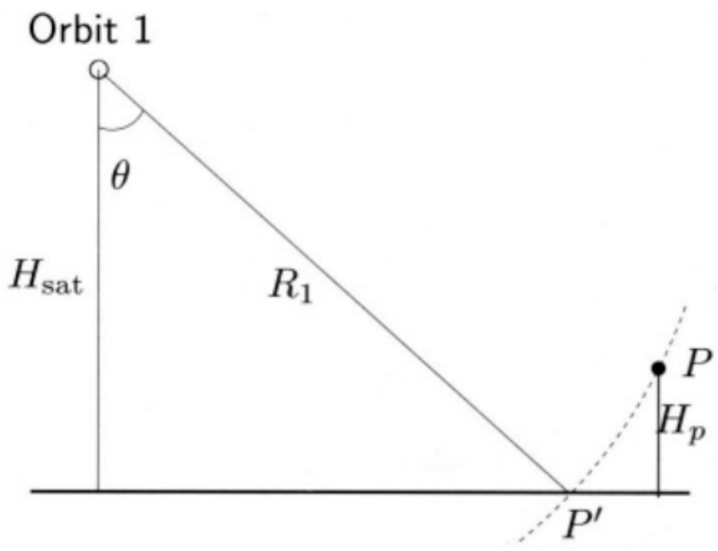
SAR Interferometry and Polarimetry

SAR Interferometry

- Problem: is it possible to measure the altitude of a ground point using SAR?



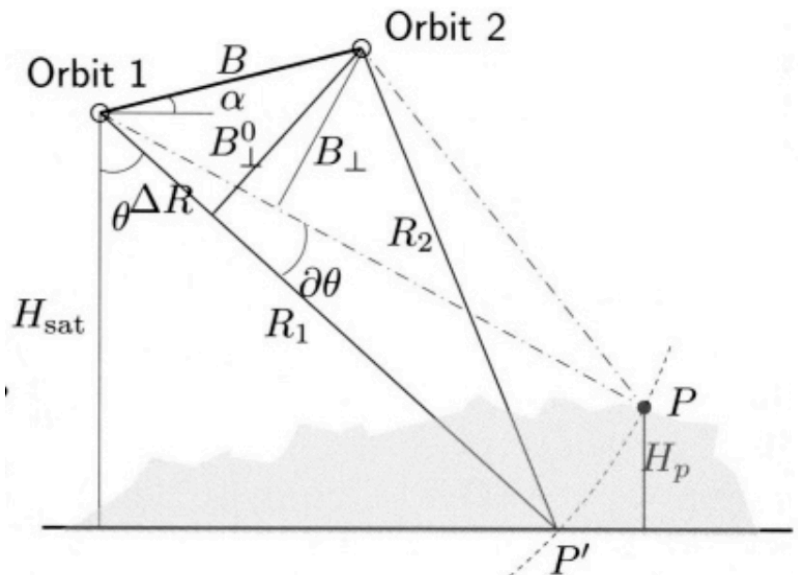
- We have seen that the SAR cannot distinguish points that are at the same distance from the sensor in that it only measures distances
- So, it is not possible to measure the angular position and thus neither the altitude H

SAR Interferometry

- A similar problem to what we have seen with aerial photography
- In that case we could only measure the angles but not the distances
- Solution:
  - For aerial photography we used the stereogrammetry, that is, the use of two images taken at different position to infer the altitude of targets from the angles
  - With SAR we can use the same idea: interferometry, the same scene is measured from two different position to infer the angles from the distances
  - We call it interferometry because in this case the information is brought by the phase difference between the signals received from the two observation points
  - The two observations can be obtained both using two different sensors or one single sensor moved in two positions

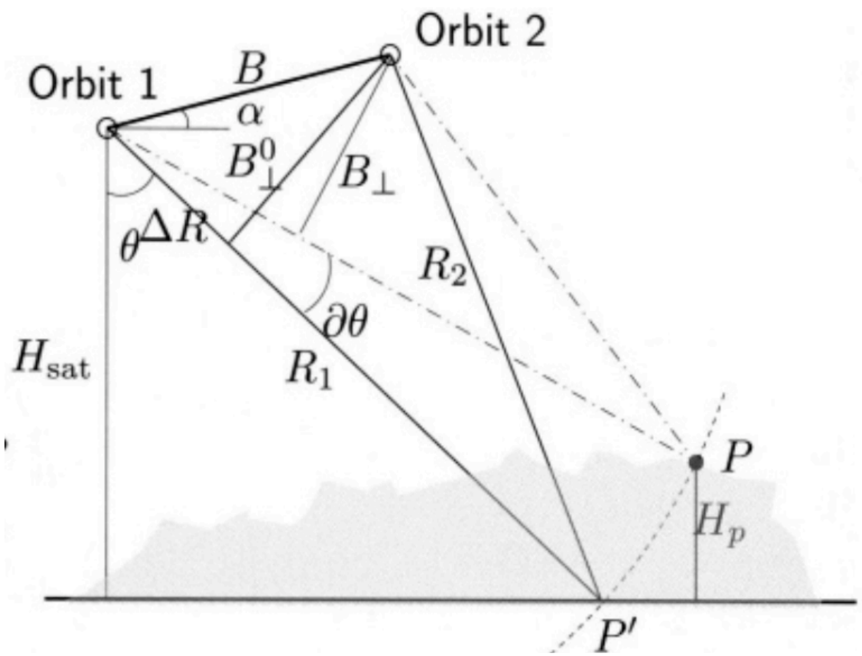
Working Principle

- The situation is the following



- The objective is to obtain information on H_p by using the measures taken on two different orbits
- It is a purely geometric problem to solve

Working principle



- We always have to keep in mind that we can only measure the distances between target and sensors
- In this case it is useful to measure the difference between the distances from the two sensors, and this can be done by using the phase of the signal

Working principle

- The phase difference between the two signals that reach the target is always related to the path length difference by the expression

$$
\begin{aligned}
\phi &= 2\frac{2\pi}{\lambda}\left(R_1 - R_2\right) \\
&= \frac{4\pi}{\lambda}\Delta R
\end{aligned}
$$

- From the geometry of the scene, using the far field approximation (nearly the same angle from the two observations)

$$
\begin{aligned}
\Delta R &\approx B\cos\left(\pi/2 - \theta + \alpha\right) \\
&= B\sin\left(\theta - \alpha\right)
\end{aligned}
$$

Working principle

- The phase difference, however, can only be observed up to a multiple of 2π
- Let us consider for a moment the derivative of the phase difference when we are in a neighborhood of the look angle θ^0

$$\partial \Delta R = B \cos\left(\theta^0 - \alpha\right) \partial \theta$$

- From this we obtain

$$\partial \phi = \frac{4\pi}{\lambda} B \cos\left(\theta^0 - \alpha\right) \partial \theta$$

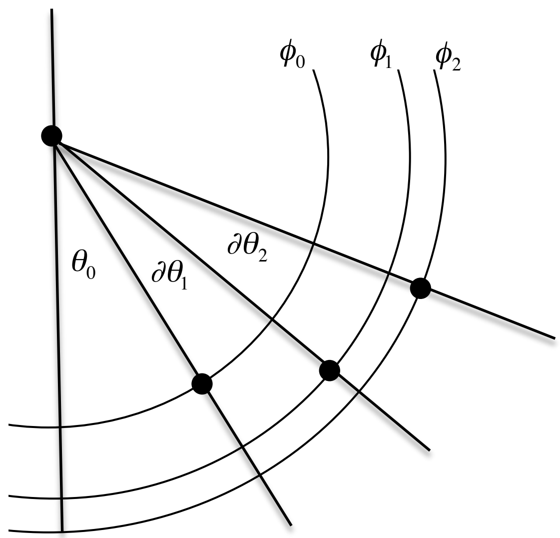
- Assuming we have a reference point on a look angle θ^0, we then see that variations in the phase difference in the two sensors are related to variations in the look angle by a known relation

Working Principle

- So, starting from the reference look angle, it is possible to determine how the look angle of different targets varies depending on the the variation of the phase difference at the two sensors
- Example

$$\partial\theta_1 \approx \frac{\lambda(\phi_1 - \phi_0)}{4\pi B\cos(\theta_0 - \alpha)}$$

$$\partial\theta_2 \approx \frac{\lambda(\phi_2 - \phi_1)}{4\pi B\cos(\theta_1 - \alpha)}$$



Working Principle

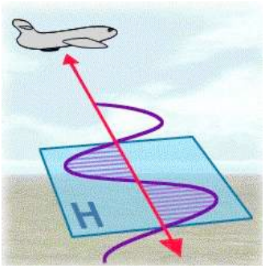
- It is then clear that starting from look angles we can then find the altitude of targets by using the altitude of the platform and the distance measures
- The main problem is the fact, as we said, the phase differences are only known up to a multiple of 2π
- So, we can have errors in the altitude estimation if the altitude difference is too high in two given points
- It is necessary to perform an operation known as the *phase- unwrapping*. Very coarsely said, since we have a 2D image, each point in the image is reached (from a reference point) using a path with small variations in the phase, so as to avoid ambiguous large phase differences

SAR Polarimetry

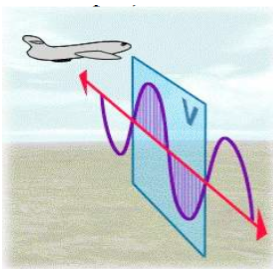
- We have discusser SAR without saying anything about the polarization of the used waves
- We have seen that EM waves can be polarized in different ways (circularly, linearly etc).
- Each polarization, however, can be seen as a combination of two linear polarization in two orthogonal directions
- In SAR remote sensing we use as basic components the linearly horizontal (H) and linearly vertical (V) polarized waves

Working Principle

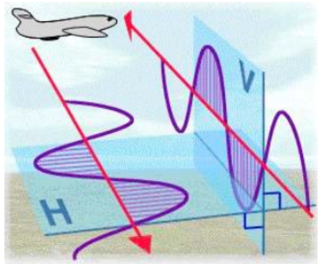
- Different combinations of H and V polarizations are used in the emitted and measured waves



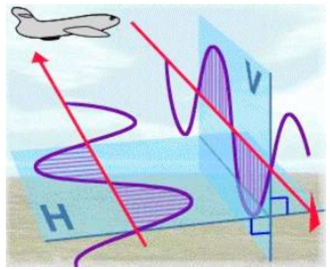
HH Mode



VV Mode



HV Mode



VH Mode

- Each of these combinations is useful to infer important information on the observed target
- The main idea is that depending on the shape and constitution of the different targets, the amount of energy and the relative phase in each polarization is different
- On a modern system all four possible combinations can be used

Working Principle

- Co-polarized methods
  - HH mode:

    This is the preferred choice, for example, for the study of the soil humidity. Vertical “structures”, like wheat and other cereals, are much more transparent to horizontally polarized waves. So, using this mode, the backscattered power almost only depends on the soil humidity and not on the vegetable health.
  - Is it also very useful in discerning water from ice and, in general, for detection of targets on water (boats etc…)
  - VV mode:

    It is a mode largely used in space systems (example: Envisat-1). This mode is useful for example in the study of water surfaces roughness and, hence, for oceanographic applications such as the wind velocity estimation etc.

Working Principle

- Cross-Polarized modes HV and VH:
  - The amount of energy backscattered by a target in cross-polarization is usually much smaller than in the co-polarized mode. It suffices to recall that an ideal boundary does not reflect at all in cross-polarization. Hence, the SNR in these modes is much smaller than in HH or VV
  - Nevertheless, due to the complex backscattering behavior of real targets, (multiple reflections etc.), these cross-polarized modes are actually useful for detecting particular properties of targets.
  - For example, they are particularly useful for the study of targets that create multiple reflections, such as boats on water, ice structures, complex buildings etc..
  - Theoretically, the two cross-polarized modes should give almost the same information since the behavior of targets should be almost symmetric in terms of the backscattered power in the two cross-polarization modes. However, in practice, the noise in the two modes is very different and it is then useful to use them both and then combine the results