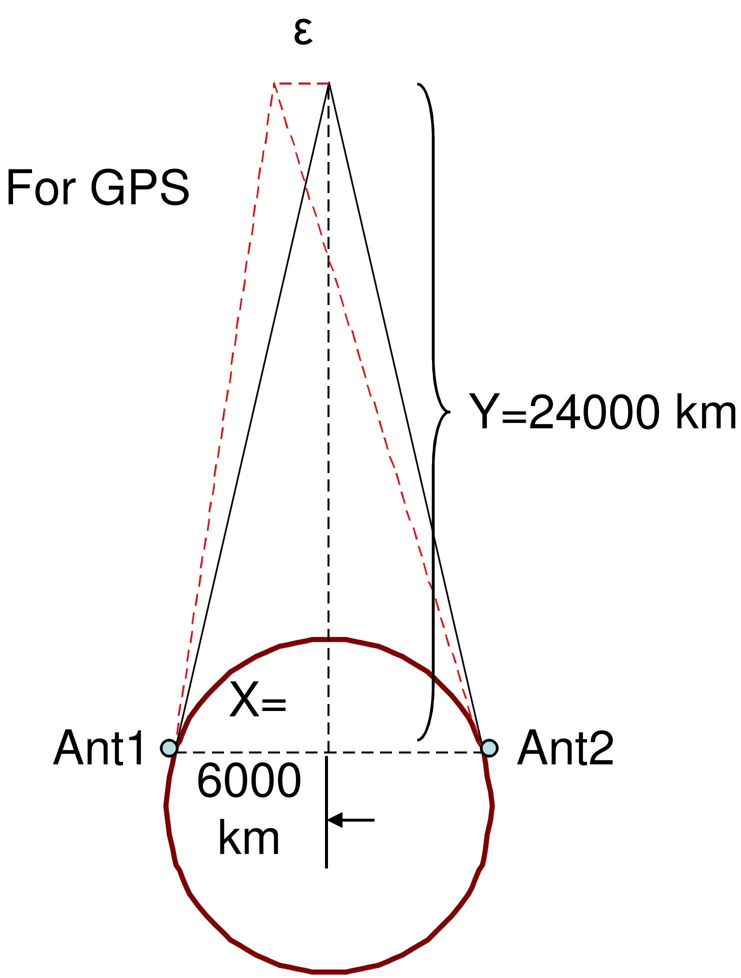
Two main VLBI2010 uses for GNSS frequencies, ~ 1-1.8 GHz

- Precise GNSS orbit determination (POD)
  - for improvement of GNSS orbits
  - as an additional data set for GNSS/VLBI comparisons
- Site ties
  - With GNSS signals sharing the same optics as the VLBI signals, this allows a direct comparison of the effective reference point of the VLBI antenna (including gravitational and thermal deformations) with the effective reference point of the GNSS antenna (including antenna and location specific phase center offsets).

POD: Along track (Tangential) orbit precision



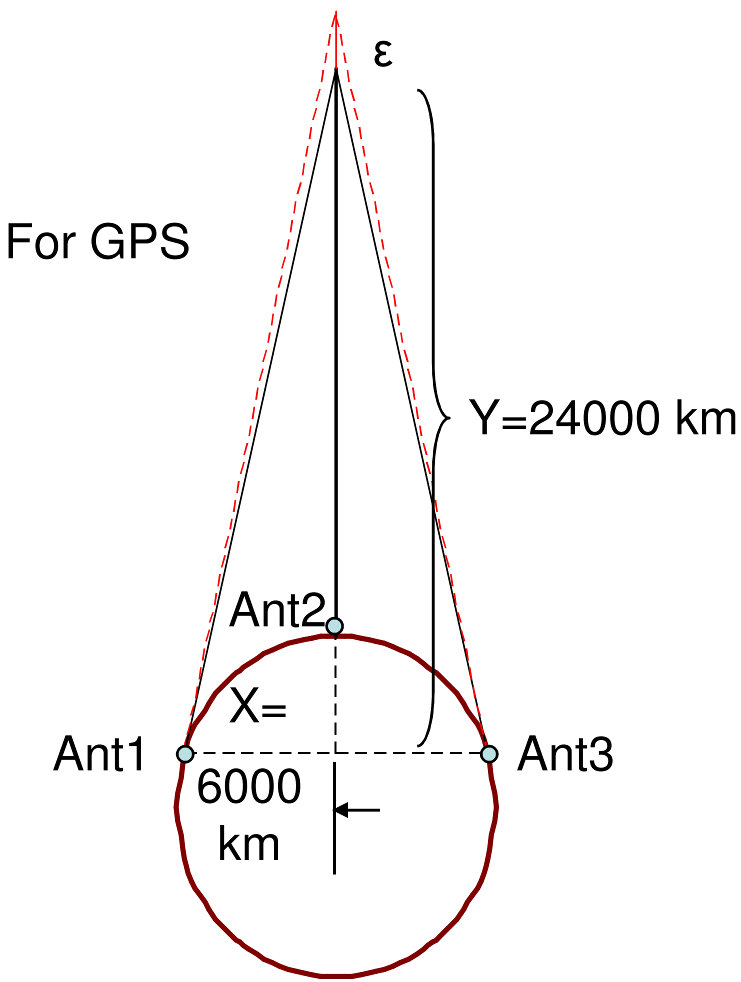
Based on simple geometry, the change in delay due to an along track error in position, ε, can be written

$$\Delta\tau_{12} = \frac{\varepsilon}{c} \cdot \frac{2x}{y}$$

If the station coordinates, clocks, atmosphere, EOP, etc are all estimated from the Quasar VLBI observations and then summed into an overall delay measurement error, δτ, a value of the along track measurement error for a single observation can be written

$$\delta\varepsilon = c \cdot \delta\tau_{12} \cdot \frac{y}{2x}$$

POD: Line of site (Radial) orbit precision



Based on simple geometry, the change in delay due to an radial track error, ε, can be written

$$\Delta\tau_{12} = \frac{\varepsilon}{c} \cdot \frac{x^2}{2y^2}$$

If the station coordinates, clocks, atmosphere, EOP, etc are all estimated from the Quasar VLBI observations and then summed into an overall delay measurement error, δτ, a value of the radial measurement error for a single observation can be written

$$\delta\varepsilon = c \cdot \delta\tau_{12} \cdot \frac{2y^2}{x^2}$$

Precise Orbit Determination with VLBI2010

- If it is assumed that the effective sum of all relevant VLBI parameter estimates for a single observation is typically 30 ps (1 cm), then the following orbit precisions can be expected. [Station coord estimates are in intertial frame.]

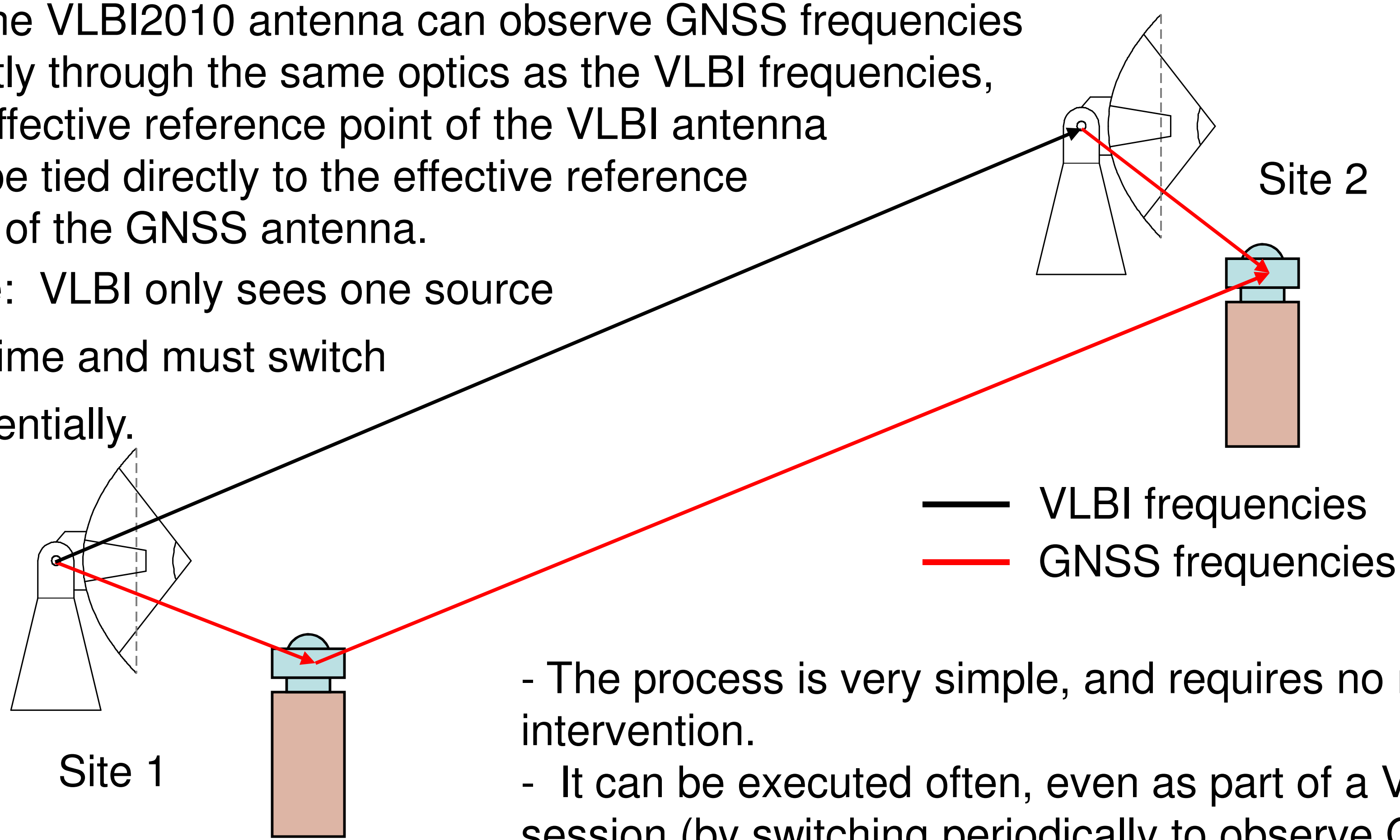
	d (km)	$\delta\varepsilon_{Tan}$ (m)	$\overline{\delta\varepsilon_{Tan}}$ (m)	$\delta\varepsilon_{Rad}$ (m)	$\overline{\delta\varepsilon_{Rad}}$ (m)
GPS	20e3	0.02	0.002	0.22	0.02
Earth-Moon	400e3	0.33	0.033	89	9
Mars (near)	70e6	58	6	273 km	27 km
Mars (far)	370e6	308	31	80e3 km	8e3 km
Jupiter	778e6	650	65	338e3 km	34e3 km

* Averages assume sqrt(N) improvement for 100 observations of the spacecraft

Observing GNSS frequencies to enable GNSS/VLBI site ties

- If the VLBI2010 antenna can observe GNSS frequencies directly through the same optics as the VLBI frequencies, the effective reference point of the VLBI antenna can be tied directly to the effective reference point of the GNSS antenna.

[Note: VLBI only sees one source at a time and must switch sequentially.



- The process is very simple, and requires no manual intervention.
- It can be executed often, even as part of a VLBI session (by switching periodically to observe GNSS satellites).

[Note: It is difficult or impossible to separate VLBI and GNSS antenna dependencies.]

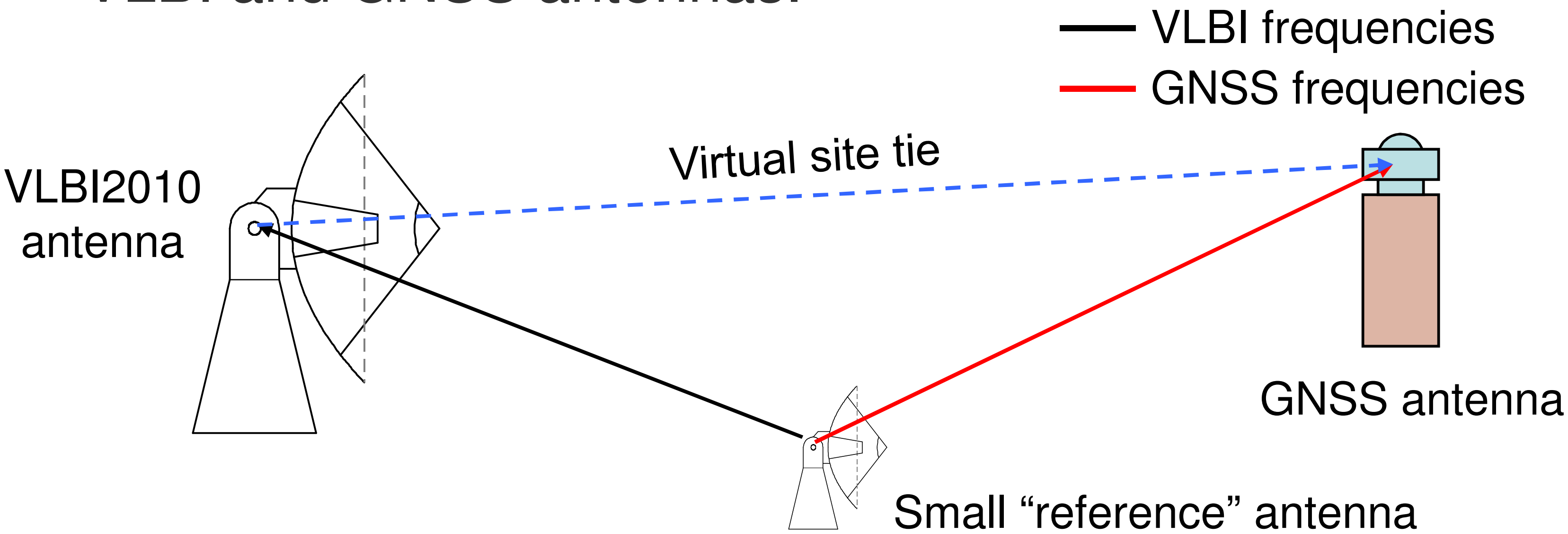
Challenges of observing GNSS on the VLBI2010 antenna

- Physical size of structures
  - A larger sub-reflector may be required
  - A larger feed (twice as large in linear dimensions) is required
    - This in turn requires a double size cryostat.
- Dynamic range
  - The GNSS signals are much stronger than those of the distant quasars. Both signal strengths cannot be simultaneously handled by the LNA.

- Perhaps we can do nothing and the GNSS signals are still strong enough to be detected.

Another solution involves the use of a small “reference” antenna*

- The idea is to use a small “reference” antenna with a feed that can observe both GNSS frequencies and some of the VLBI frequencies. Ties can be made between the “reference” antenna and both VLBI and GNSS antennas.

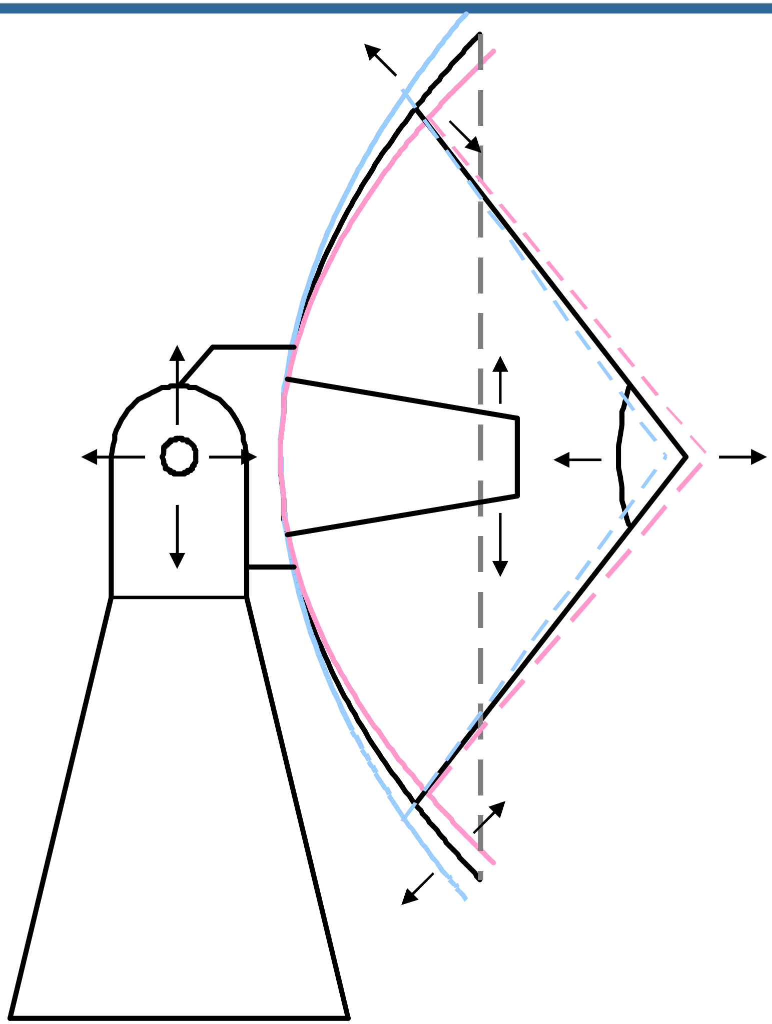


* The idea was first mentioned to me in 2004 by Yasuhiro Koyama

Reference antenna characteristics

- Diameter ~ 2 m
- Tsys with uncooled receiver ~ 100 K
- Efficiency ~ 50%
- SEFD ~ 125,000
- HPBW at 1.6 / 1.2 GHz ~ 6 / 8 deg
  - Min elev observation without multipath ~ 10 / 15 deg
- Frequencies with a “combination” feed and receiver
  - 1.1 – 1.8 GHz for GNSS
  - 8.5-14.5 GHz for VLBI (and Ku-band holography)
- Antenna must be stiff, thermally well understood, and with stable electronics and cable delays.
  - [For better environmental control, perhaps a radome can be used.]

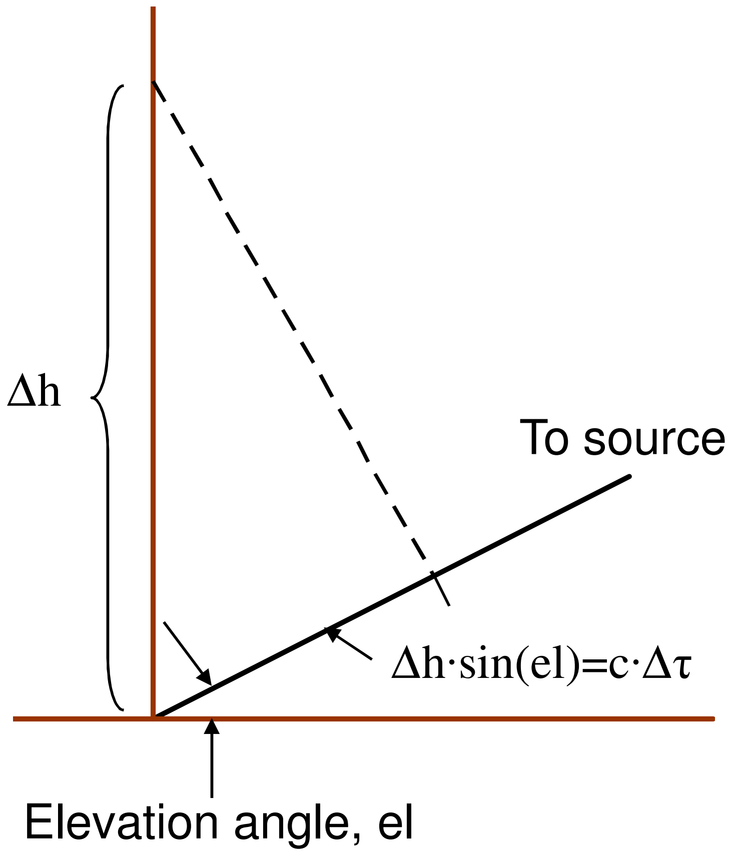
VLBI2010 antenna deformation models



Measuring the impact of antenna deformations using classical techniques is complex:

- Changes in the shape, position, and orientation of the tower, primary reflector, sub-reflector, and feed support structure must all be measured accurately with respect to both temperature and elevation angle.
- This takes an extended period and the impact of real time changes in temperature must be accounted for.
- A model relating offsets of the VLBI delay observable with respect to temperature, elevation angle, and perhaps solar irratiation must be determined.

Correlation between height change and gravitational deformation



The delay dependence due to a change in height is

$$\Delta\tau^{h}(el) = \Delta h \cdot \sin(el)$$

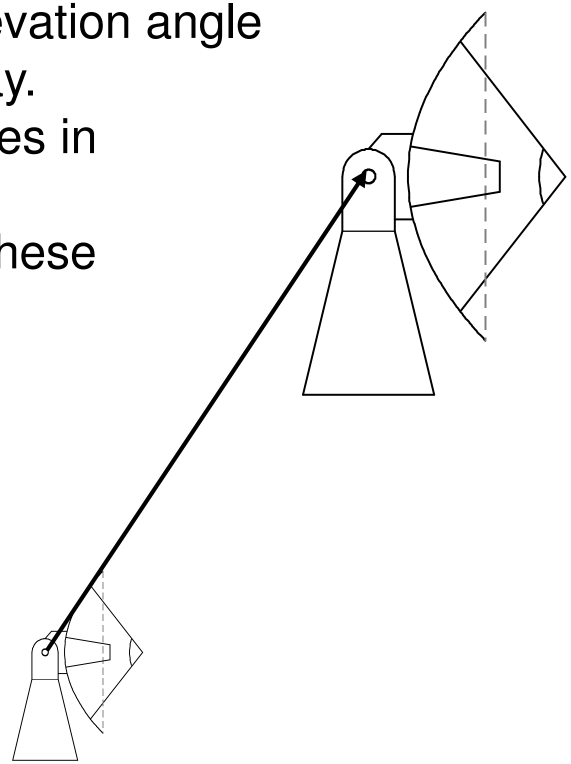
The delay dependence due to gravitational sag is

$$\Delta\tau^{Grav}(el)$$

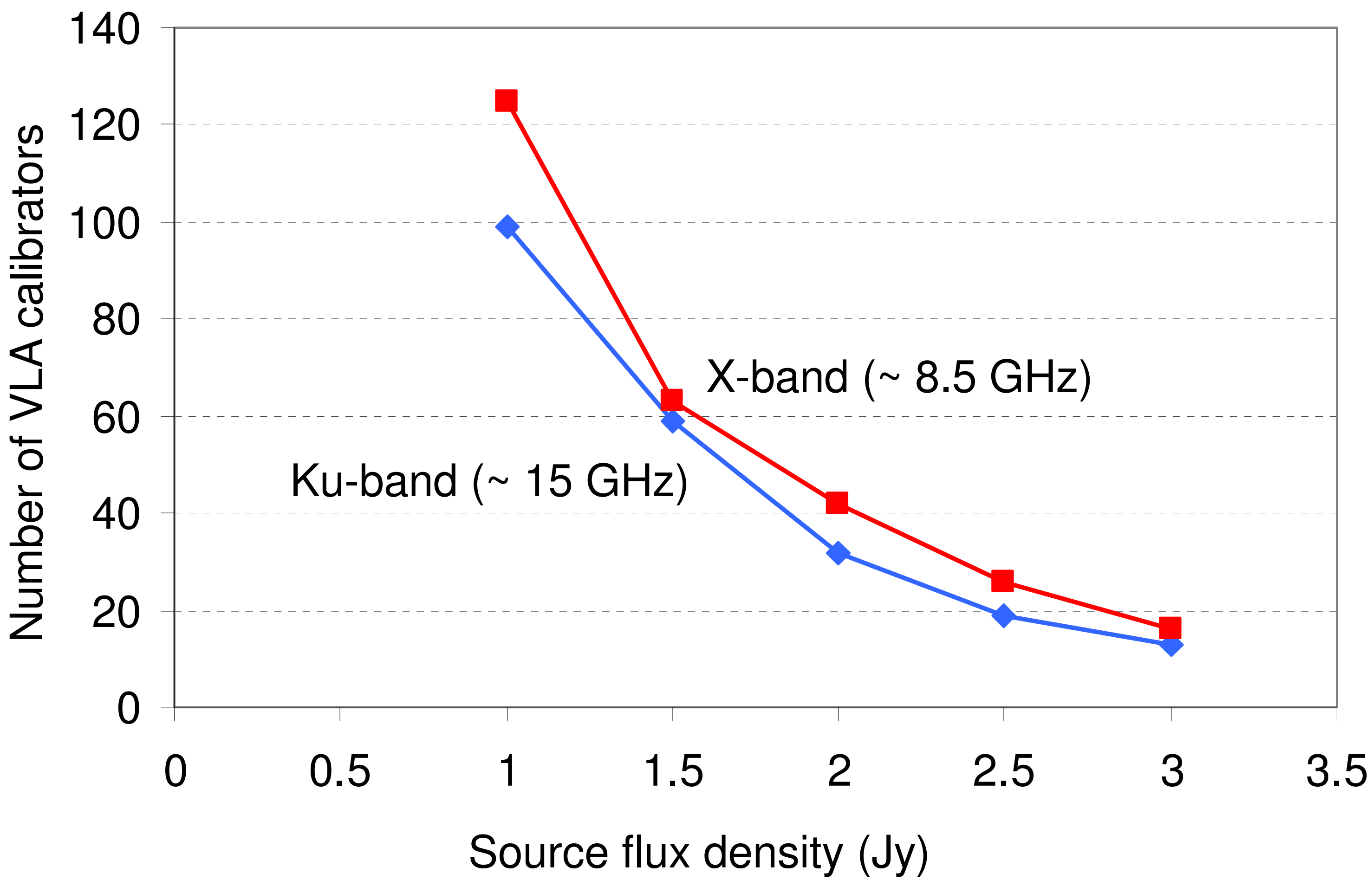
Since both height change and gravitational deformation have an elevation angle dependence, the gravitational sag can bias the height measurement

In comparison, using a "reference" antenna is simple

- The "reference" antenna does connected element interferometry with the VLBI2010 antenna.
- It does this under a wide range of thermal and elevation angle conditions and measures the related changes in delay.
- As a result, models can be built up relating changes in delay with thermal and elevation angle conditions.
- Since this model is built up using interferometry, these are exactly the same delay changes that will be experienced when this antenna does VLBI observations with other antennas.
- The process is simple and can be done regularly and with no manual intervention
- It can even be done during a VLBI session if occasional strong sources are worked into the schedule for that purpose.
- To make this work, the reference antenna must be stable in every way.

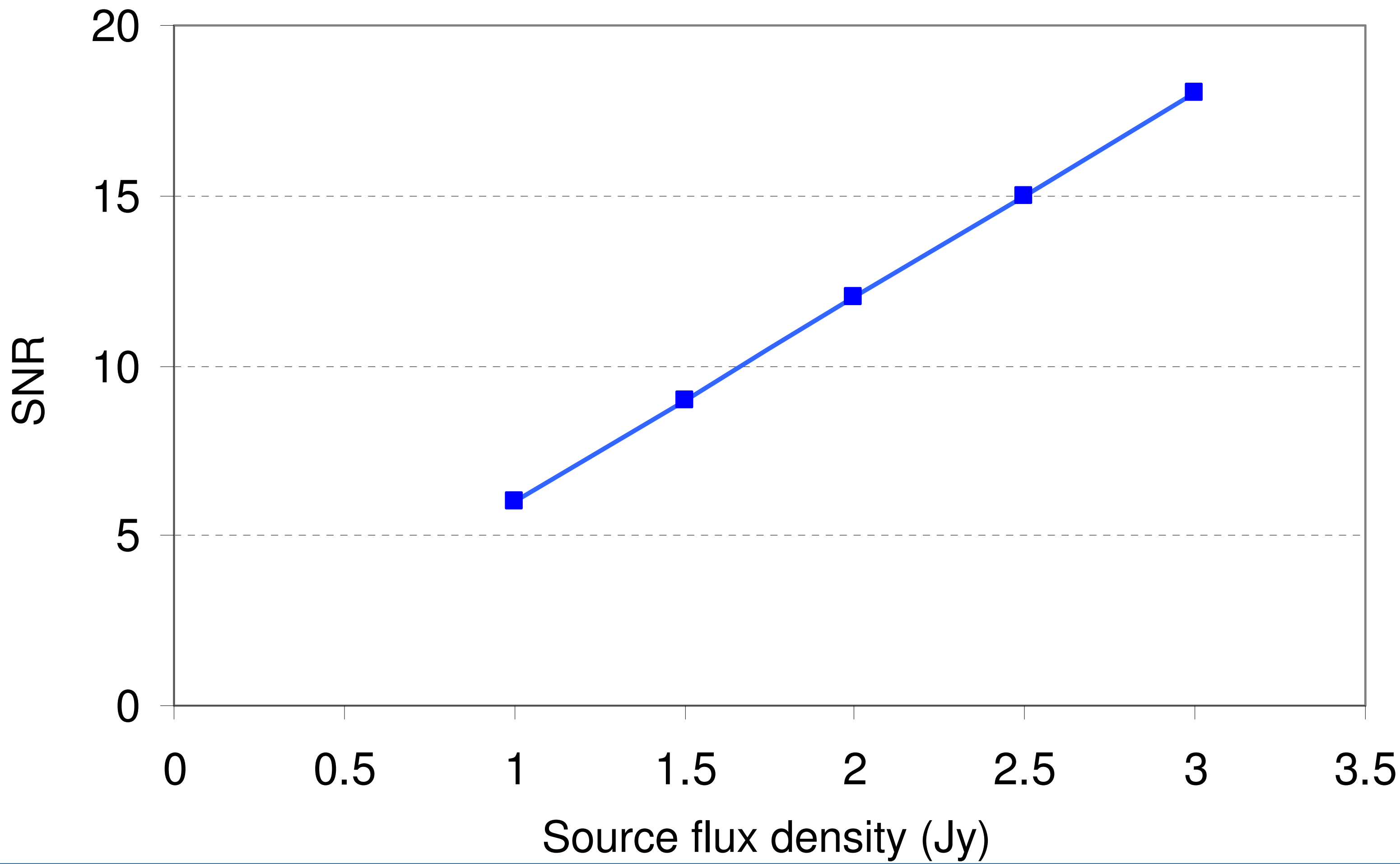


Are enough strong sources available?

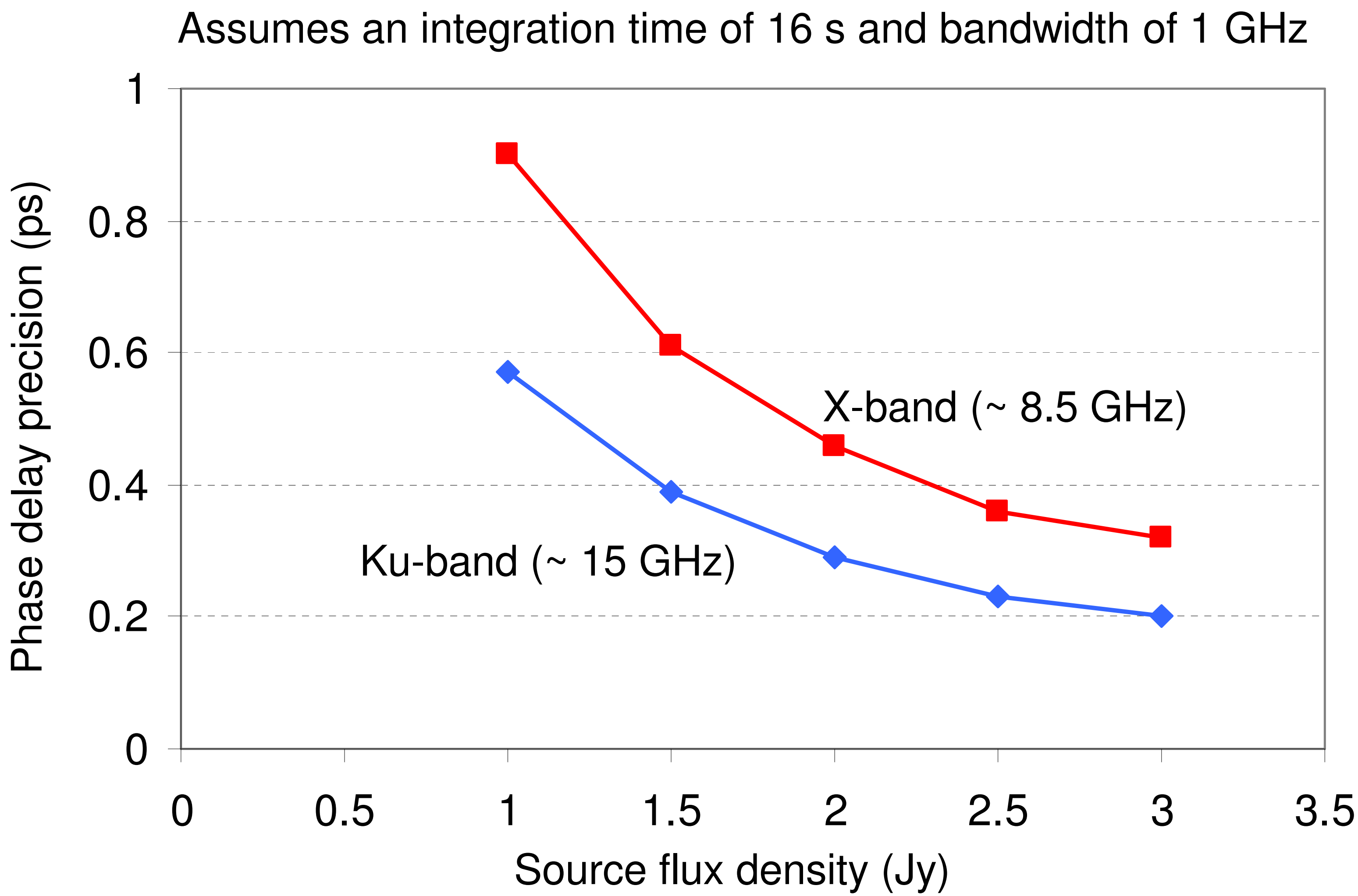


For a given flux density, what SNR can be expected?

Assumes an integration time of 16 s and bandwidth of 1 GHz

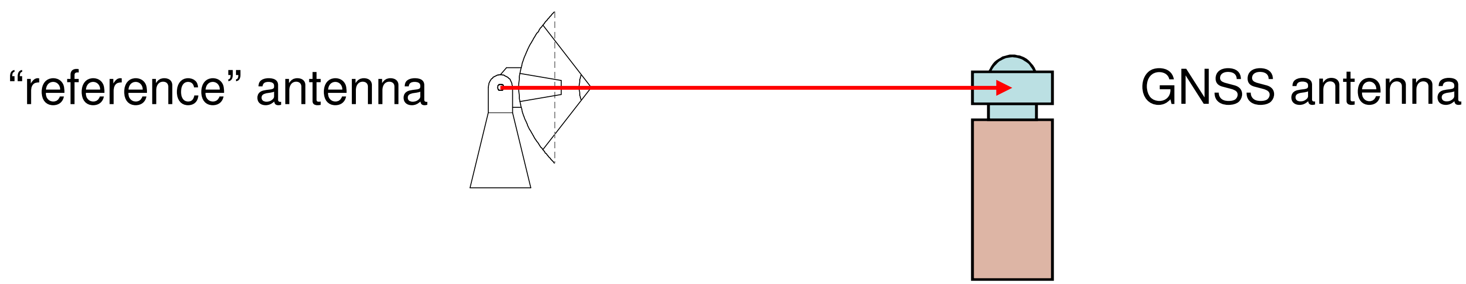


What phase delay precision can be expected?



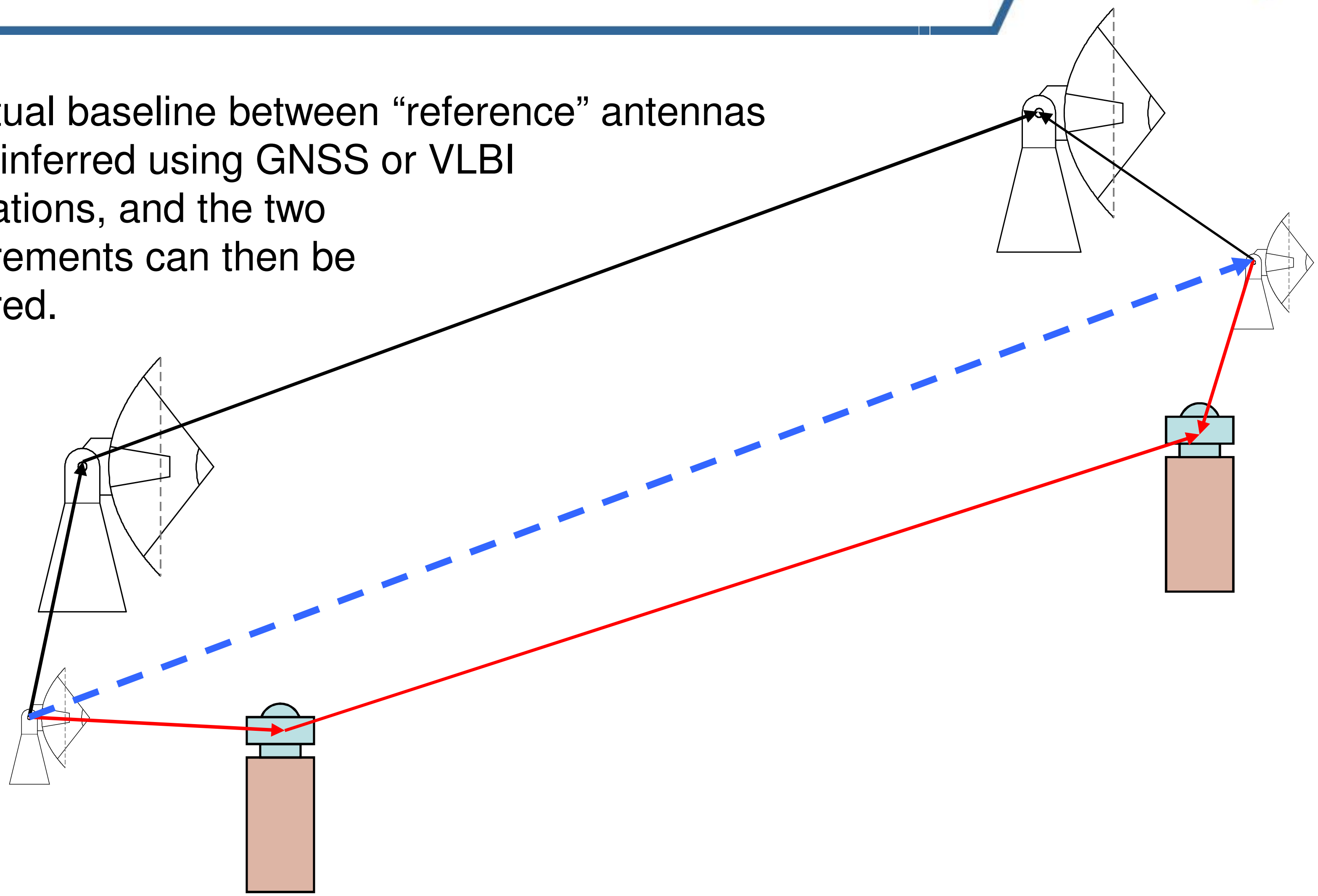
GNSS phase center models

- Since the “reference” antenna also observes GNSS frequencies, it will, in the same way as with the VLBI2010 antenna, be possible to generate phase center offset models for the GNSS antenna.
- Although the “reference” antenna will observe satellites sequentially, this should not affect the ability to track phase because the baseline is very short.
- Because the “reference” antenna has a narrow beam and must be pointed, it has a well defined reference point and experiences no multipath



Using the "reference" antenna for site ties

The virtual baseline between "reference" antennas can be inferred using GNSS or VLBI observations, and the two measurements can then be compared.



POD with the “reference” antenna

- Benefits of using the “reference” antenna for POD
  - GNSS signals are strong so they can easily be detected by the “reference” antenna
  - It has no multipath
  - It has a well-defined reference point
  - The VLBI2010 antenna can help determine clocks, atmosphere, station coordinates and UT1 with the “reference” antenna concentrating on POD
  - Phase ambiguity resolution can be done with the assistance of the local GNSS antenna
  - Observations can be made concurrent with VLBI observations

Uses of the “reference” antenna

- It can be used to develop effective thermal and gravitational deformation models for the VLBI2010 antenna
- It can be used to determine phase center offset models for the GNSS antenna.
- It can be used for site ties
  - The site tie is simple, requires no manual intervention, and can be performed repeatedly without significantly impacting regular observations.
  - If a directional GNSS antenna (spiral?) is attached the SLR antenna, it can also be included in the site tie.
- It can be used to produce an independent precise orbit determination.
- It’s reference point is well defined and can be accessed externally.

Conclusions

- It may be possible to get the benefits of GNSS frequencies withoutobserving them directly with the VLBI2010 antenna
- There may be significant benefit to the use of a small, directional, dual frequency (VLBI/GNSS) reference antenna for
  - Antenna deformation and phase center studies
  - Site ties
  - Precise orbit determination
  - External access to the space geodesy reference point.

Thanks for your attention!

Question? Comments?
Discussion?