Considerations on the Orbital Tube for Interferometric Applications

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Introduction

- The size of the orbital tube impacts directly the sensitivity to the height of the scatterers
  \[
  \phi = -\frac{4\pi}{\lambda} \frac{B_\perp}{r_0 \cdot \sin \theta} \cdot h
  \]

- Similarly, it defines the achievable tomographic resolution.

- Additionally, the size influences:
  - Burst synchronization for long data takes (burst modes only)
  - Azimuth spectral shift (due to crossing angle)
  - Coregistration requirements (Geometry-based approach)
Burst Synchronization for Long Data Takes

• Sentinel-1 can synchronize with very good accuracy at the beginning of the data take (better than 2 ms std. dev.).

![Burst mis-synchronization [ms]](image)

- Std.Dev. Burst mis at data take start: 1.8 ms

• However, a drift was observed during the commissioning phase in the synchronization of long data takes.
Burst Synchronization for Long Data Takes

Tunisia – Genoa
07.08.2014 – 19.08.2014

Malta - Austria
09.08.2014 – 21.08.2014
Burst Synchronization for Long Data Takes

- The synchronization changes during the data take.
- This can become an issue for long data takes (Note that sentinel-1 can potentially acquire 25 minutes per orbit).
- This behavior can be explained using the Clohessy-Wiltshire equations, which describe the motion of a satellite with respect to a reference orbit (i.e., the baseline). Specifically, the along-track component.

\[
\begin{align*}
\Delta x(t) &= \Delta x_0 + 2 \cdot A \cdot \sin(\phi_{lat} + \alpha), \\
\Delta y(t) &= -B \cdot \cos(\phi_{lat}), \\
\Delta z(t) &= -A \cdot \cos(\phi_{lat} + \alpha)
\end{align*}
\]

Depends on difference between orbit eccentricities

Depends on difference between inclination vectors
Burst Synchronization for Long Data Takes

- Time-dependent **along-track baseline** coupled with TOPS **scanning pattern** ⇒ **Missynchronization** of scanning pattern ⇒ targets observed under a different squint angle ⇒ **azimuth spectral decorrelation**.
Burst Synchronization for Long Data Takes

Target observed under different Doppler frequencies = Azimuth spectral decorrelation!
Burst Synchronization for Long Data Takes

- Numerical evaluation using Sentinel-1 real orbits:

  - Observations:
    - For a 25 minutes data take (a quarter of orbit), up to 30 ms mis-synchronization at the end of the data take ⇒ 15 % azimuth bandwidth (30% worst case in stacks!)
    - Drift depends on latitude: (±0.4 ms/deg). Worst case at equator.

- Along-track component depends on radial tube dimension ⇒ Radius of radial tube, $A$, depends on difference between orbit eccentricities ⇒ Tighter orbit eccentricity control to mitigate effect (does not necessarily imply more maneuvers or fuel!!)
Burst Synchronization for Long Data Takes

- **Reduction of radial tube size** implemented in Sentinel-1 (tighter eccentricity control):

![Graph showing burst synchronization and Doppler misalignment before and after implementation.](image)
Crossing Orbit

- The variation of the baseline results in a small **crossing angle** between the orbits (**non-parallel** orbits).
- In most practical cases for Sentinel-1, the spectral shift can be neglected.
- A larger cross-track tube will increase proportionally the spectral shift.

![Diagram showing crossing angles and spectral shifts](image)
- TOPS InSAR methodology: Geometric coregistration + constant offset.
- The non-parallel orbit increases the requirement in the DEM accuracy when it is used for coregistration*.

Range:  Small orbital tube of S-1 (50m in diameter). No stringent requirement.
Azimuth: Small S-1 orbit crossing angles anticipated (0.001° worst case).
SRTM/ASTER DEMs sufficiently accurate!

Coregistration Requirements

- Accurate computation of DEM requirement using Sentinel-1 orbits.
- The larger the variation in across-track ($B$ variable in the Clohessy-Wiltshire equations), the larger the crossing angle will be.
- The plot on the right shows the azimuth coregistration error for different error heights (ranging from 300m to 3300 m in steps of 300 m) using real Sentinel-1 orbits.
- Errors in the DEM up to 300m produce less than $\pm 1.5^\circ$ phase error. DEM requirement proportional to cross-track dimension of tube.
Mount Etna Example

- Mount Etna interferogram 09.08.2014 – 21.08.2014:
  - Orbit crossing angle: ~0.3 mdeg
  - Bperp (per Sub-swath): 140.5 / 129.4 / 118.2 m
  - Burst mis-sync: 3ms
- Slave image coregistered using:
  - SRTM
  - Ellipsoid (height = 0m)
- Interferogram between the two slaves

Observations:
- No difference at sea level elevation
- Linear ramp due to topography offset
- Bias at mountain peaks
- Good coregistration accuracy even with large height deviations
RMS radial radius: 12 m
RMS cross-track radius: 66 m

RMS perpendicular radius: 58 m
RMS parallel radius: 34.7 m
($\theta_{inc} = 30^\circ$)

$L_{Rayleigh} = \frac{\lambda r_0}{2\delta h} = \{\delta h = 5m\} \approx 5 \text{ km}$

Absence of interfering scatterers: $L_{CS} = \frac{L_{Rayleigh}}{SR} = \{SR = [10, \ldots, 100]^*\} \approx [500, \ldots, 50] \text{ m}$

Two interfering scatterers: $L_{CS} = \frac{L_{Rayleigh}}{SR} = \{SR = [1.5, \ldots, 25]^*\} \approx [3000, \ldots, 200] \text{ m}$

• Spectral shift and coregistration requirement for different baselines.
• Gray curves going from 300m to 3.3 km (steps of 300m).
• 10 Hz is ~3% of the TOPS azimuth bandwidth.

\[ B_{\text{cross-track}} = 960 \text{ m} \]

Spectral shift and DEM requirements increase approx. linearly with the cross-track baseline. For a cross-track baseline of 960 m \((B_\perp \approx 830 \text{ m})\):
• Spectral shift of 6%
• DEM error of 300m will induce biases up to 10º in the interferogram.
Conclusion

• Considerations on the orbital tube in the frame of Sentinel-1 TOPS:
  – Variation of the along-track baseline induces burst missynchronization (azimuth spectral decorrelation) ⇒ Solution for Sentinel-1: tighter eccentricity control.
  – Crossing angle induces a negligible azimuth spectral shift for Sentinel-1 for the current orbital tube.
  – DEM requirement linked to crossing angle.

• Crossing angle and DEM requirements depend approx. linearly on the cross-track dimension of the tube.

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Role of the Orbital Tube in Interferometric Spaceborne SAR Missions, accepted in IEEE GRSL.
Thank you for your attention!