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E4230
Microwave EO Instrumetation

(5 cr)
Jaan Praks, Oleg Antropov
Aalto University

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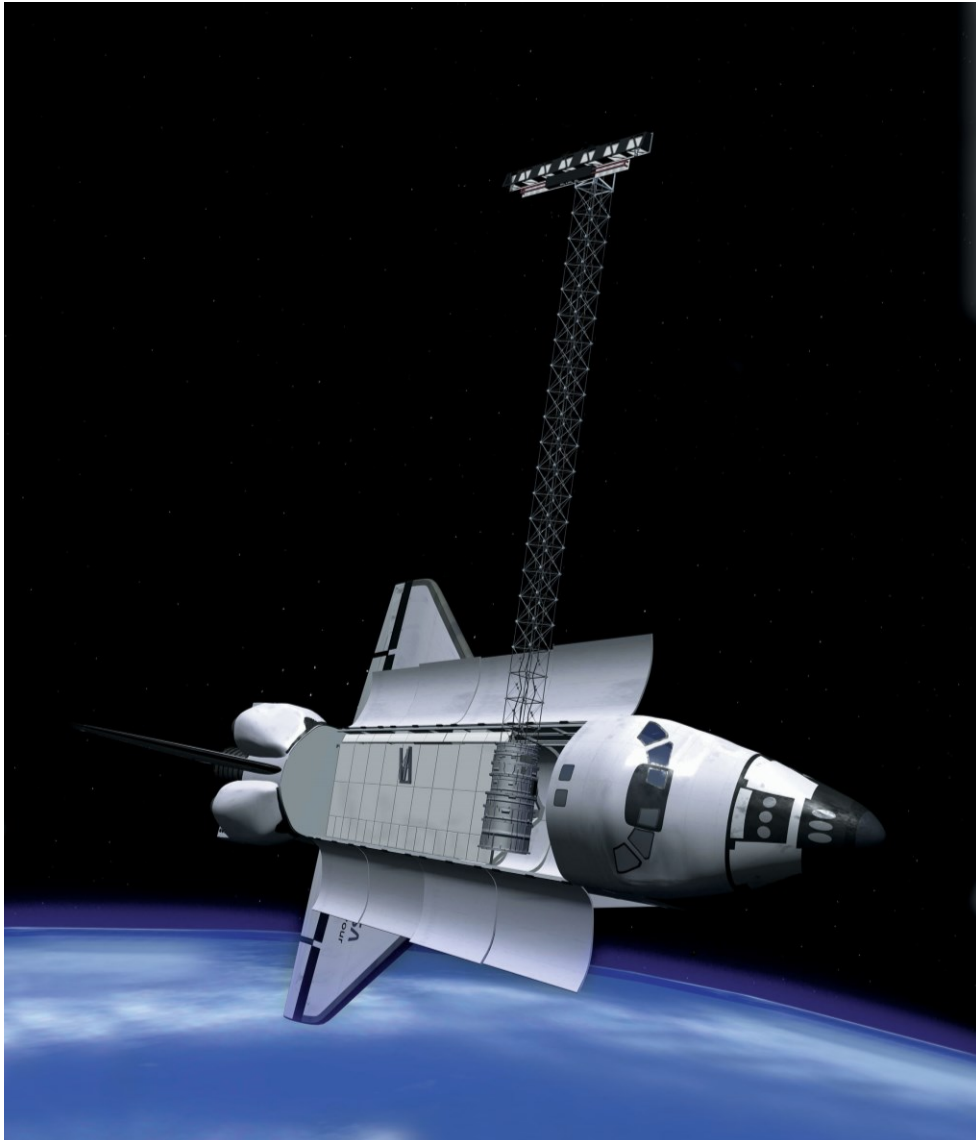
Imaging Radars



Iceye team with first proto

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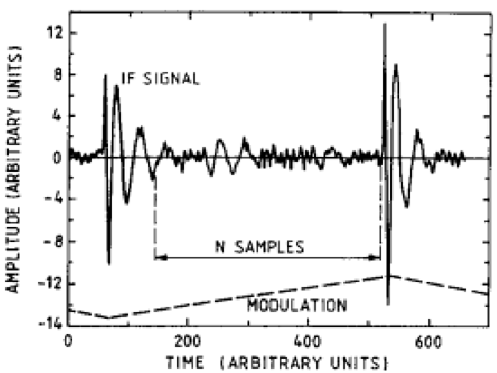
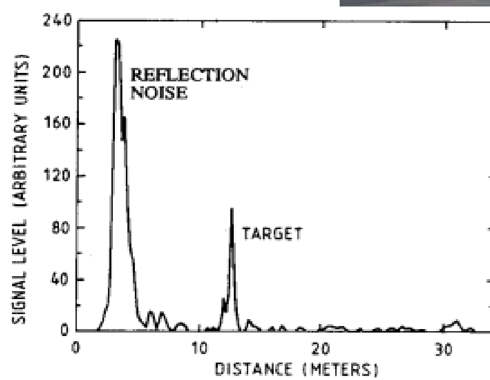
Scattero meter

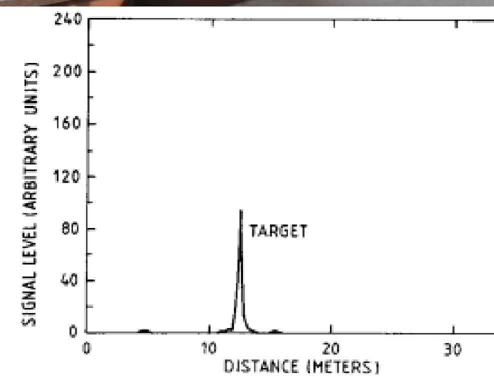
Installing HUTSCAT

HUTSCAT, FM-CW radar

HUTSCAT operates in C- and X-band and measures radar echo magnitude as a function of distance

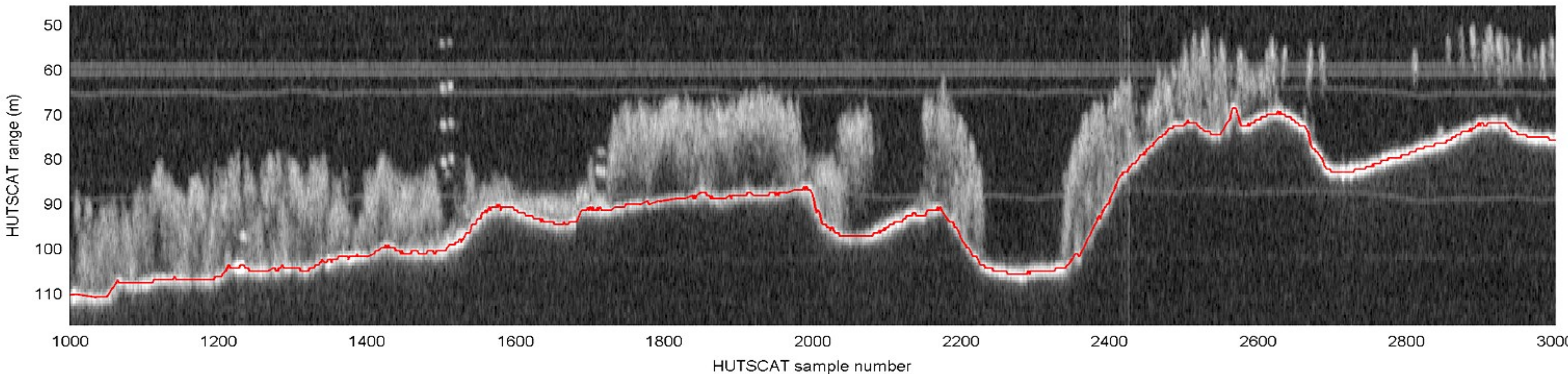






HUTSCAT

- Scatterometer, one type of radar, measures the scattering profile
- X-band multipol (HH HV VH VV)
- C-band multipol (HH HV VH VV)
- Range resolution 0.65 m
- Vertical resolution is achieved by measuring the delay of the received pulse
- Horisontal resolution is achieved by platform movement



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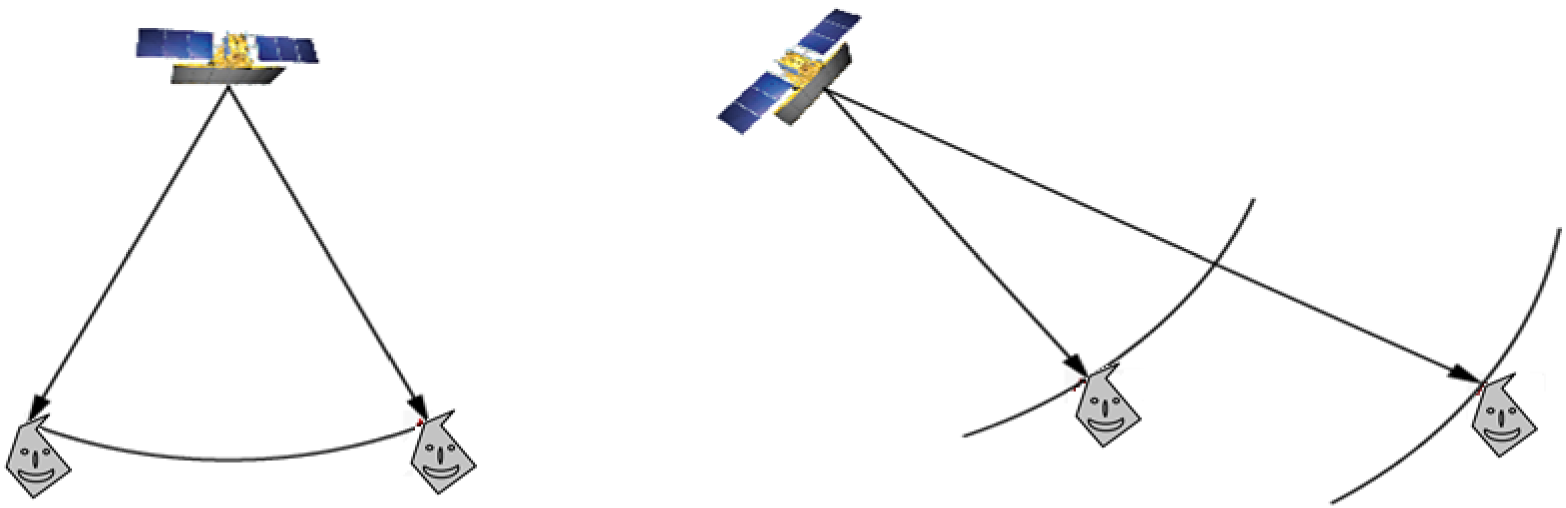
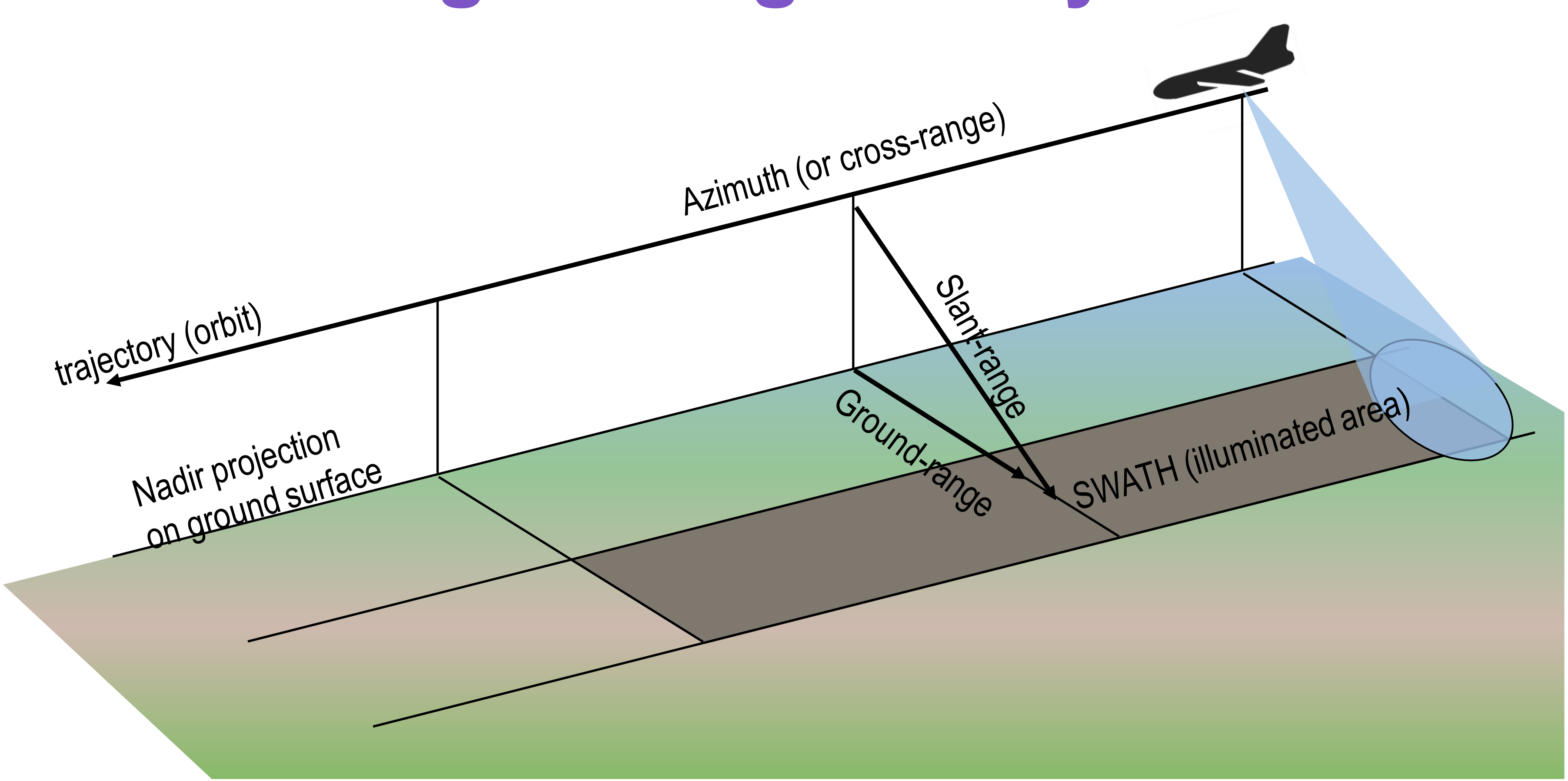
Real Aperture Radar

Radar : side looking geometry

- A radar can distinguish objects by their range (distance)
- Nadir looking: same distance at right and left - ambiguity
- Solution: Side looking geometry



Side Looking Radar geometry



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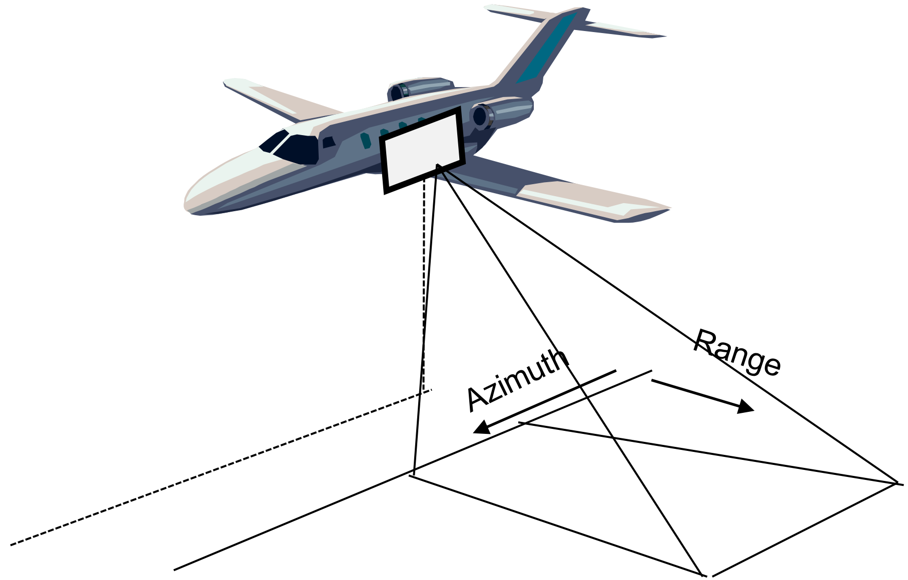
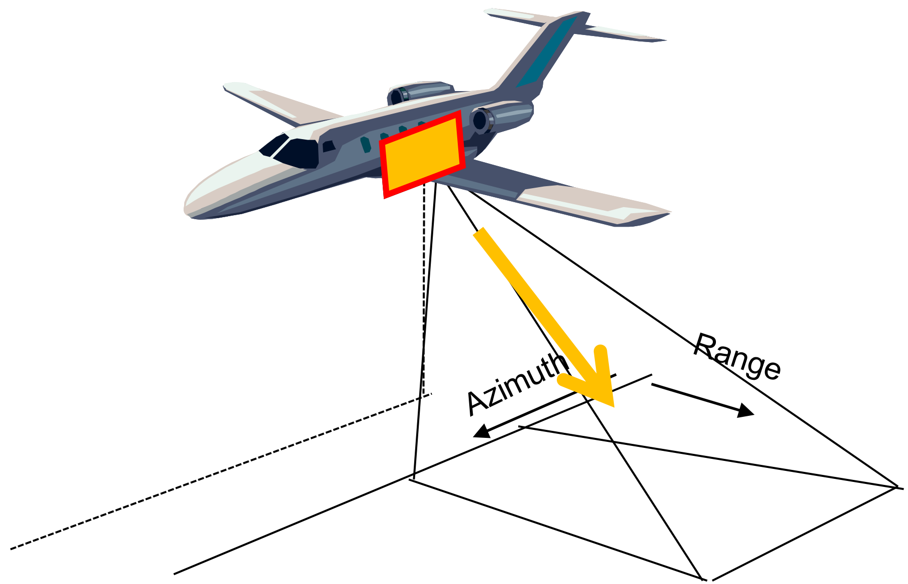
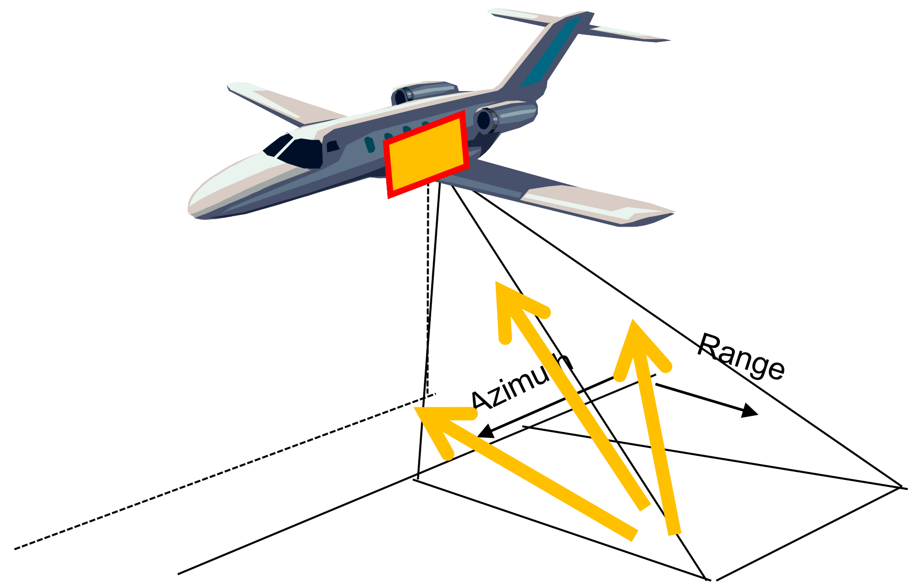
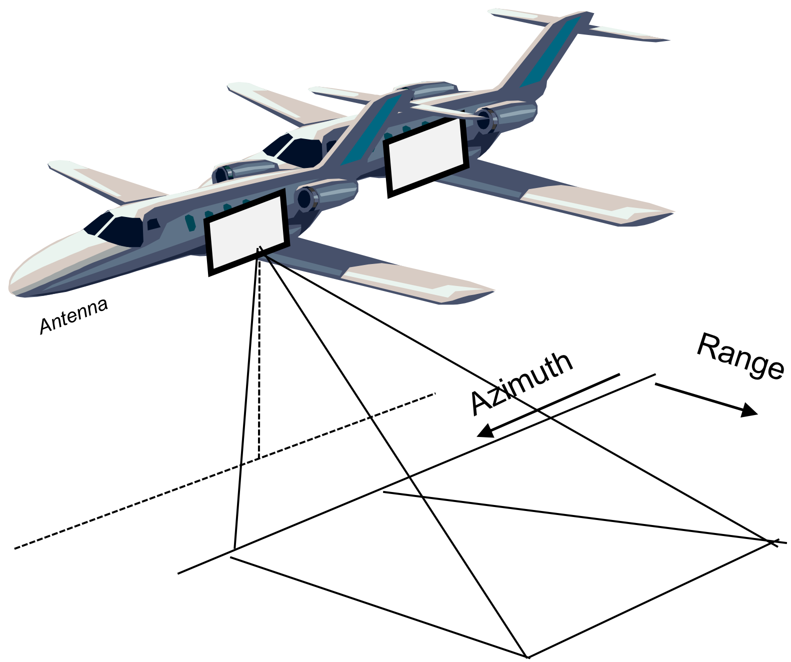
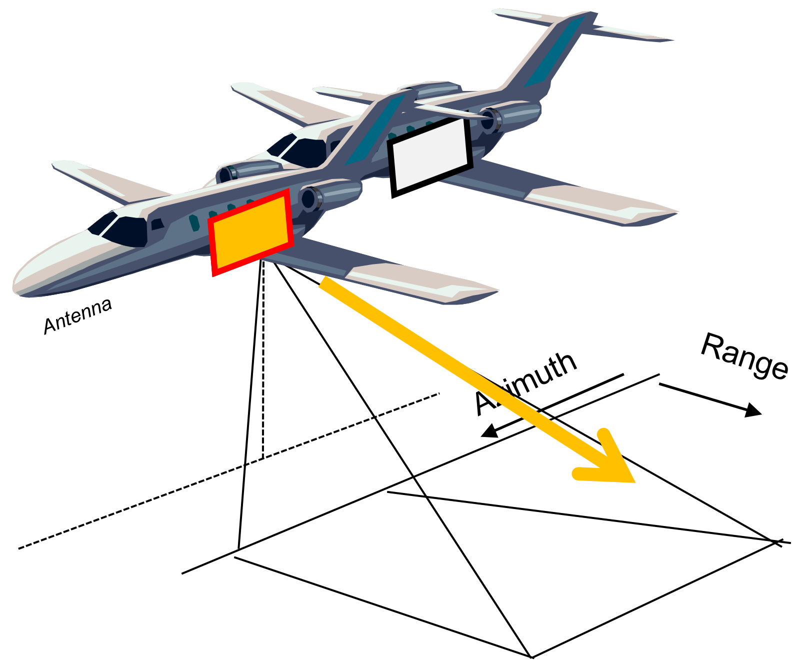

Azimuth
Range


Azimuth
Range

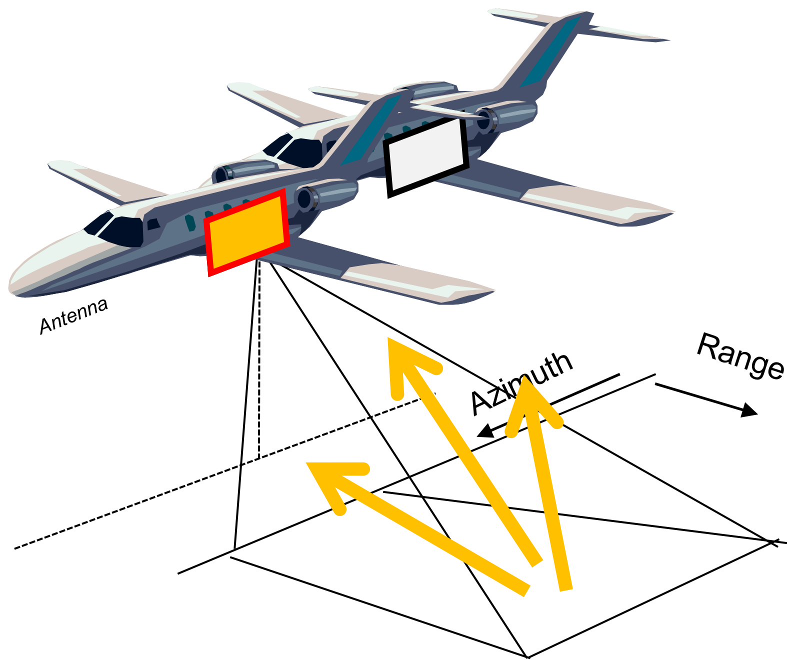

Range
Azimuth



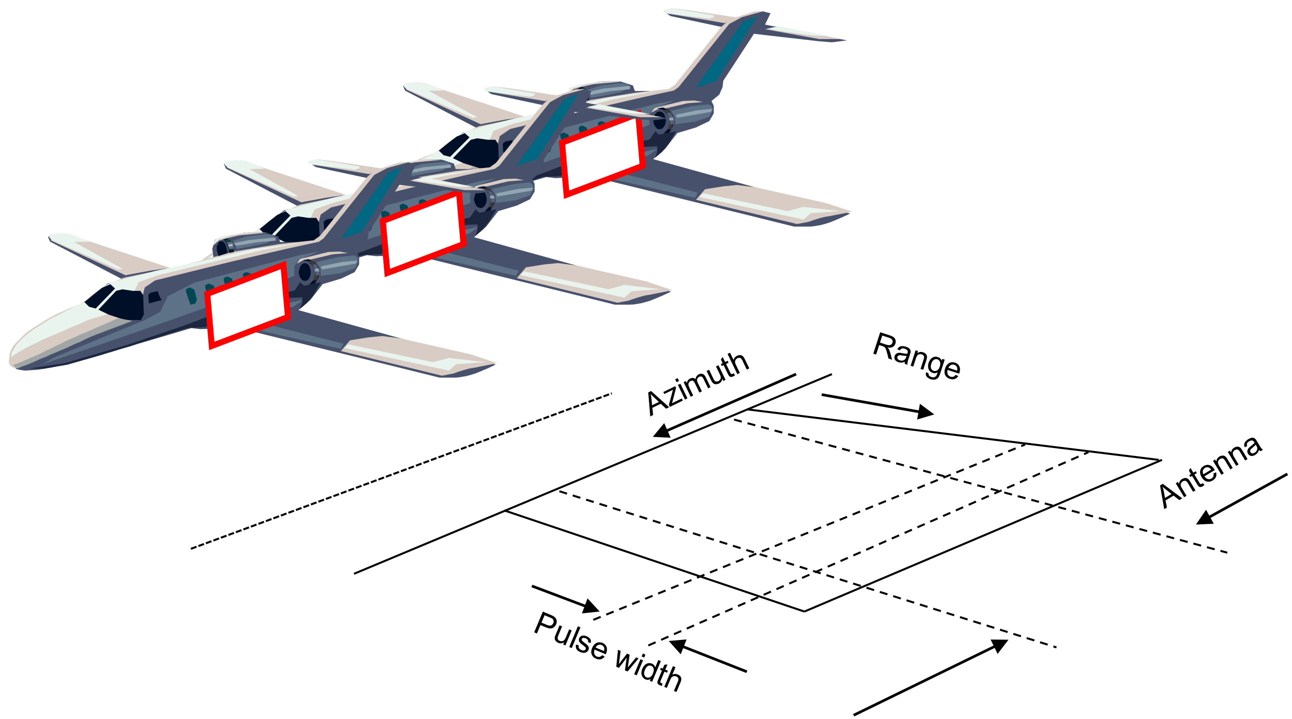
Antenna
Azimuth
Range

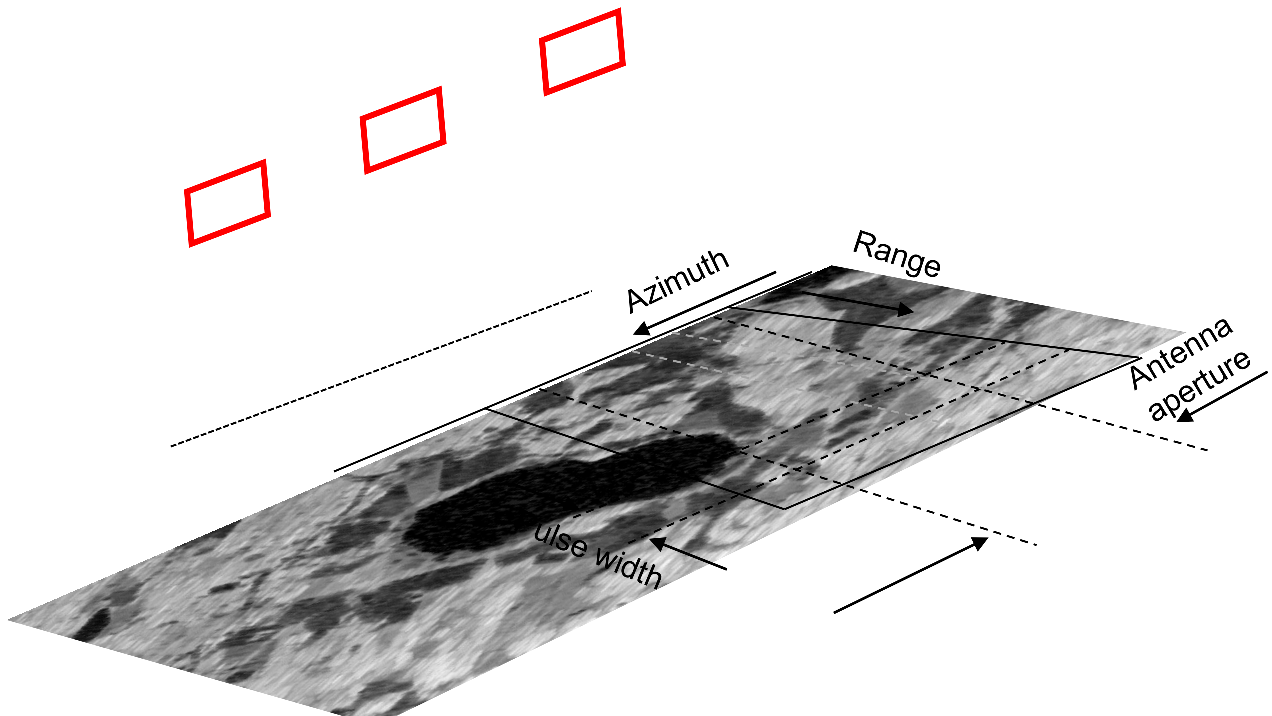


Antenna
Range



Antenna
Azimuth
Range


Range
Azimuth
Antenna
Pulse width



Range
Azimuth
Antenna
aperture
ulse width

Side looking radar SLAR

slant range
slant-range resolution
along-track resolution
real-aperture
horizontal beamwidth

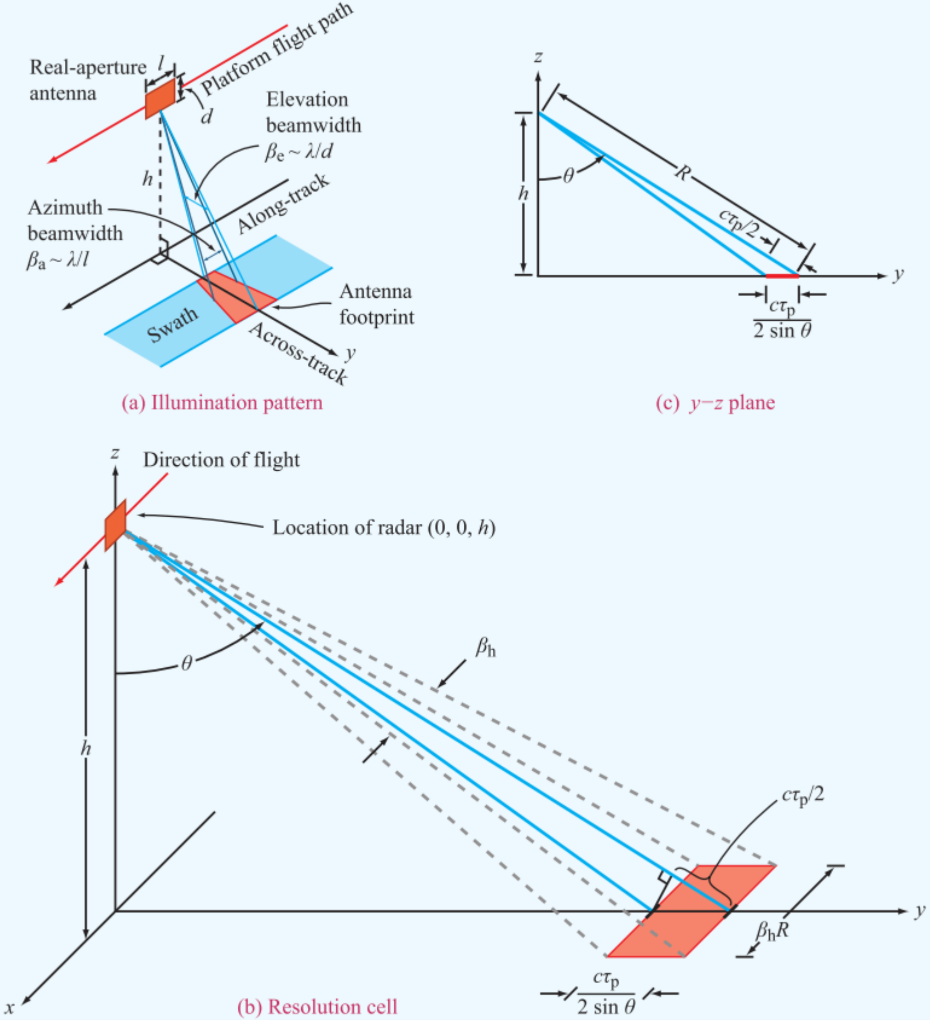


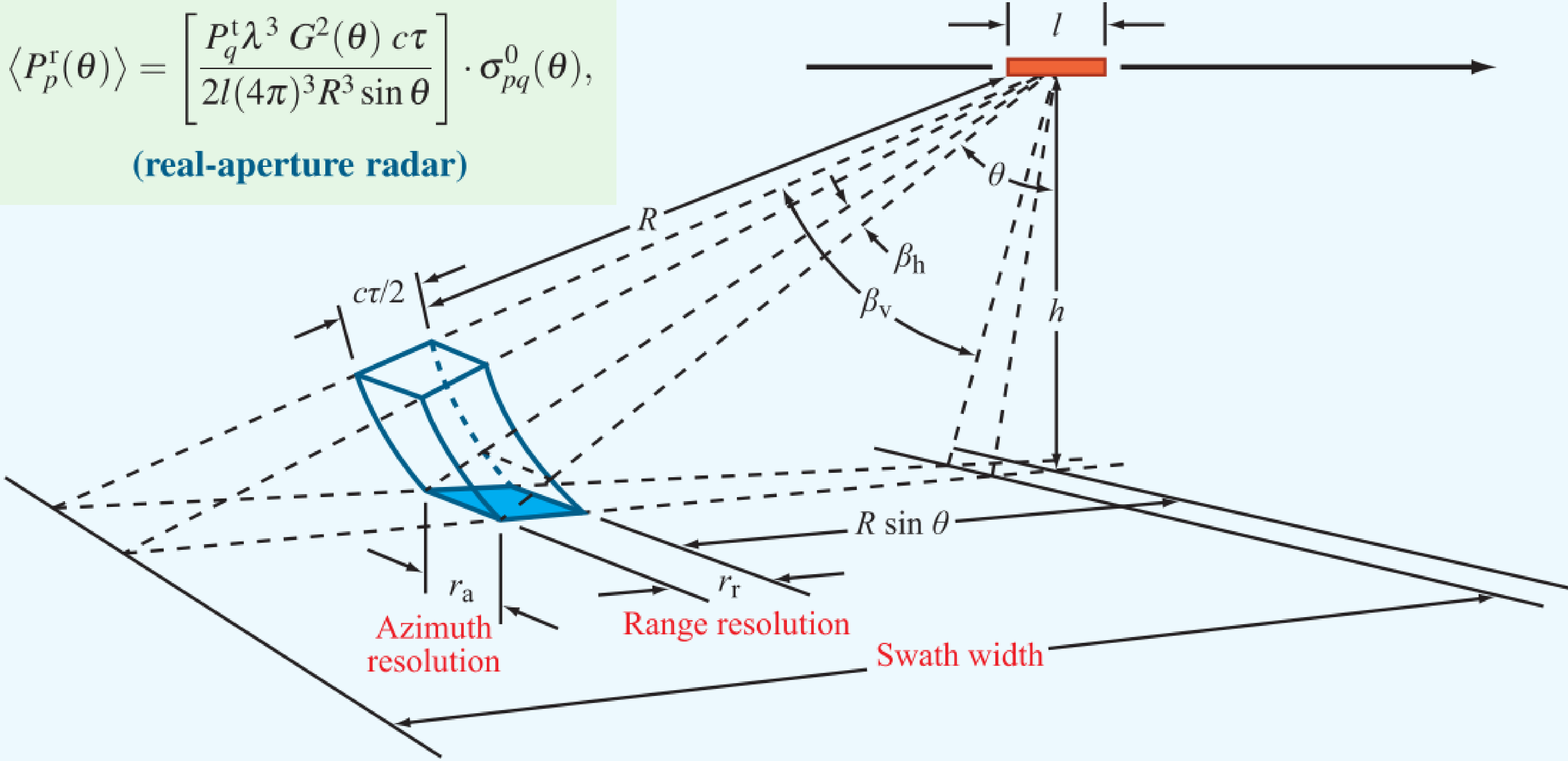
Figure 14-3: Geometry of real-aperture SLAR: (a) antenna illumination pattern on ground, (b) three-dimensional view of one resolution cell, and (c) view in the y–z (cross-track/vertical) plane.

From: Microwave Radar and Radiometric Remote Sensing, by Ulaby and Long, 2014, with permission.

Real Aperture Radar

$$\langle P_p^{\mathrm{r}}(\theta)\rangle = \left[\frac{P_q^{\mathrm{t}}\lambda^3\, G^2(\theta)\, c\tau}{2l(4\pi)^3 R^3 \sin\theta}\right]\cdot \sigma_{pq}^0(\theta),$$

(real-aperture radar)



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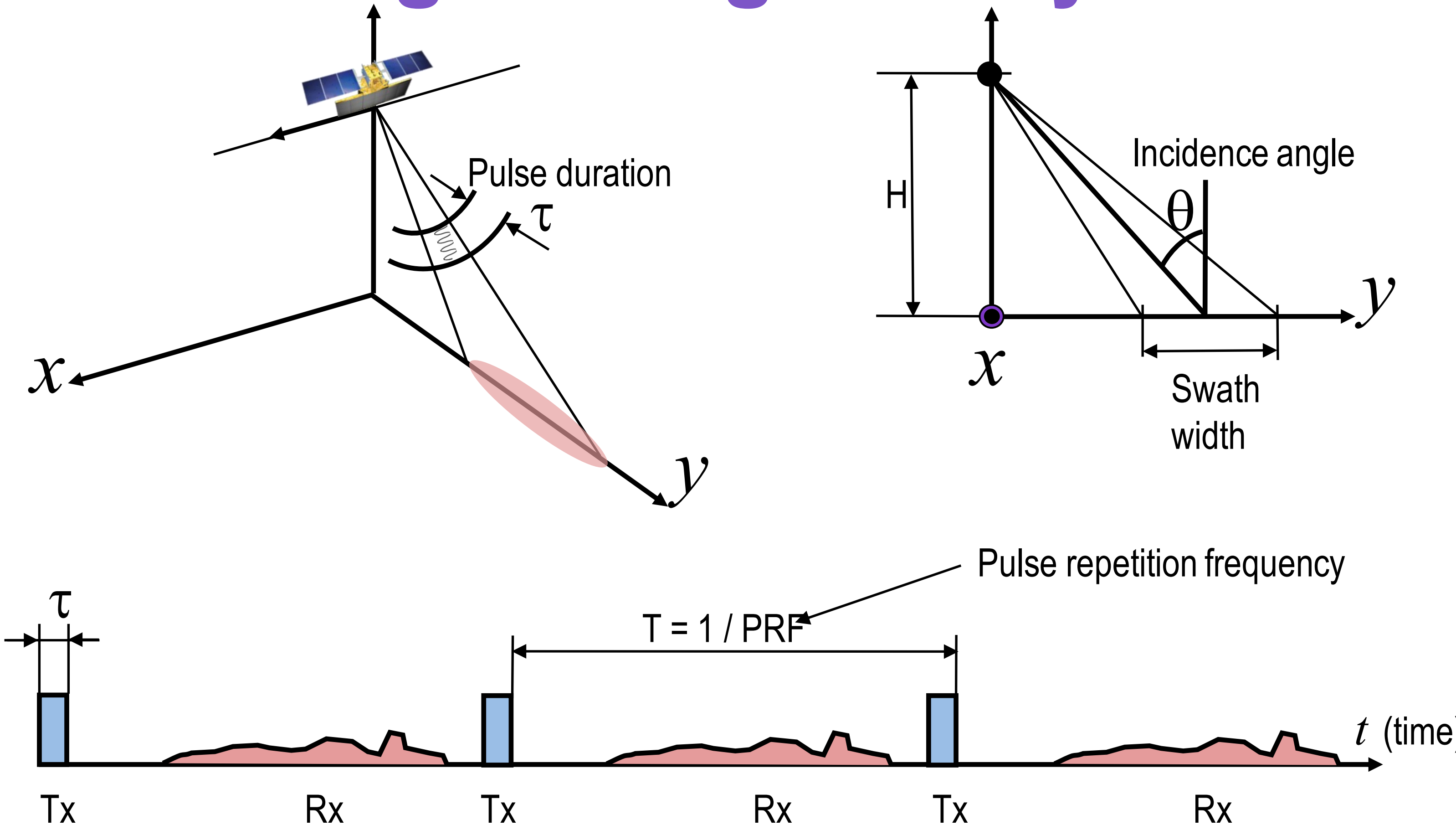
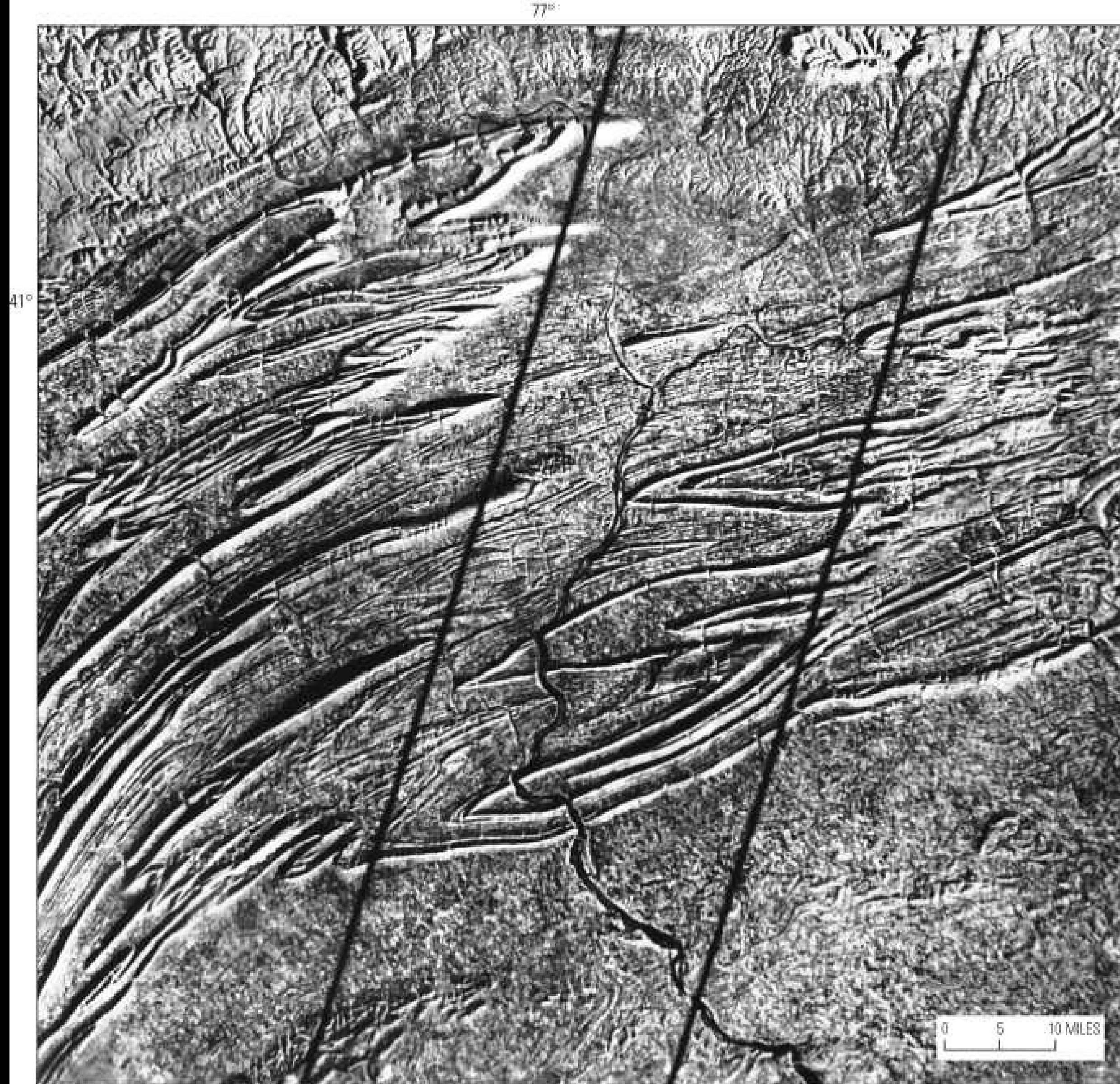
Side Looking Radar geometry



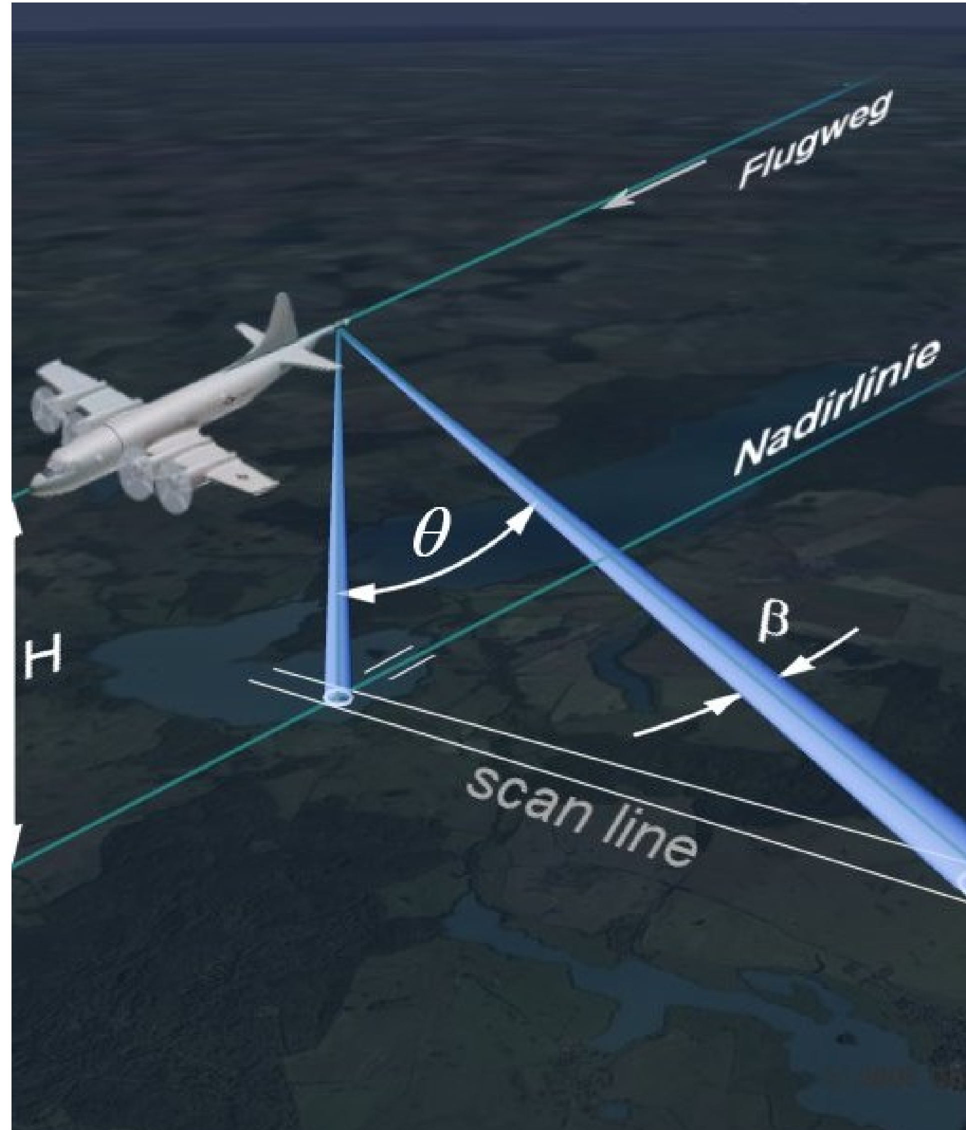

BELGIAN NORTH SEA AERIAL SURVEY
NO STEP
© Photo Tom Brinckman (www.aerobel.be)
www.belgian-wings.be



U.S. Geological Survey Bulletin 2163
Lateral Ramps in the Folded Appalachians and in Overthrust Belts Worldwide --A Fundamental Element of Thrust-Belt Architecture
By Howard A. Pohn

Aalto University
School of Electrical Engineering

Real aperture radar resolution

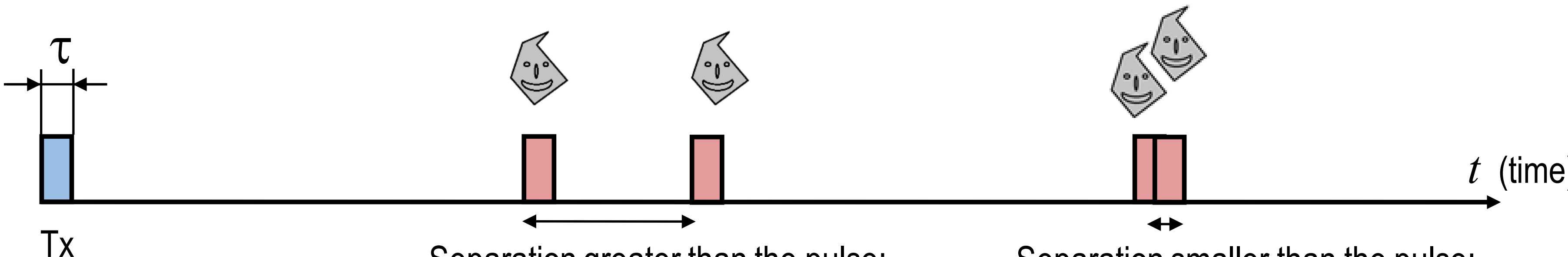


Radar resolution in range and azimuth

- A SLAR is intended to provide a 2D image of the Earth surface
- Spatial resolution: minimum distance between two objects to be distinguished in the image
- How can the radar get resolution? First options:
  - Resolution in range provided by a short duration of the pulses
  - Resolution in azimuth provided by the angular resolution obtained with a narrow antenna beam
- How does it work?

Range resolution

- We can resolve two objects when they are separated more than the pulse duration



- Definition of resolution in range:

$$\rho_r = \frac{c\tau}{2}$$

The smaller the pulse duration, the better the resolution

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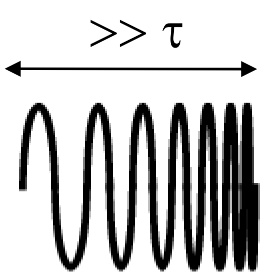
Range resolution

- Fine resolution in range demands extremely short pulses: problem for transmitting enough power
- Alternative formulation in frequency

$$B \approx \frac{1}{\tau}$$ Frequency bandwidth is the inverse of the pulse duration

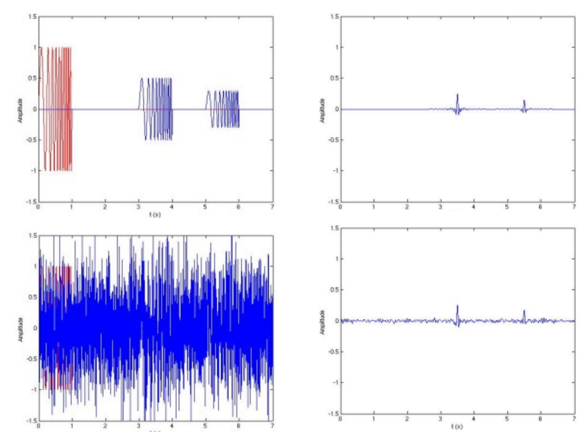
$$\rho_r = \frac{c}{2B}$$ The greater the bandwidth, the better the resolution

- Solution: pulse with the required bandwidth and longer duration (e.g. CHIRP)



Frequency increases linearly

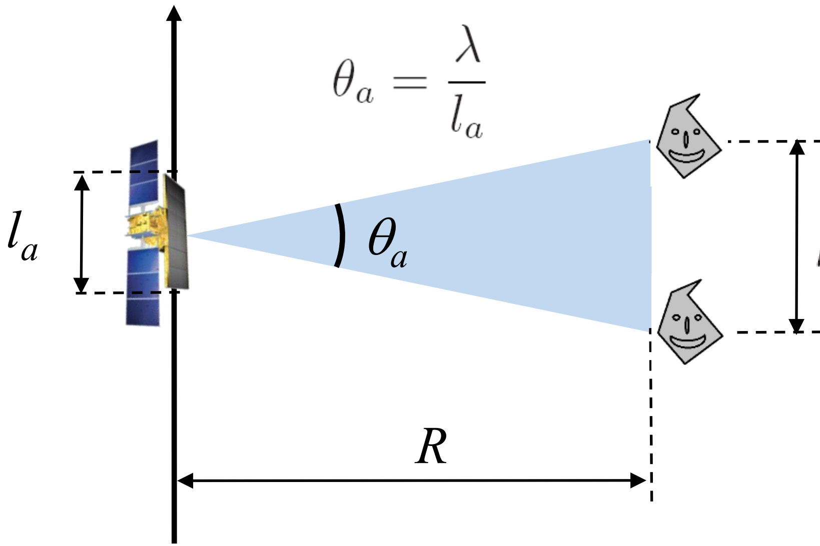
matched filtering
for synthesizing
and localizing
short pulses



Azimuth resolution

- RAR: real aperture radar
  - Resolution in azimuth is provided by the width of the antenna beam

$$\theta_a = \frac{\lambda}{l_a}$$



$$\rho_a = R \cdot \theta_a = R \frac{\lambda}{l_a}$$

It varies with range (variable within an image)
It depends on the antenna size

- Antenna requirements: $\rho_a = 5$ m $\quad \lambda = 5.6$ cm (C-band)

Airborne: $R = 3$ km $\Rightarrow$ $l_a = 33.6$ m

Spaceborne: $R = 800$ km $\Rightarrow$ $l_a = 9$ km

Challenge!

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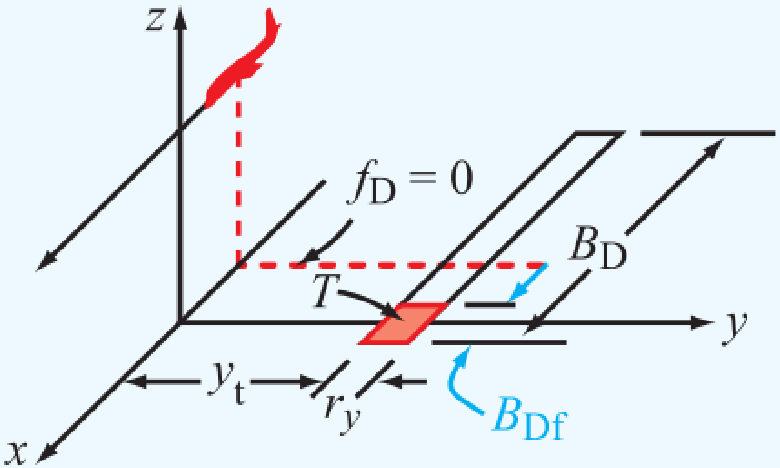
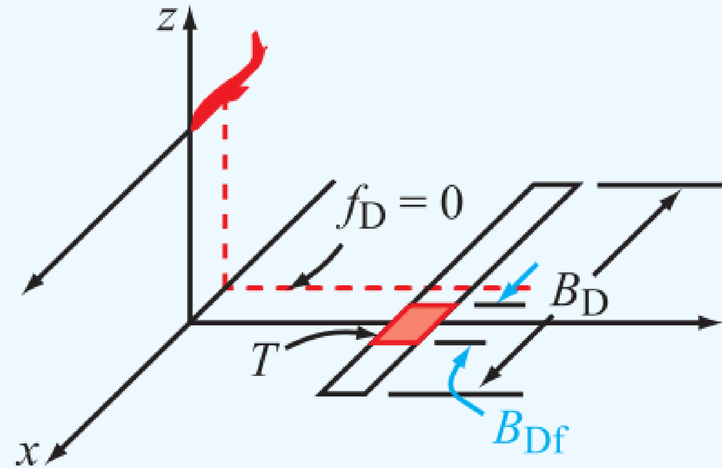
Doppler beam sharpener



(b) High positive Doppler frequency



(c) Medium positive Doppler frequency

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Synthetic Aperture Radar

Solution – Synthetic Aperture!

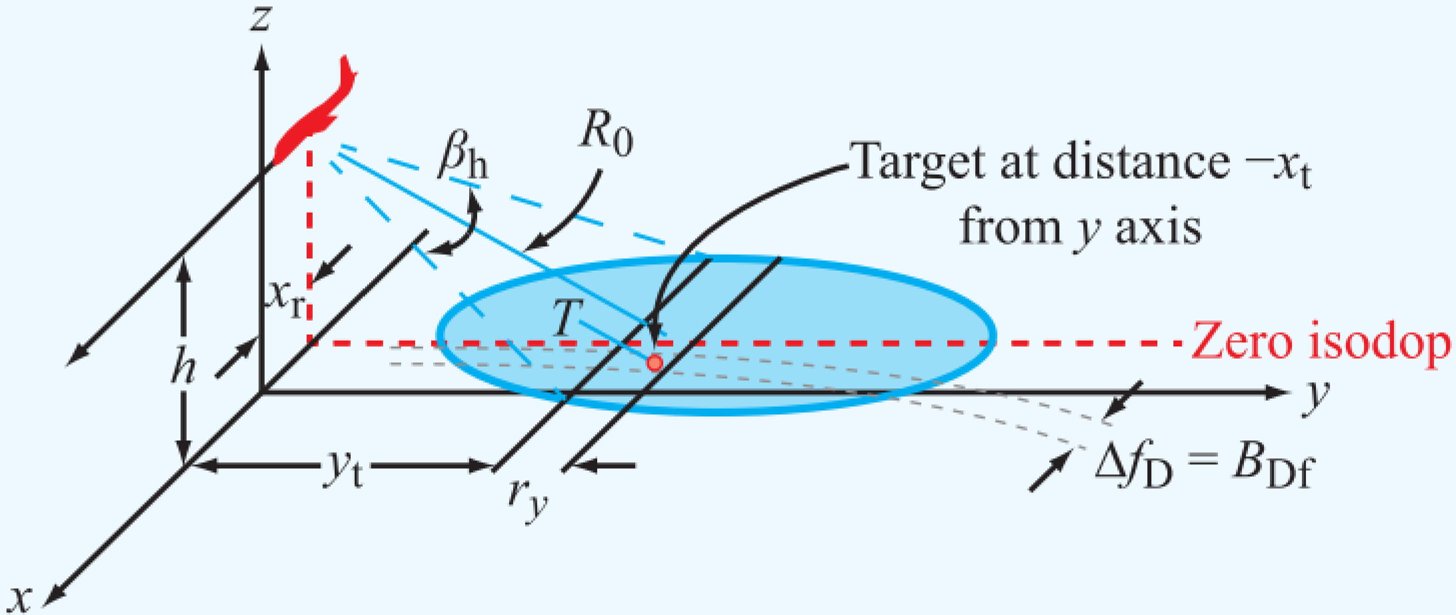
The idea (Carl Wiley, 1951):

- A large aperture antenna - required for achieving a high spatial resolution in azimuth is "synthesized" using an array of small antennas working together.

This array of small antennas is formed by using a moving real aperture antenna:

- mounted on a moving (with velocity vp) platform and
- operated in a pulsed mode (with a pulse repetition frequency given by PRF).

Doppler beam sharpener



(a) Geometry of SAR Doppler calculations

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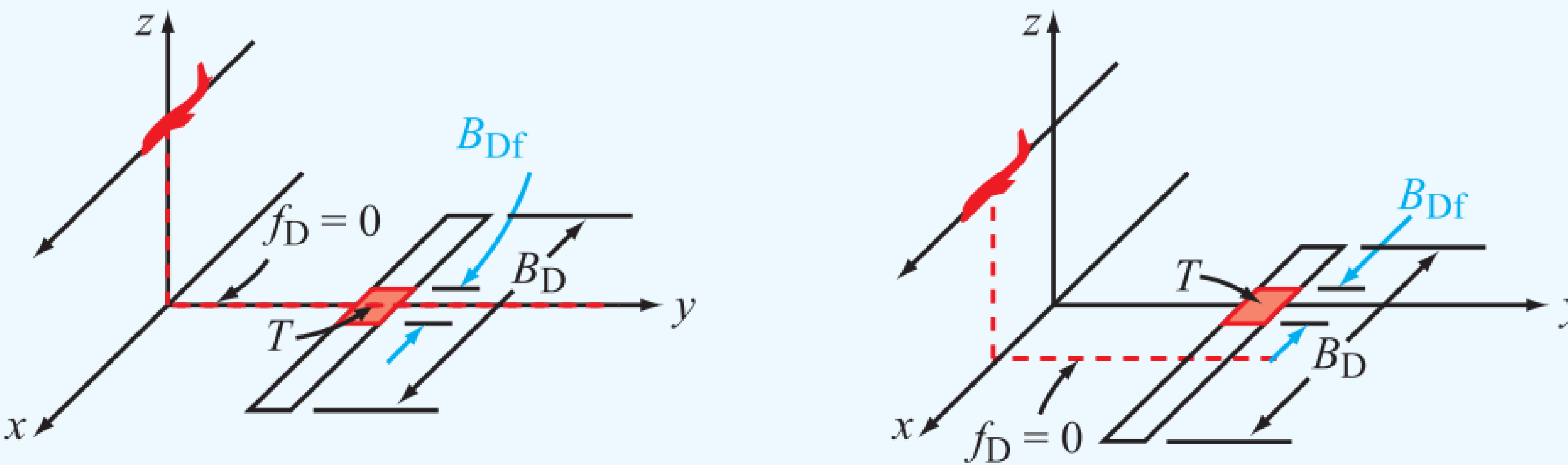
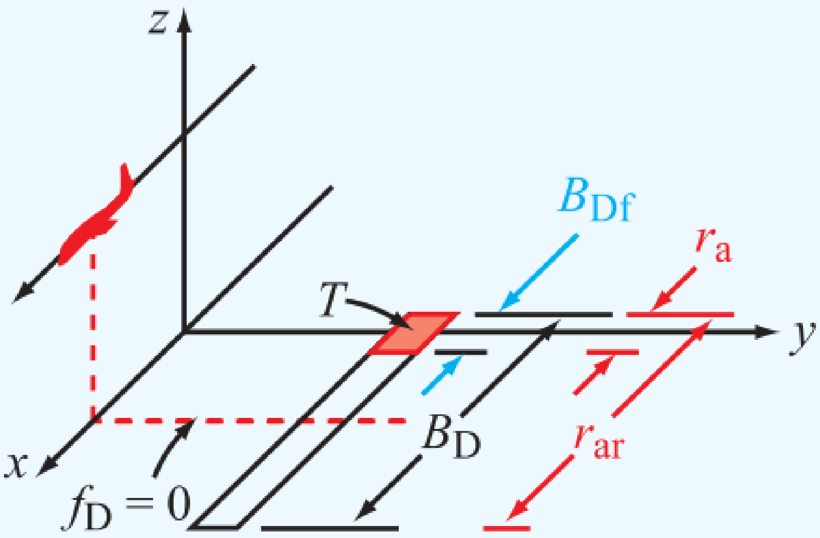
Doppler beam sharpener



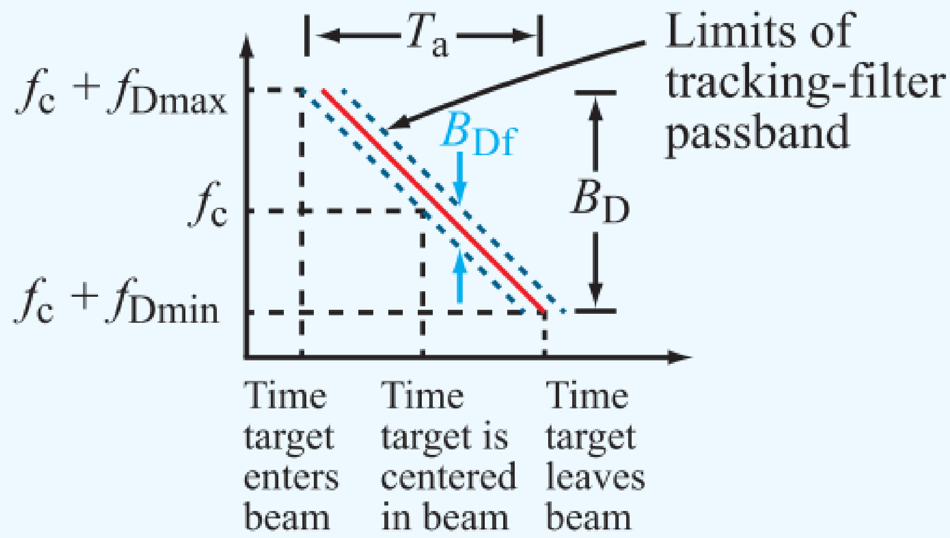
(d) Zero Doppler frequency

(e) Medium negative Doppler frequency

Doppler beam sharpener



(f) High negative Doppler frequency



(g) Frequencies involved

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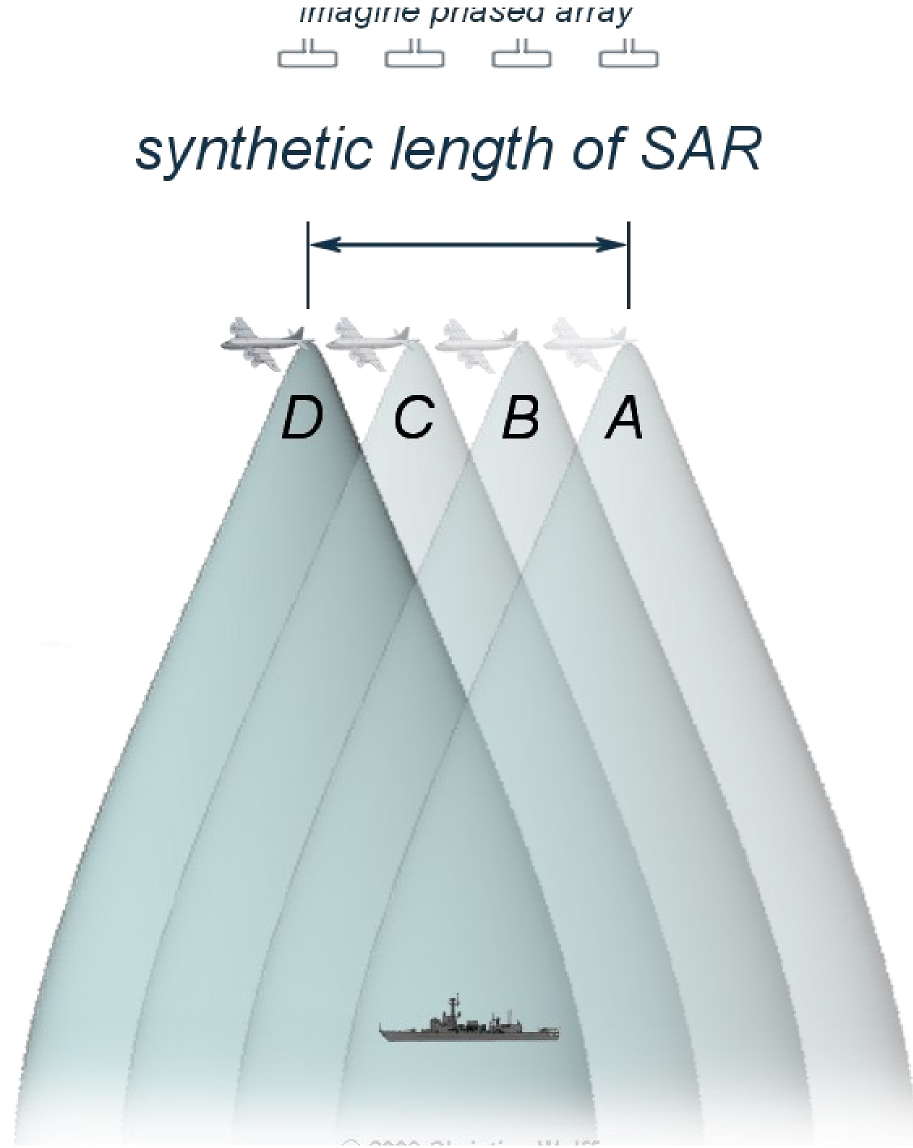
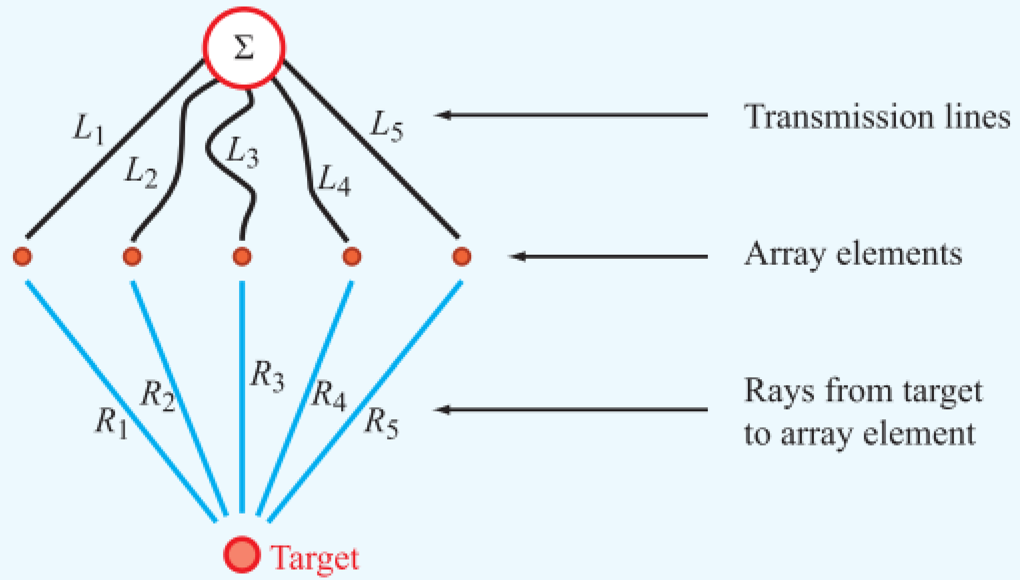
Synthetic Aperture



Synthetic aperture

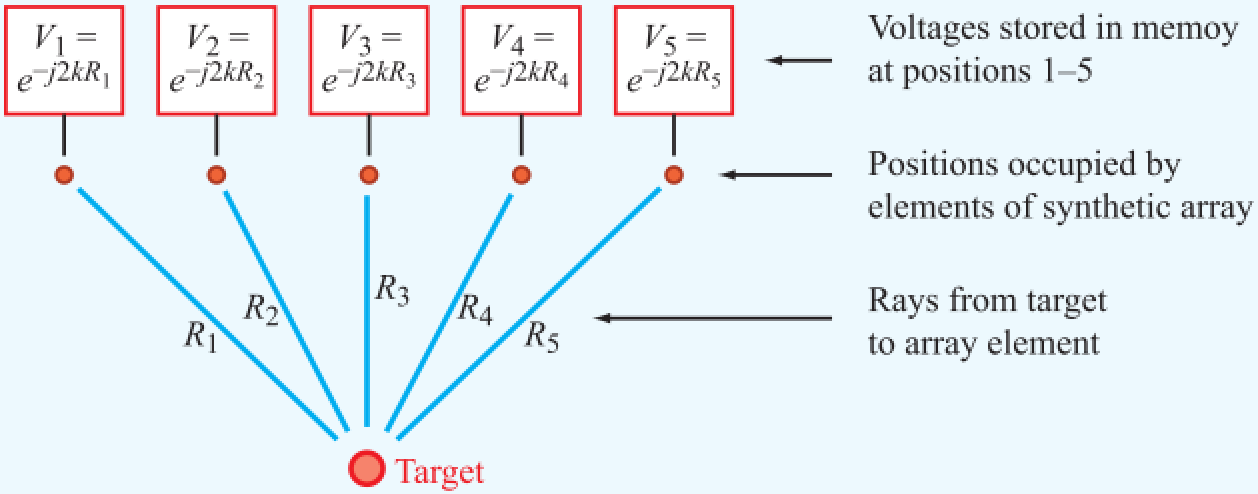


(a) Real-aperture equivalent array focused on target

$L_1 + R_1 = L_2 + R_2 = L_3 + R_3 = L_4 + R_4 = L_5 + R_5$

From: Microwave Radar and Radiometric Remote Sensing, by Ulaby and Long, 2014, with permission.

Synthetic aperture



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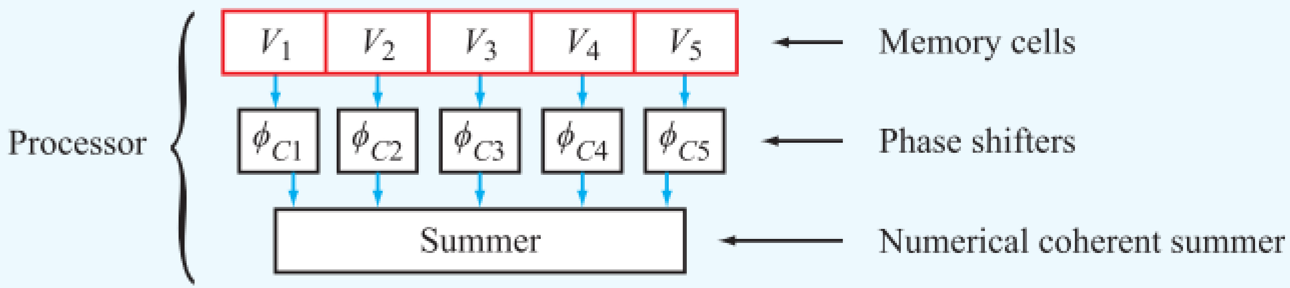
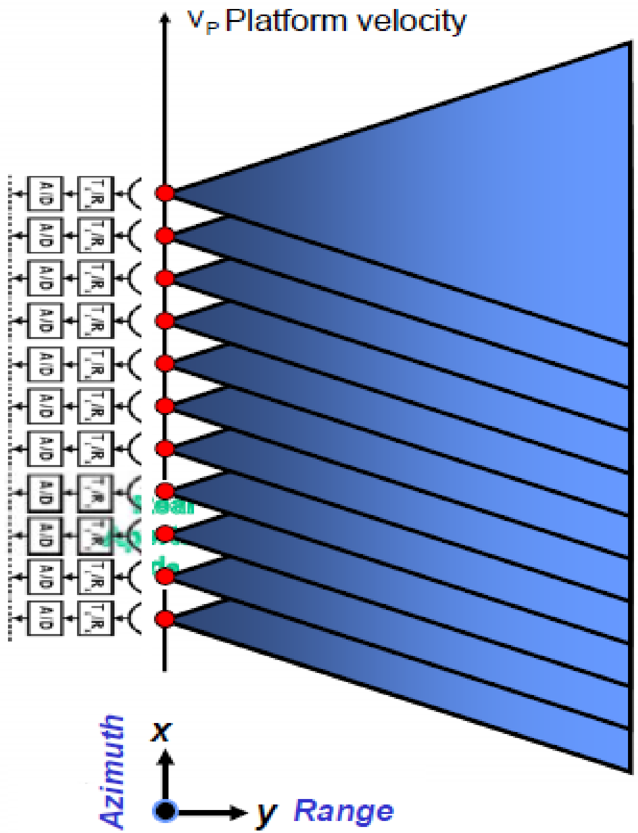
Synthetic aperture



(b) Synthetic-aperture equivalent of (a)

The total phase delay for a signal arriving at the summing point from the target must be the same for each element if the contributions of the different elements are to add in phase; when they do add in phase, the array is said to be focused at the target point.

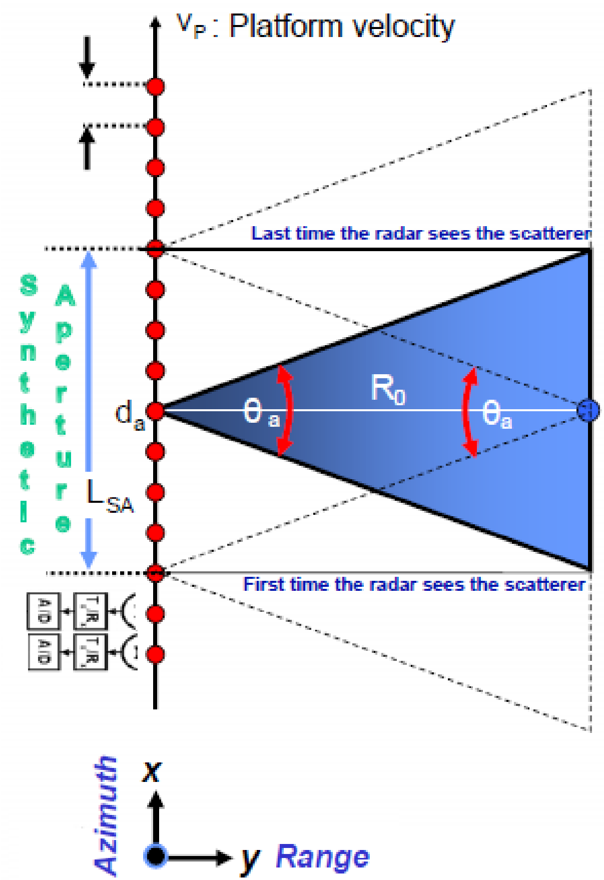
Synthesizing the aperture: acquisition



The real aperture antenna is moving forward with velocity v_P and operates in a pulsed mode

Azimuth resolution of the real aperture at distance R_0: $\delta_a = \theta_a R_0$

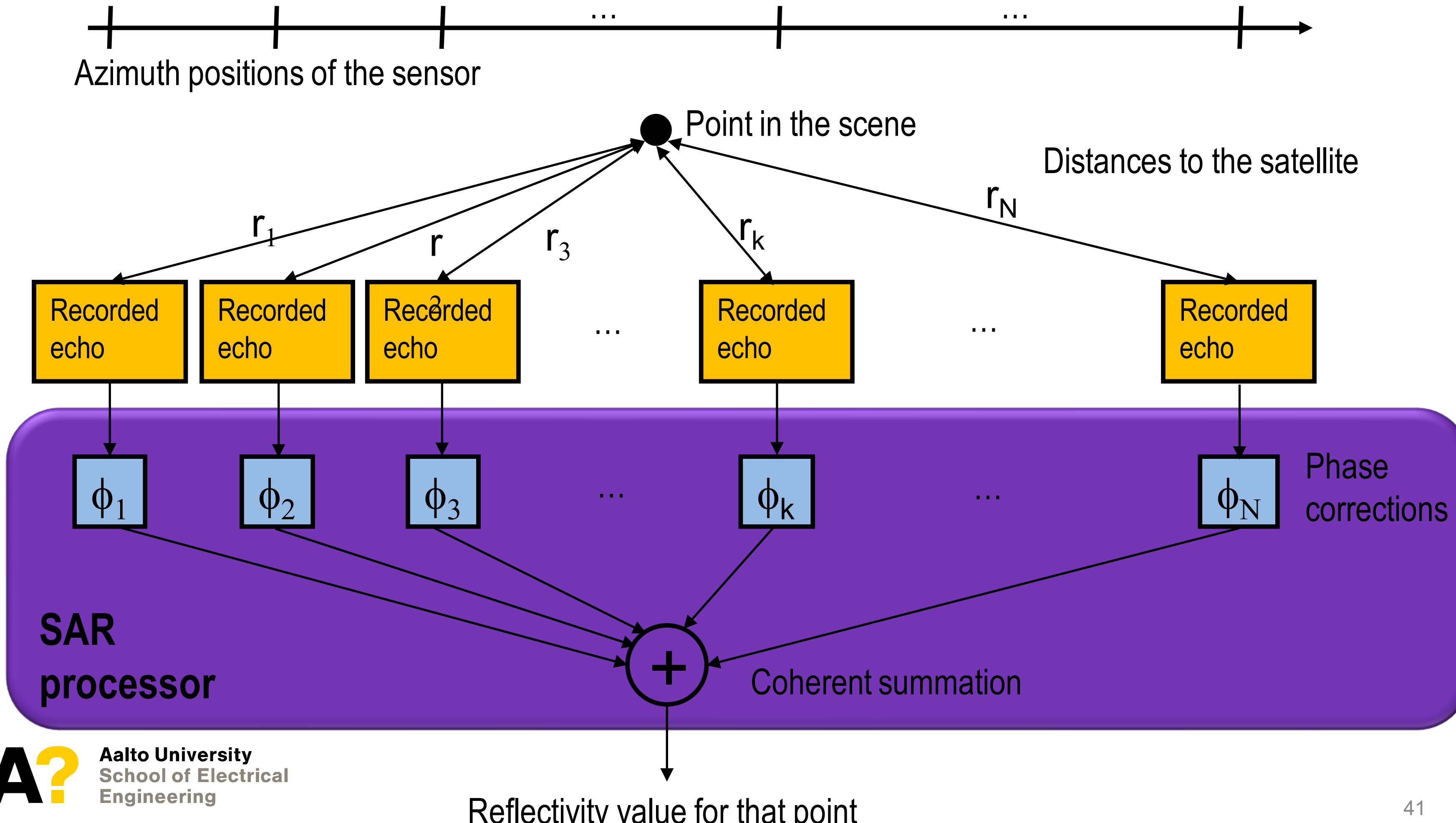
Synthesizing the aperture



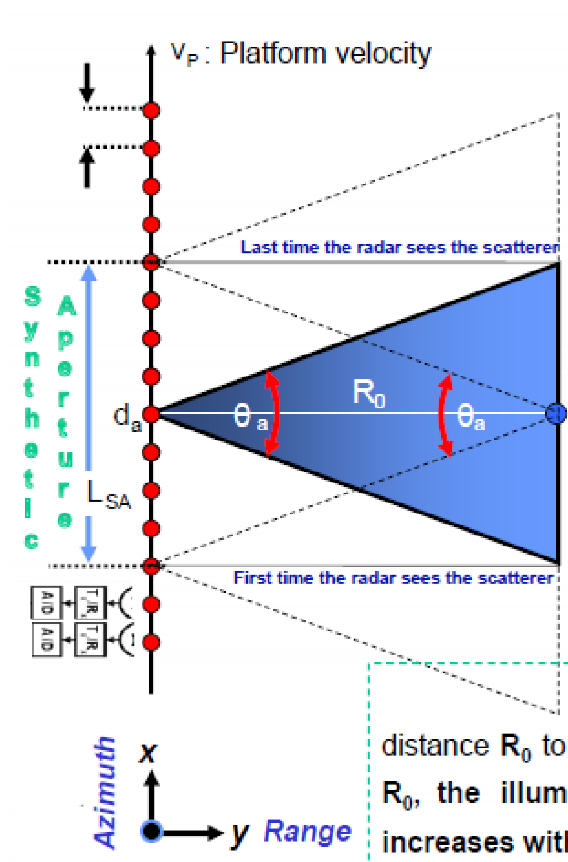
Looking on a scatterer at distance R_0

All echoes received from the scatterer between the first and last echo can be coherently combined to "synthesise" a Synthetic Aperture

Synthesizing the aperture



Synthetic aperture: azimuth resolution



- Angular resolution of synthetic antenna:

$$\theta_{SA} = \frac{\lambda}{2L_{SA}} = \frac{d_a}{2R_0}$$ decreases with distance R_0

- Length of the synthetic aperture (at distance R_0):

$$L_{SA} = \delta_a = \theta_a R_0 = \frac{\lambda}{d_a} R_0$$ increases with R_0

- Illumination time of an scatterer at distance R_0:

$$t_{SA} = \frac{L_{SA}}{v_P} = \frac{\lambda}{d_a}\frac{R_0}{v_P}$$ increases with R_0

- Azimuth resolution: δ_a v_P: velocity of the platform

$$\delta_{SA} = \theta_{SA} R_0 = \frac{d_a}{2}$$ = Half (Real) Antenna Length!

The azimuth resolution is independent on range (i.e. the distance R_0 to the scatterer): **While the angular resolution decreases with R_0, the illumination time (i.e. the length of the synthetic aperture) increases with R_0.**

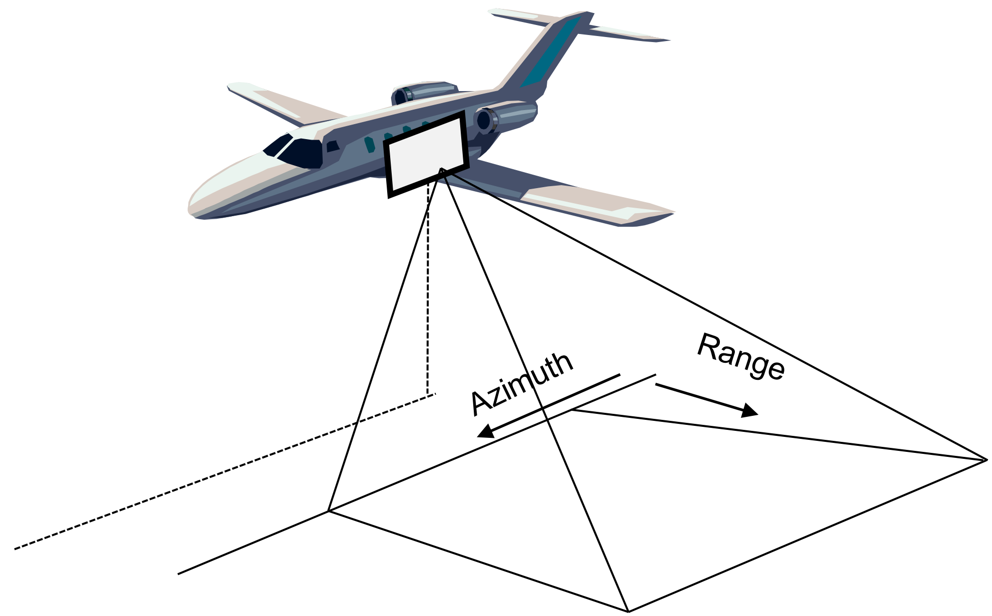
Synthetic Aperture Radar (SAR)

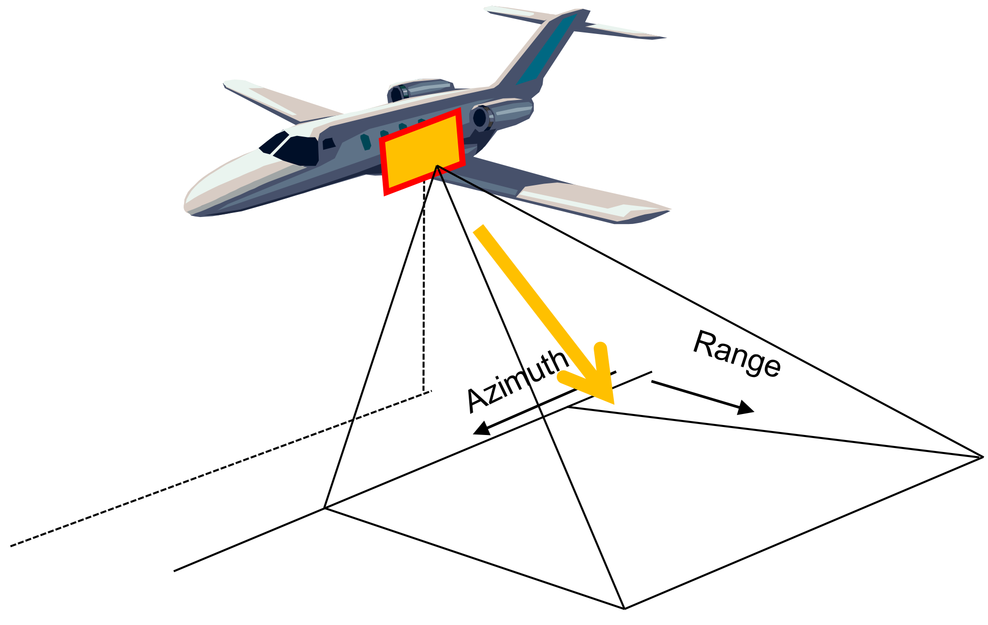
- Resolution is obtained in the image formation (i.e. by processing)
- Range resolution: $\rho_r = \frac{c}{2B}$

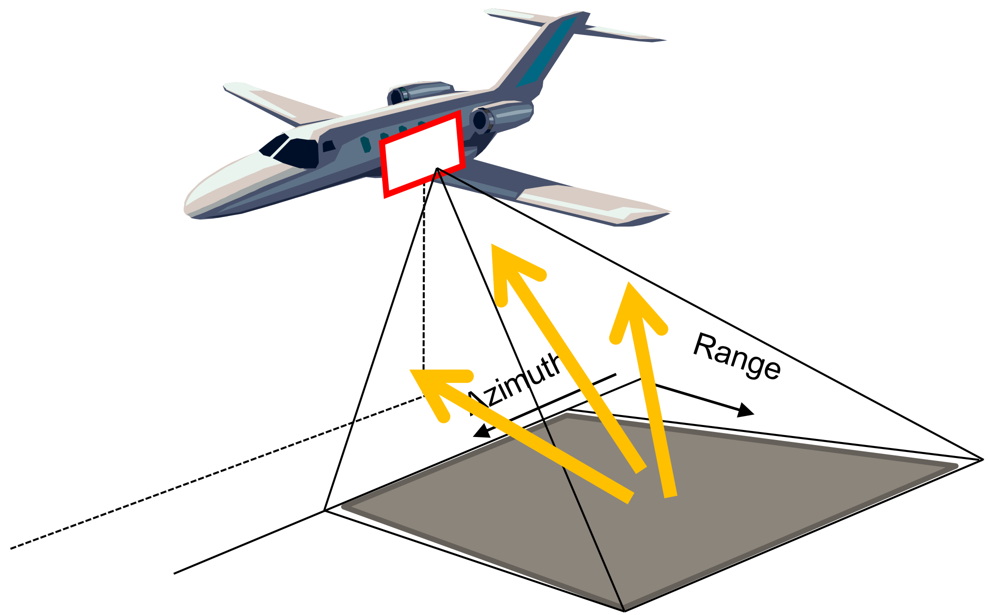
  ← Signal bandwidth

- Azimuth resolution: $\rho_a = \frac{l_a}{2}$ ← Antenna size in azimuth direction

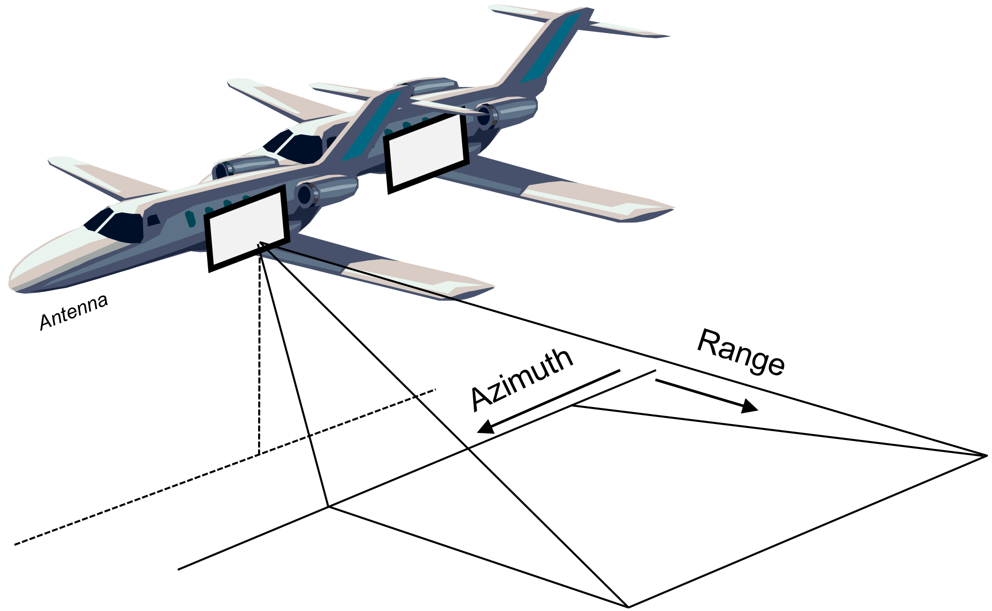
- Measurements must be coherent to provide this functionality

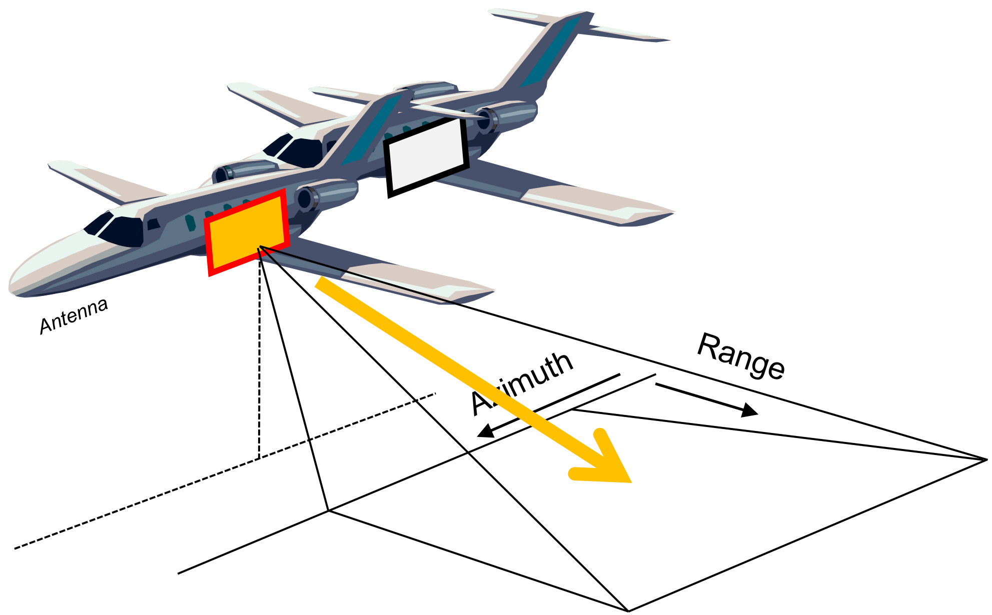

Azimuth
Range

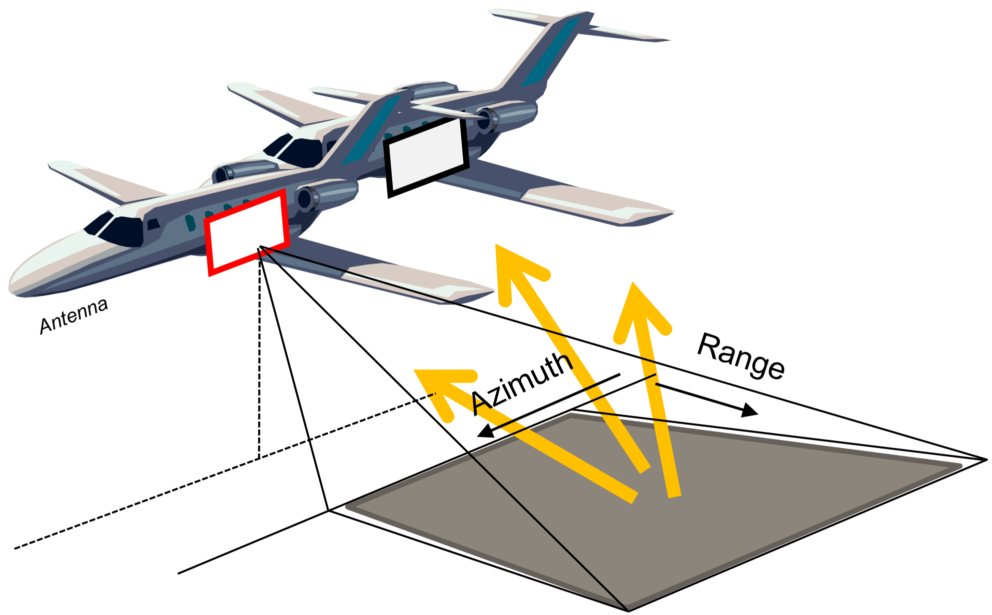

Azimuth
Range

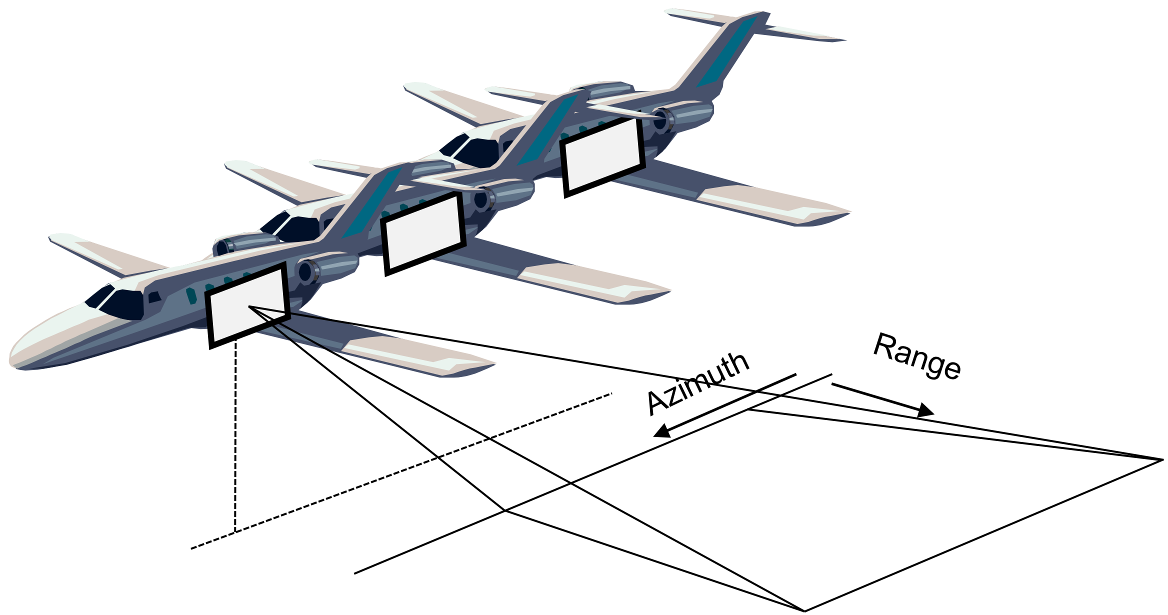


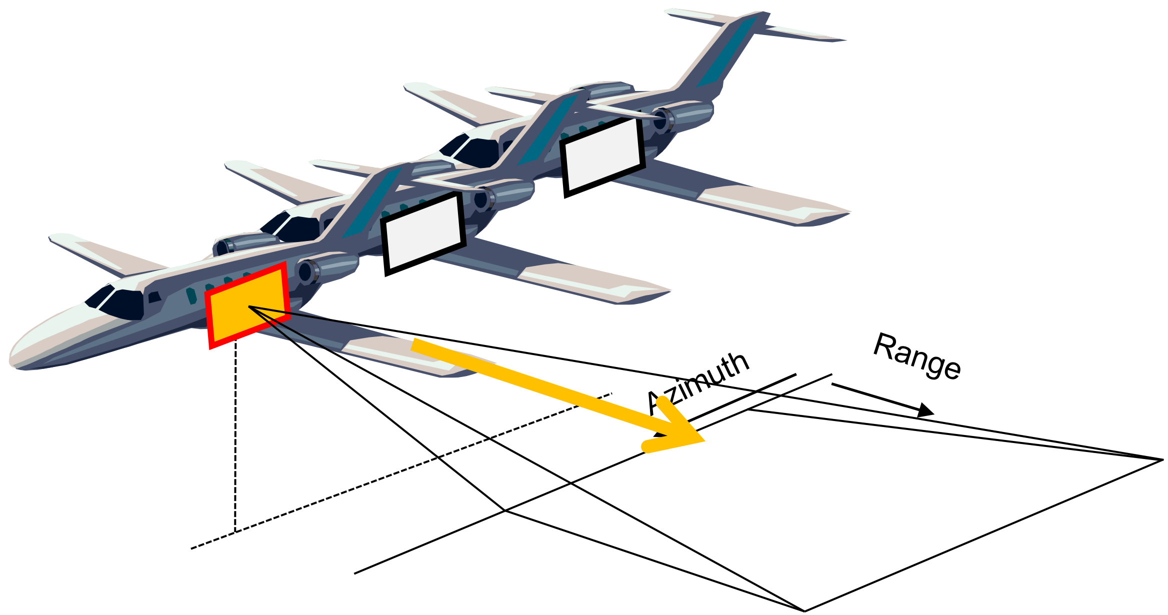
Range
Azimuth

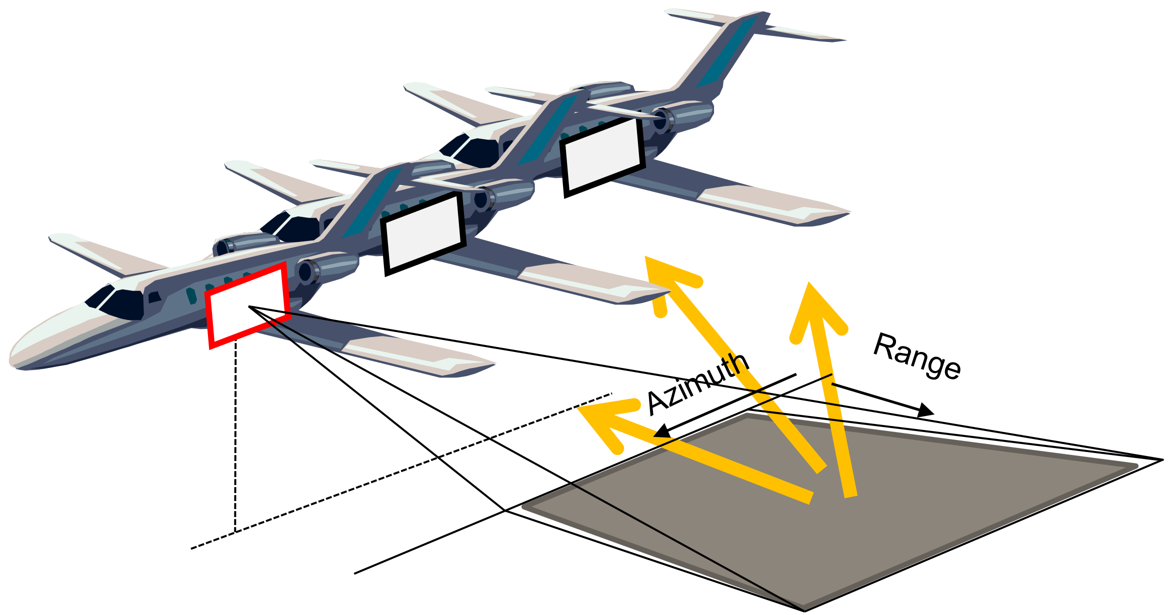

Antenna
Azimuth
Range


Antenna
Range
Azimuth

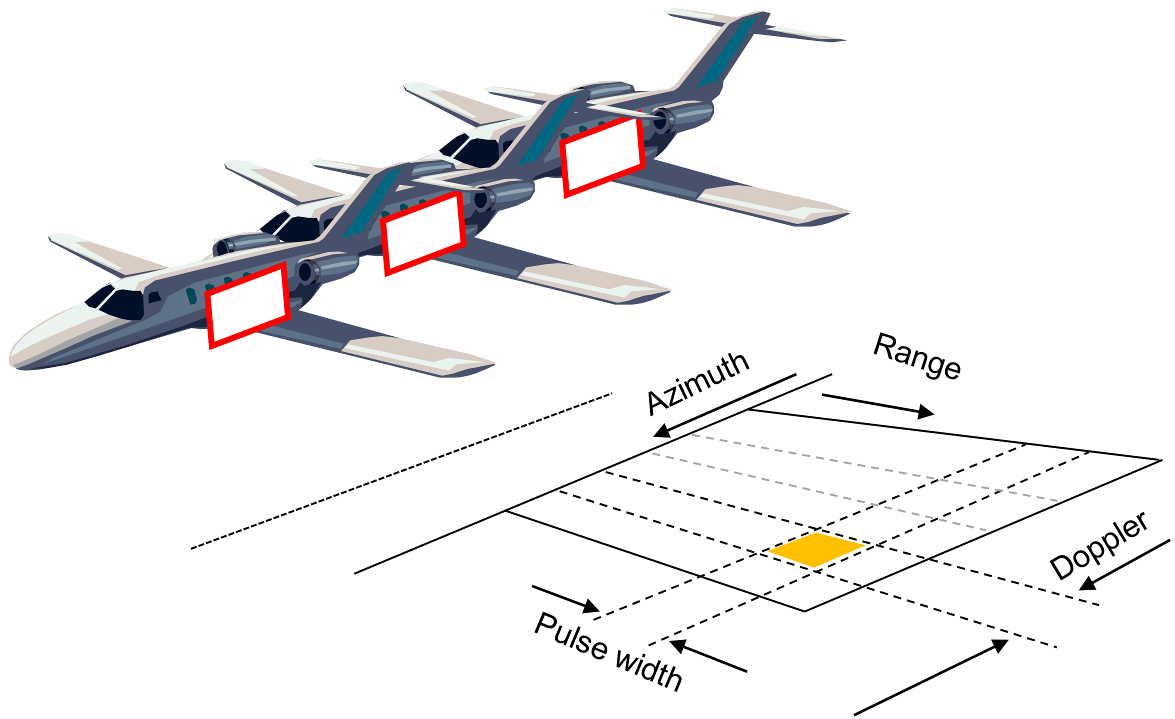

Antenna
Azimuth
Range

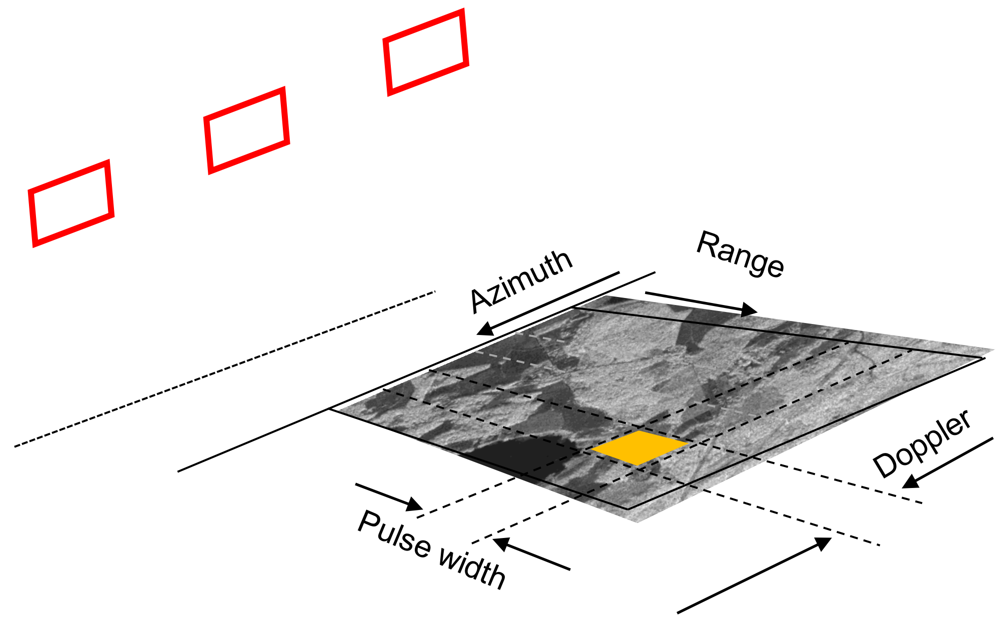

Range
Azimuth


Azimuth
Range



Azimuth
Range

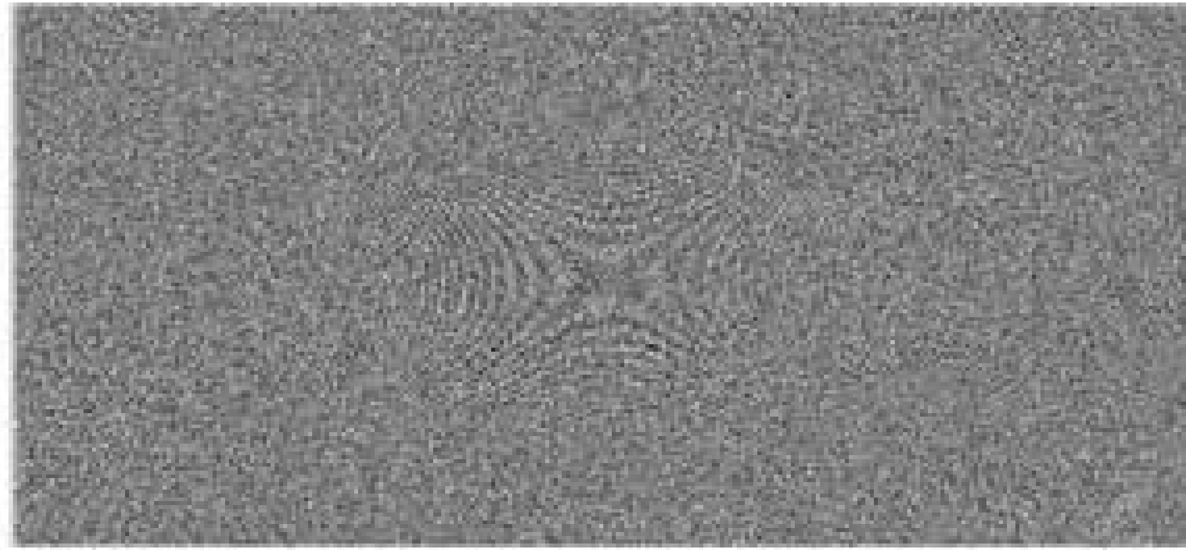

Azimuth
Range
Doppler
Pulse width



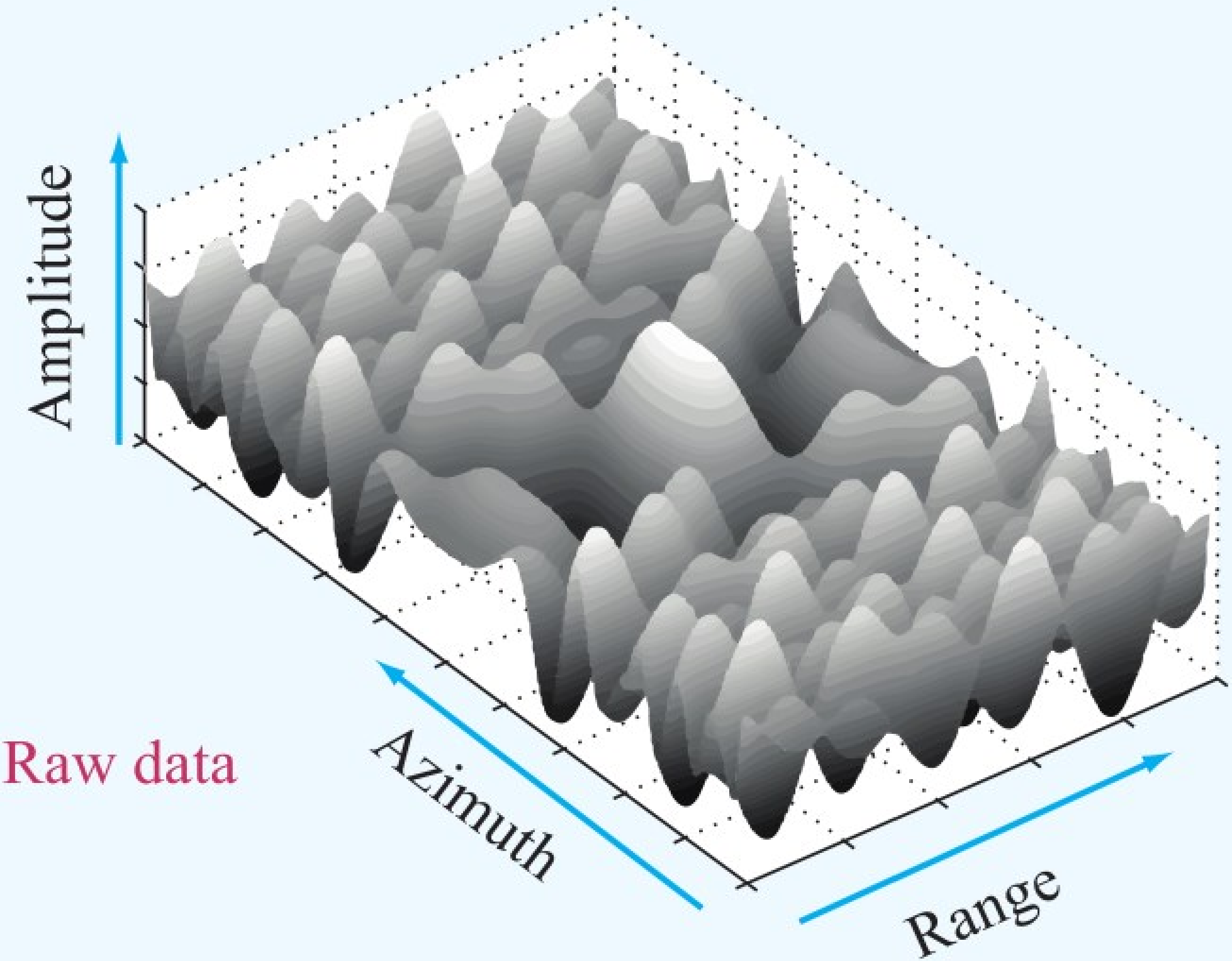
Range
Azimuth
Doppler
Pulse width


F-SAR DLR

Raw SAR image



Focused SAR image



(a) Raw data

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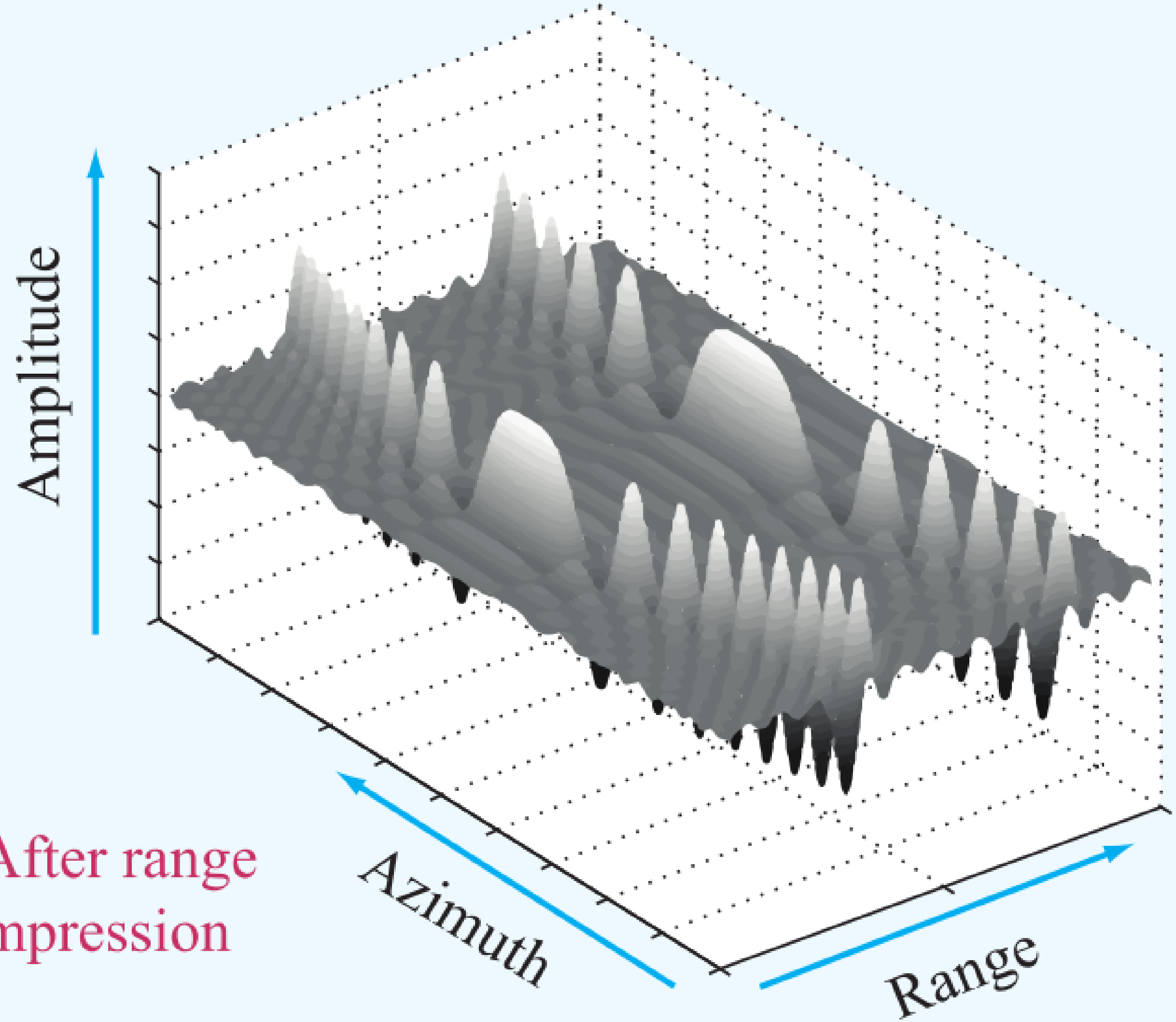
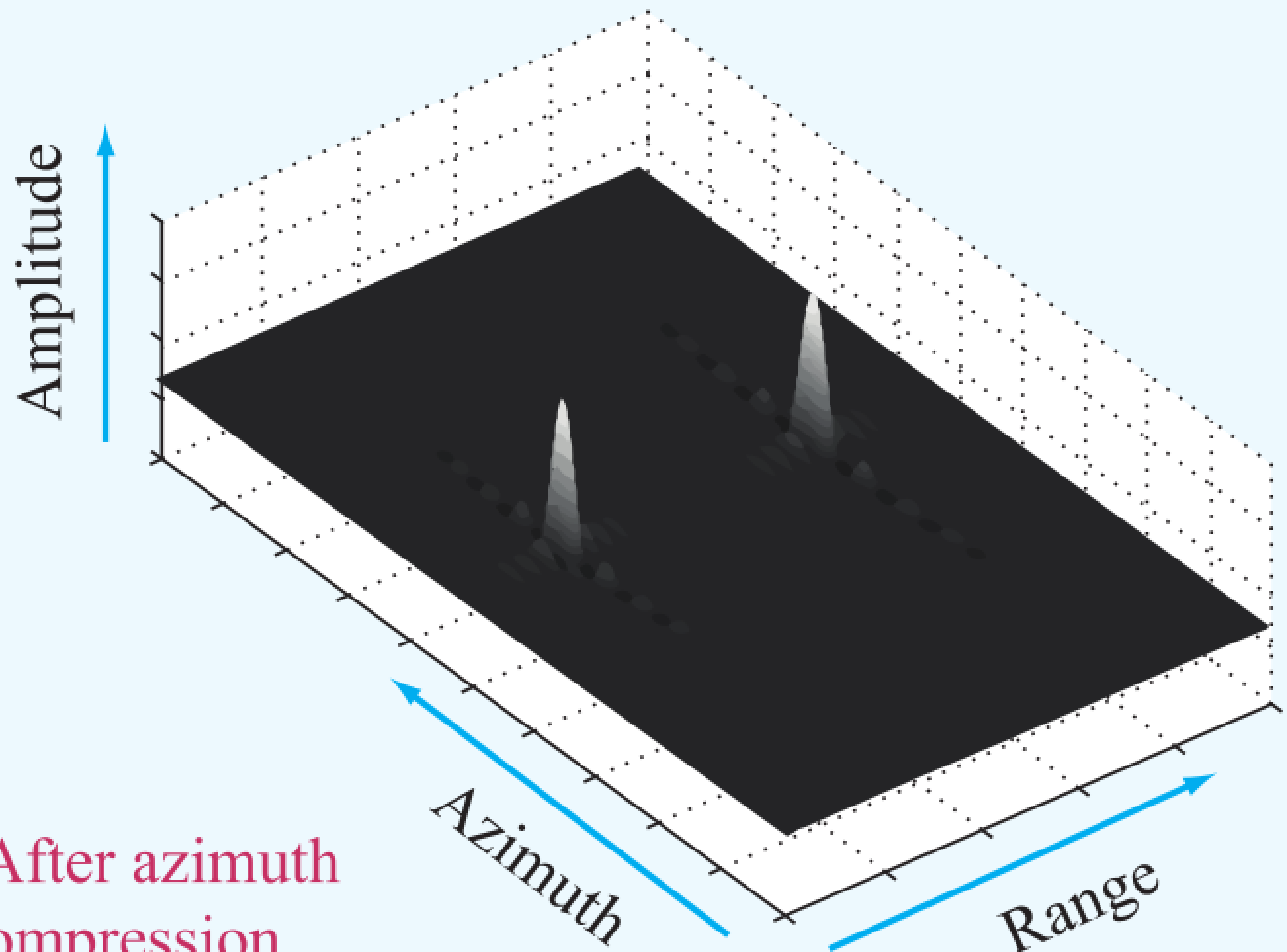


(b) After range compression



(c) After azimuth compression

SAR image Range-Doppler Algorithm

First, range compression is accomplished for a chirped radar signal by chirp matched filter.

At this stage, data are arranged in range lines, which should be rearranged into azimuth lines for the latter process.

This data rearrangement process is called corner turning.

Then, azimuth compression is achieved with an azimuth filter generated separately.

Processed results are formed into an image.

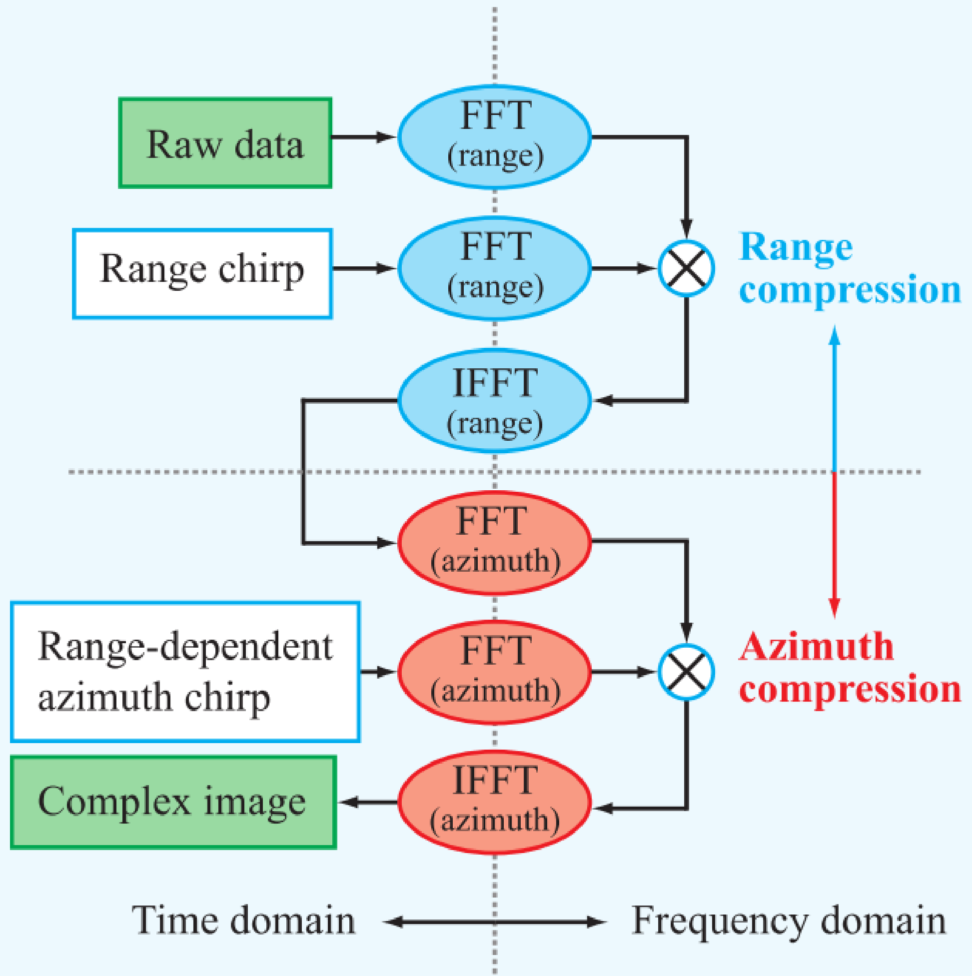


Figure 14-37: Signal-processing diagram for the range-Doppler algorithm.

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Understanding Radar Image

Image by ICEYE radar

Different radars measure the same property

Narrow beam scatterometer, real aperture radar and synthetic aperture radar measure same parameter.

In radar remote sensing, the differential scattering coefficient σ_{pq}^{0} is the critical **link between** the **radar** as a sensing instrument **and** the **intended application**.

$$\langle P_p^{\mathrm{r}}(\theta)\rangle = \left[\frac{P_q^{\mathrm{t}}\lambda^3\, G^2(\theta)\, c\tau}{2l(4\pi)^3 R^3 \sin\theta}\right]\cdot \sigma_{pq}^{0}(\theta),$$

(real-aperture radar)

$$\langle P_p^{\mathrm{r}}(\theta)\rangle = \left[\frac{P_q^{\mathrm{t}}\lambda^2\, G^2(\theta)\, lc\tau}{4(4\pi)^3 R^4 \sin\theta}\right]\cdot \sigma_{pq}^{0}(\theta).$$

(synthetic-aperture radar)

$$\langle P_p^{\mathrm{r}}(\theta)\rangle = K_{pq}\, \sigma_{pq}^{0}(\theta),$$

(transmit *q* / receive *p* polarization)

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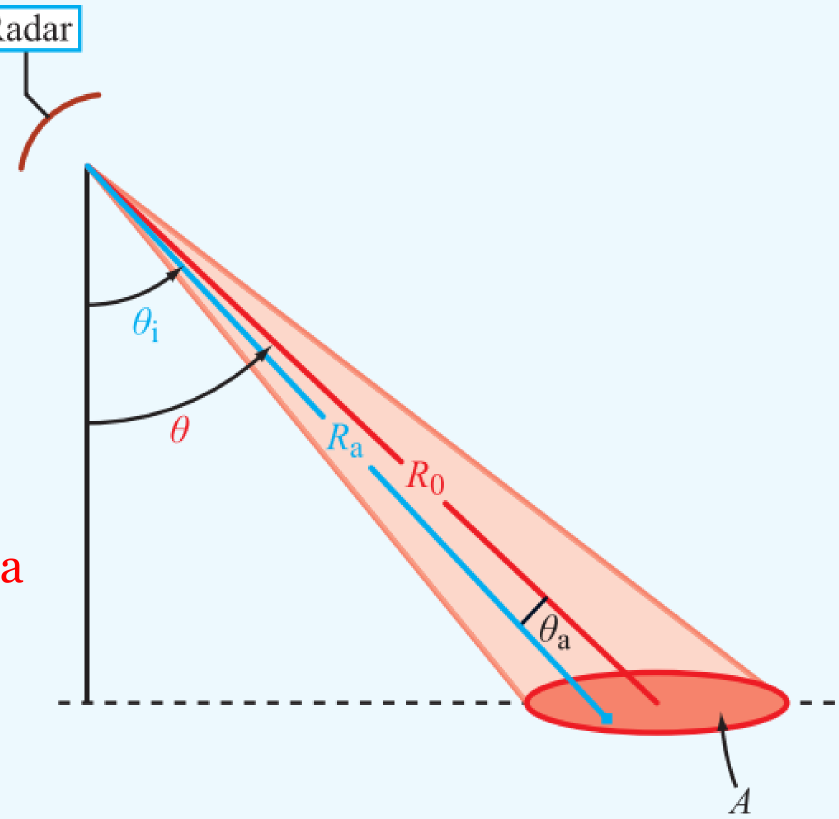
Distributed targets and σ_o

Installing radar reflector

When imaging land, the target is not point target!

$$P_p^{\rm r}(\theta) = \iint_A \frac{P_q^{\rm t}\, G^2(\theta_{\rm a},\phi_{\rm a})\,\lambda^2}{(4\pi)^3 R_{\rm a}^4} \cdot \sigma_{pq}^0 \, dA$$

$$\sigma_{pq}^0 = \sigma_{pq}/A$$



- backscattering cross section per unit area
- backscattering coefficient
- radar reflectivity

are the same parameter

From: Microwave Radar and Radiometric Remote Sensing, by Ulaby and Long, 2014, with permission.

Radar reflectivity measures
(normalized to different area projections)

Beta_o, β_o

Slant range backscattering coefficient (measured)

Sigma_o, σ_o

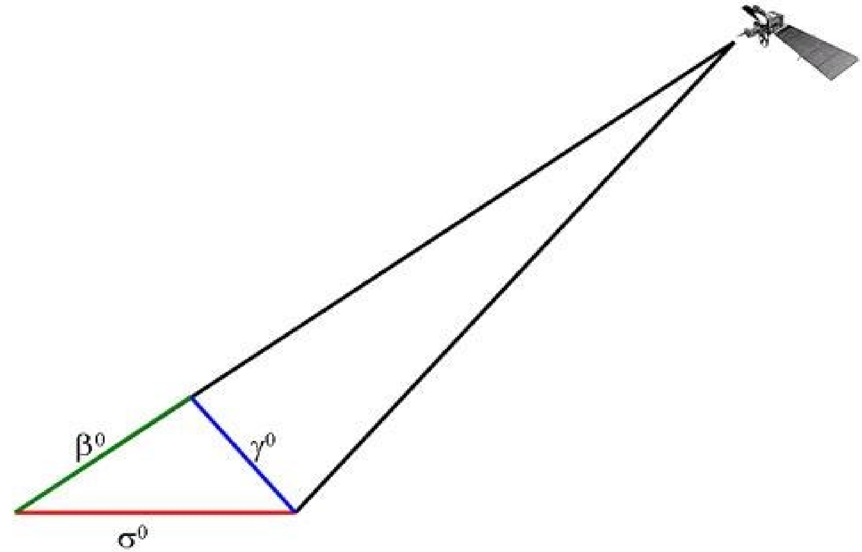
Ground area normalized backscattering coefficient (normalized by ground)

$$\sigma_0 = \beta_0 \sin(\theta)$$

Gamma_o, γ_o

used sometimes in calibration (normalized by antenna cone)

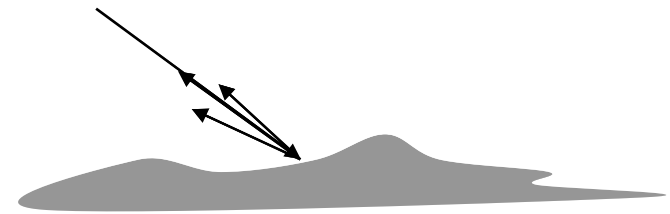
$$\gamma_0 = \beta_0 \tan(\theta)$$



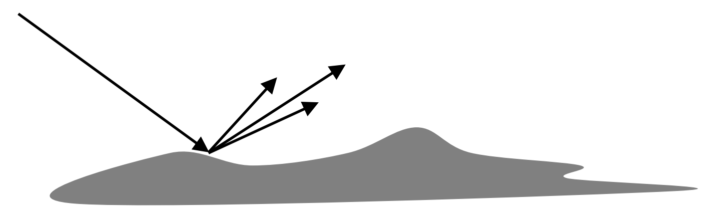
Radar cross section, interpretation of σ_0

Normalized radar cross-section (backscattering coefficient) is given by:

$$\sigma_0(dB) = 10\log_{10}\left(\frac{received\,energy\,by\,the\,sensor}{energy\,if\;reflected\,isotropically}\right)$$



The backscattered coefficient can be a positive number if there is a focusing of backscattered energy towards the radar



The backscattered coefficient can be a negative number if there is a focusing of backscattered energy way from the radar (e.g. smooth surface)

Measured values

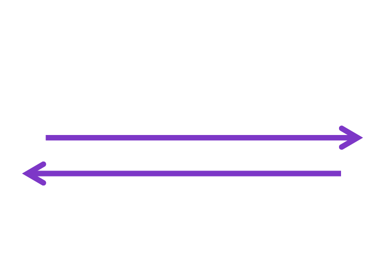
- “Typical” values of backscattering coefficient:

Values	Scenes
$\sigma_0 > 0$ dB	Man-made objects, urban areas Slopes facing the radar
-10 dB $< \sigma_0 <$ 0 dB	Very rough surfaces Forests (dense vegetation)
-20 dB $< \sigma_0 <$ -10 dB	Rough surfaces (sea with wind) Agricultural crops
$\sigma_0 <$ -20 dB	Calm water Smooth surfaces (roads) Very dry ground (sand)

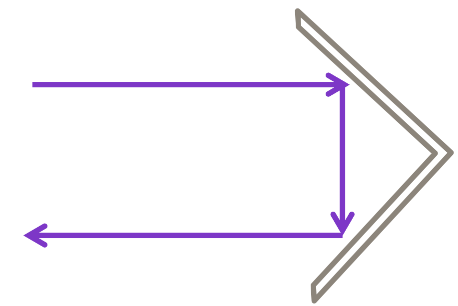
CAUTION: They are very dependent on frequency band and incidence angle

Reflections

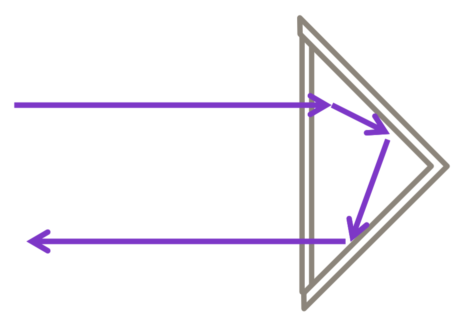
Single bounce

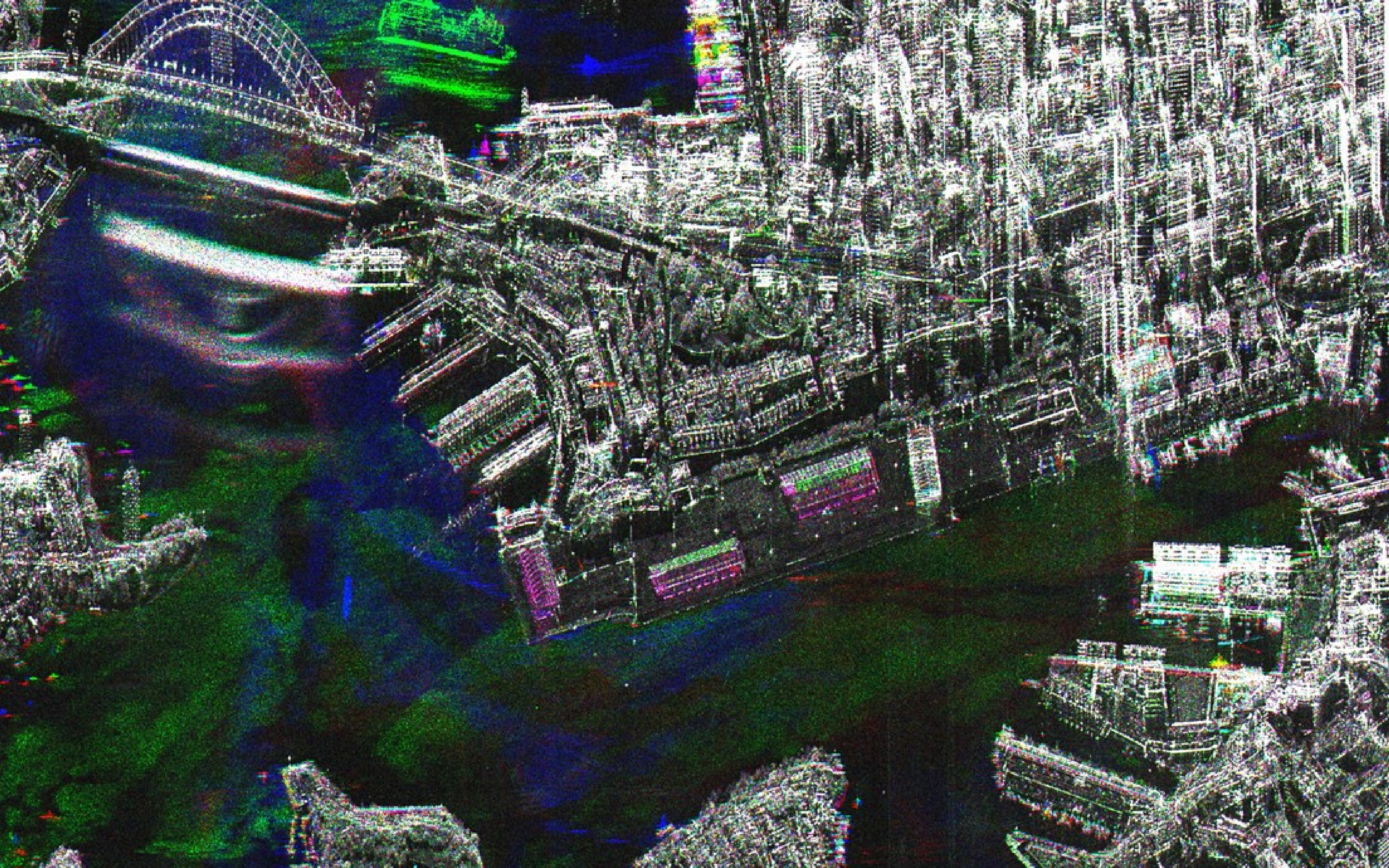


Double bounce



Triple bounce (corner reflector)





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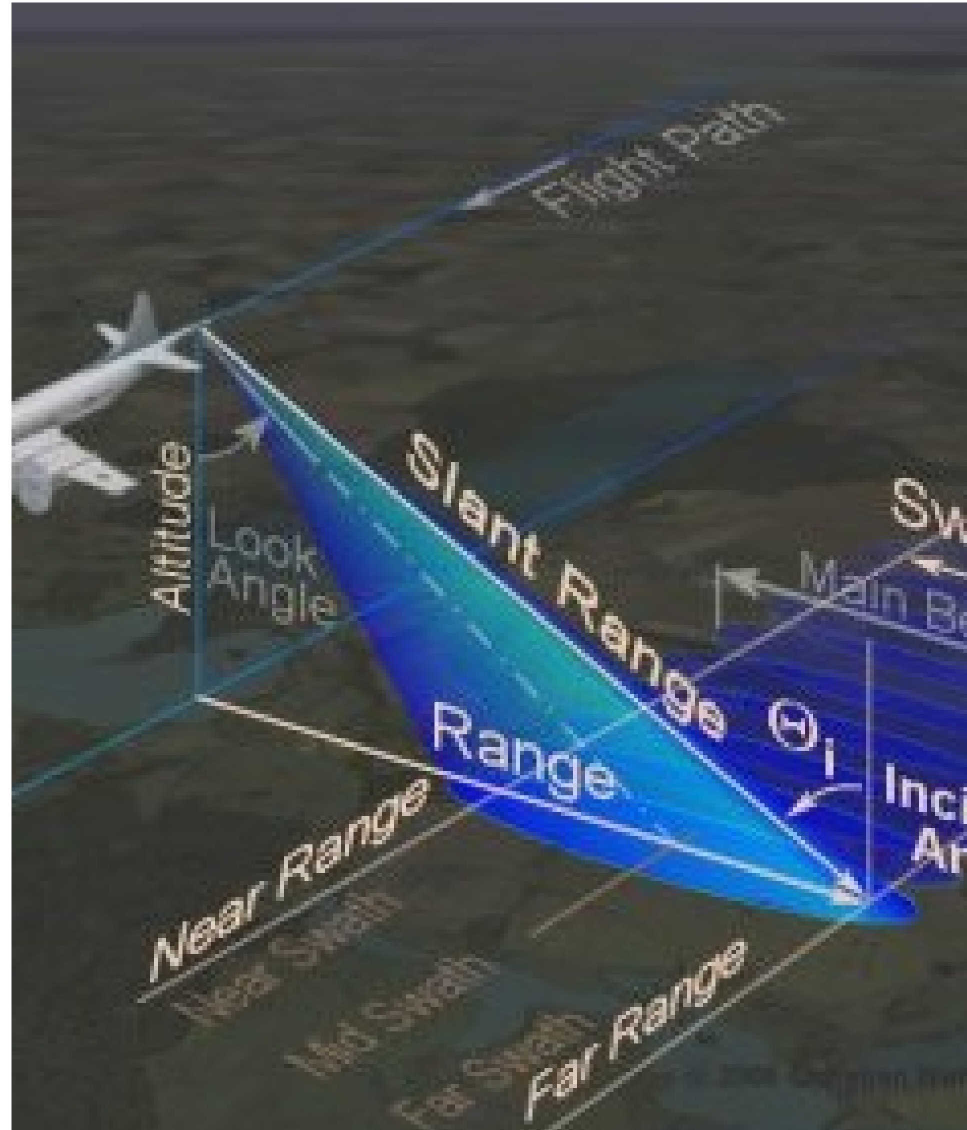
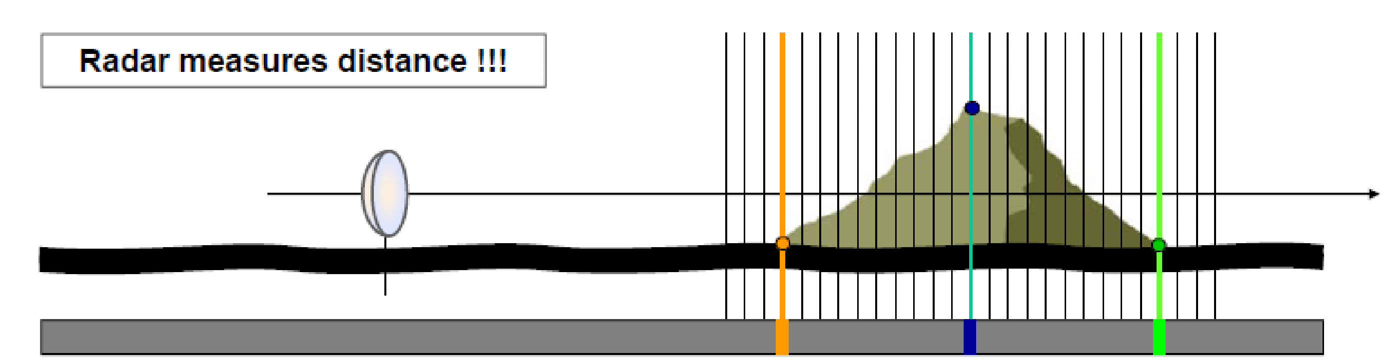
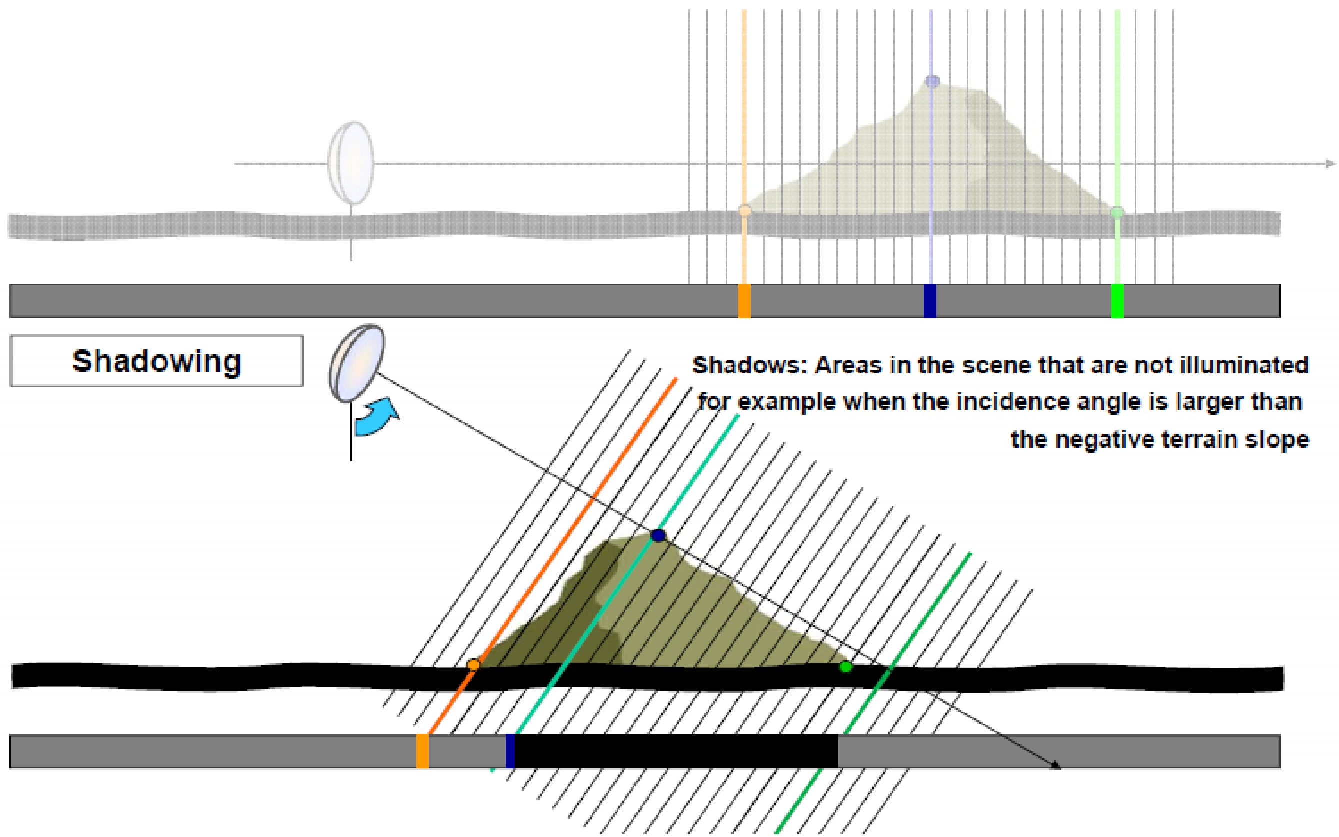
Imaging geometry effects and distortions



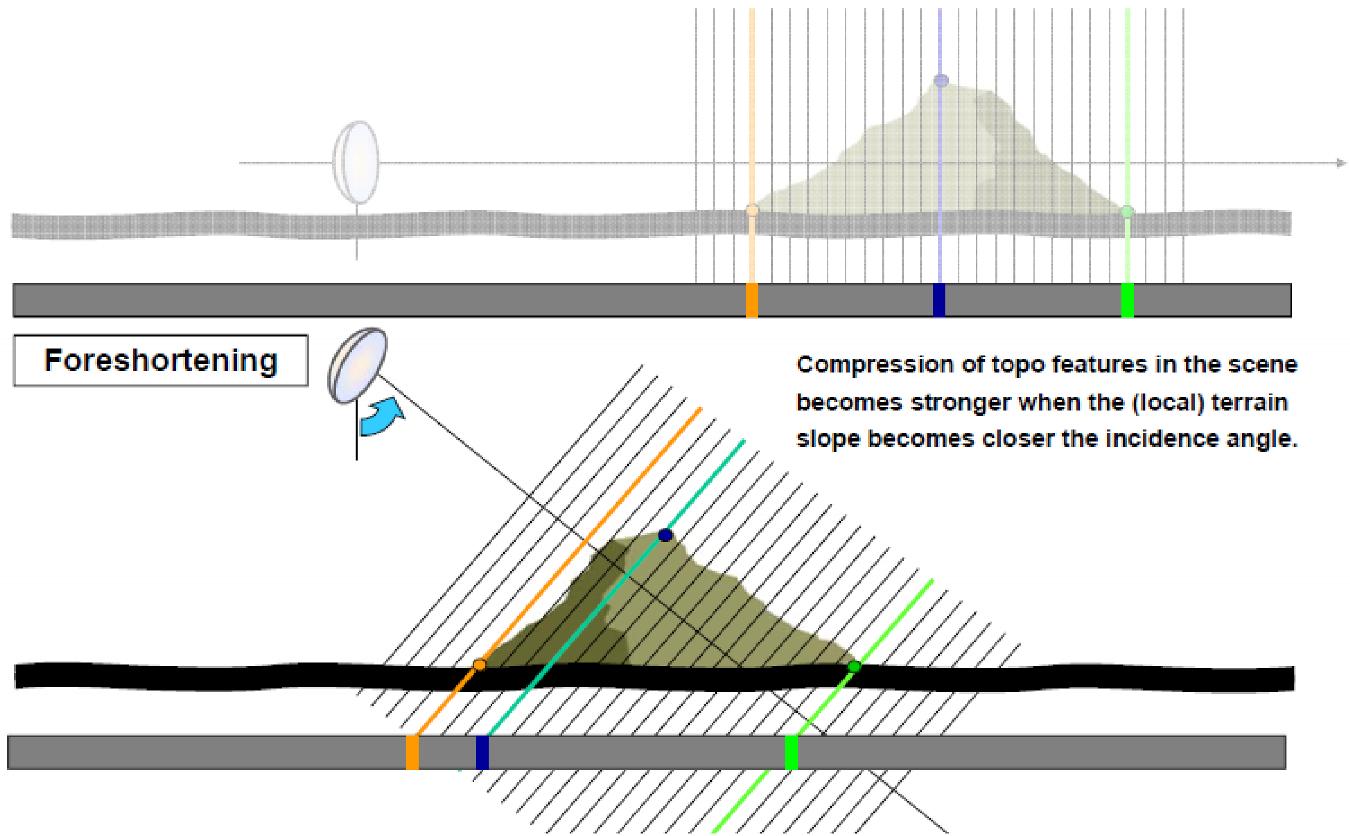
SAR geometrical distortions



SAR geometrical distortions

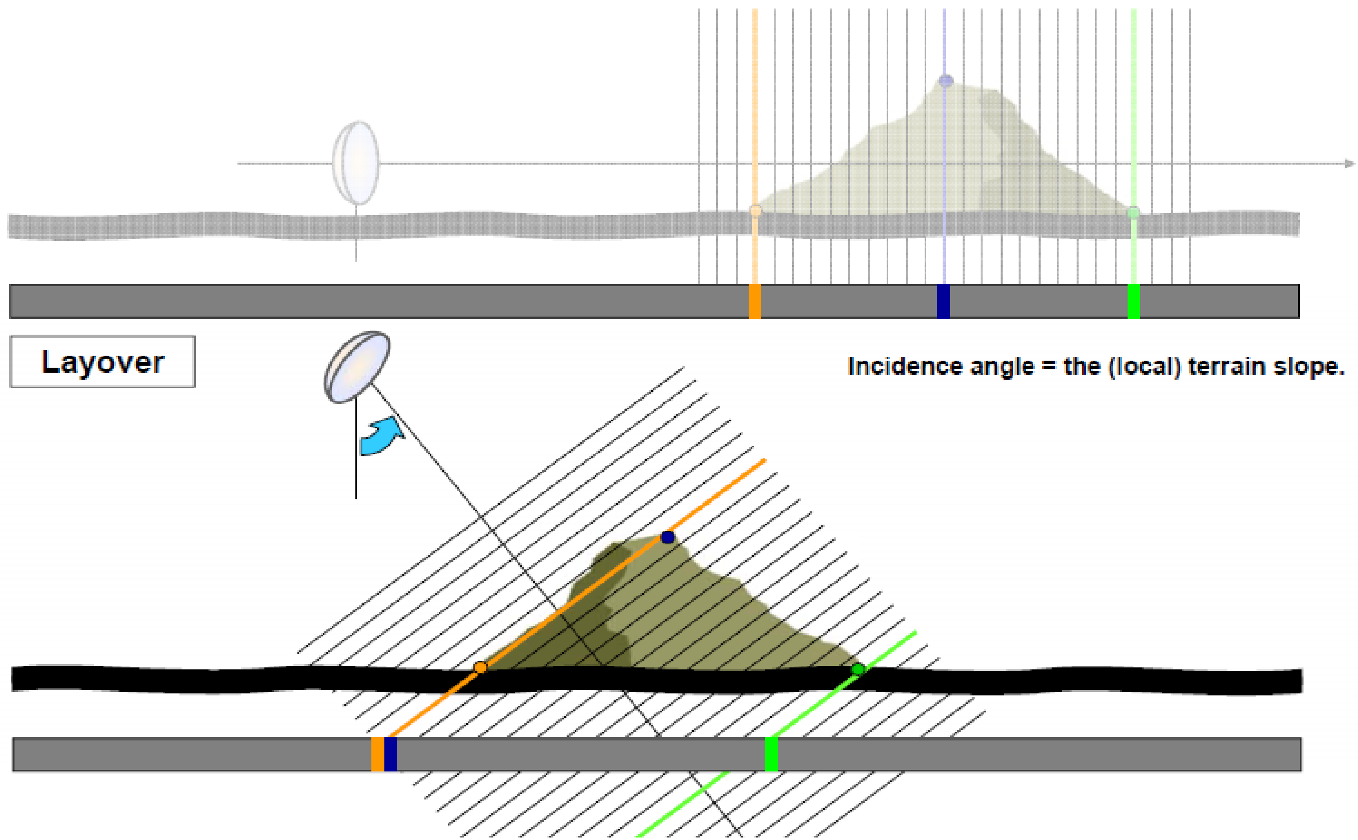


SAR geometrical distortions

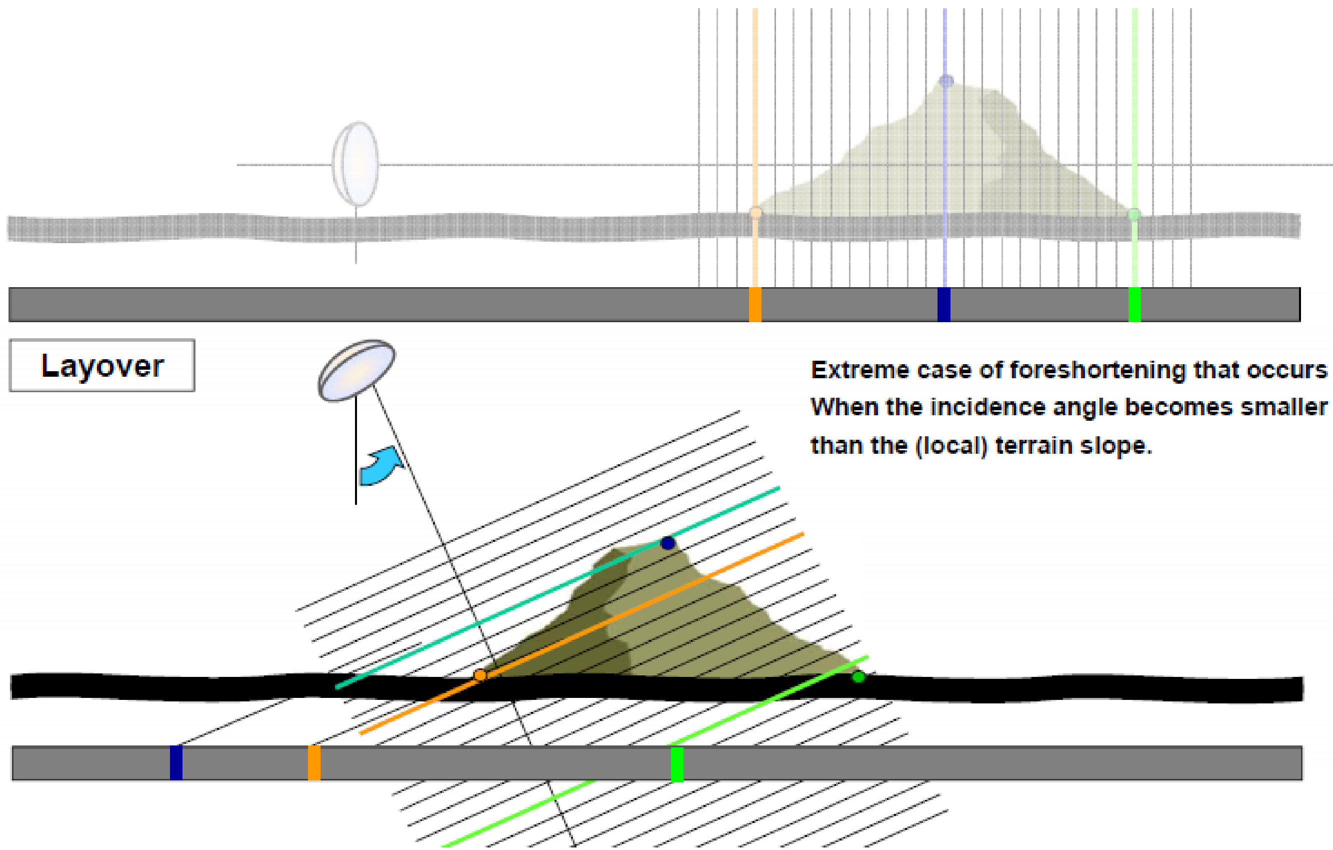


Compression of topo features in the scene becomes stronger when the (local) terrain slope becomes closer the incidence angle.

SAR geometrical distortions

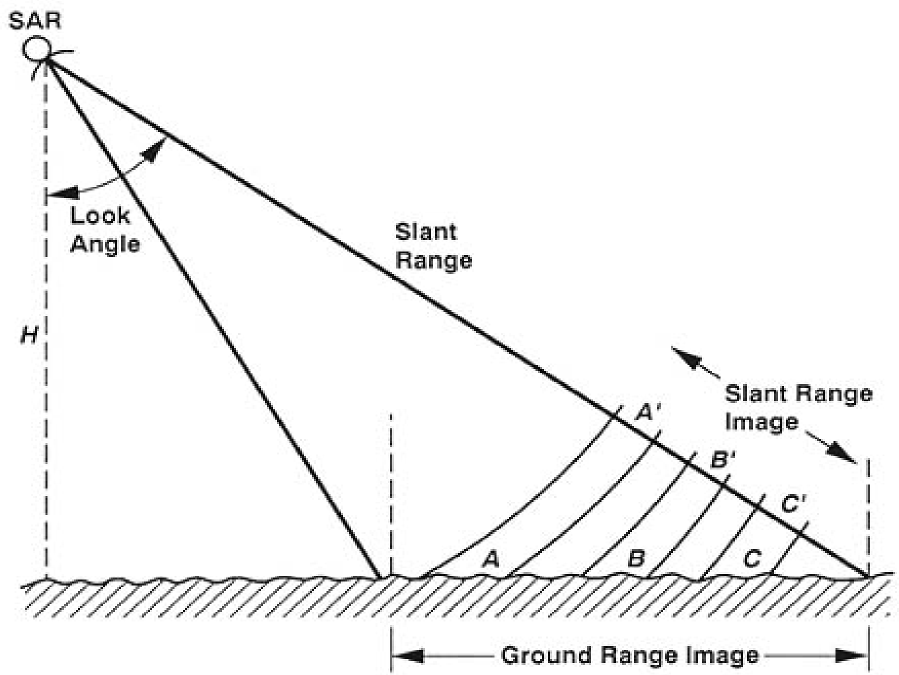


SAR geometrical distortions

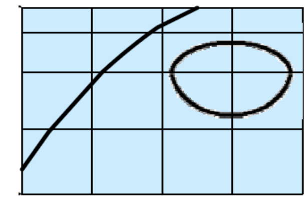


Extreme case of foreshortening that occurs When the incidence angle becomes smaller than the (local) terrain slope.

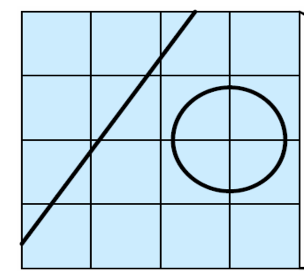
Slant Range vs. Ground Range



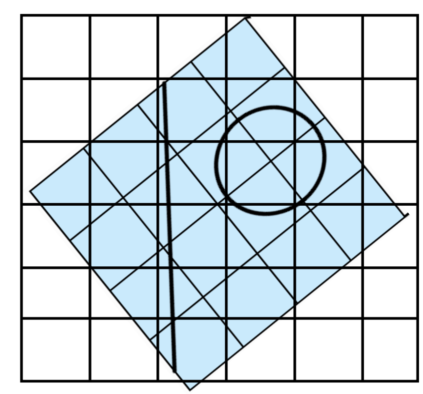
Slant range



Ground range

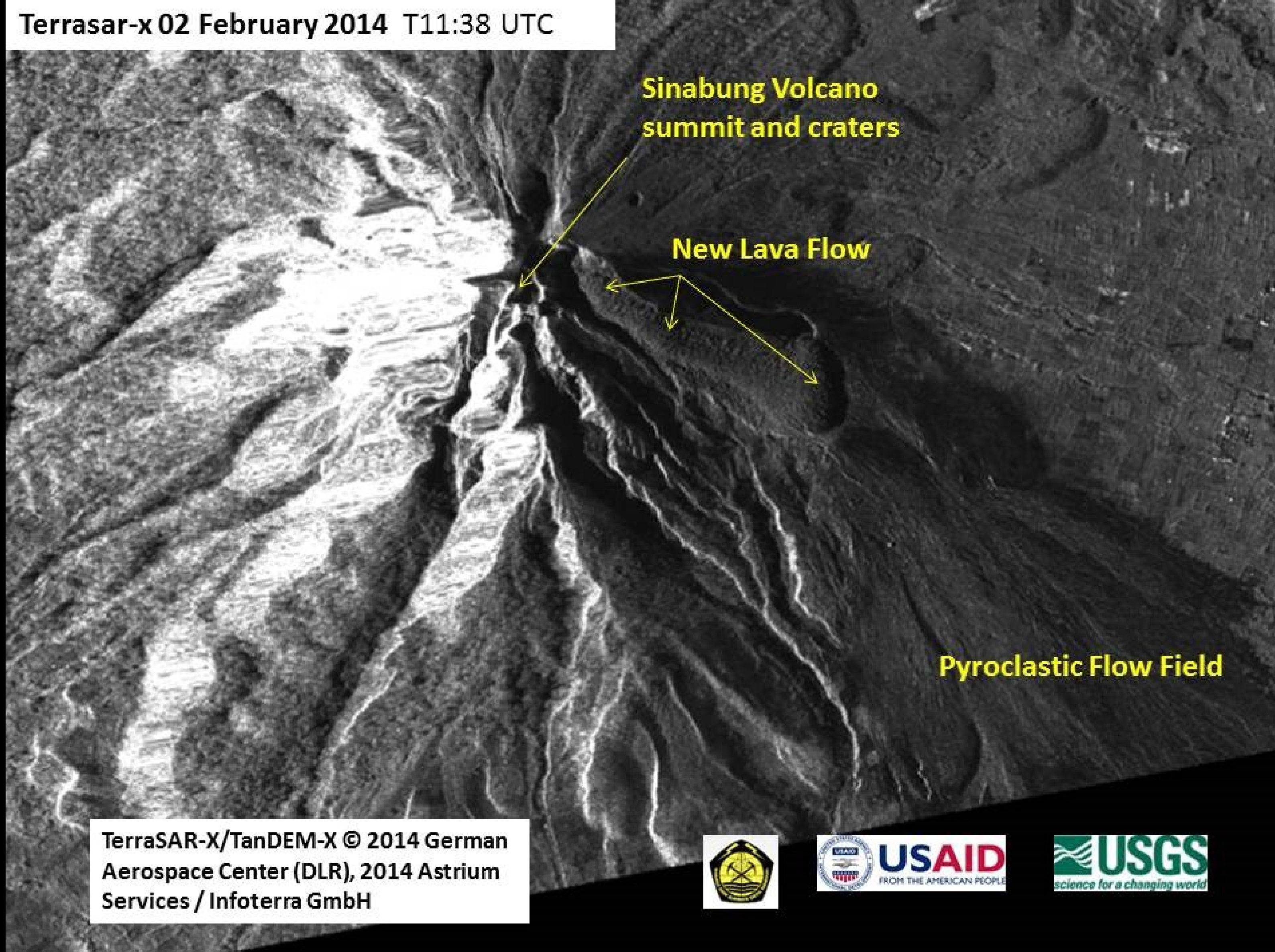


Geocoded



- Slant range – image in SAR coordinates
- Ground range – range direction projected to flat earth
- Geocoded – image in geocoordiantes

http://history.nasa.gov/JPL-93-24/ch5.htm
NASA: Guide to Magellan Image Interpretation
Chapter 5. Radar Interactions With Geologic Surfaces
Tom G. Farr



Terrasar-x 02 February 2014 T11:38 UTC
Sinabung Volcano summit and craters
New Lava Flow
Pyroclastic Flow Field
TerraSAR-X/TanDEM-X © 2014 German Aerospace Center (DLR), 2014 Astrium Services / Infoterra GmbH
USAID
FROM THE AMERICAN PEOPLE
USGS
science for a changing world

Q?

Backscattering coefficient of the target is 2 dB, what kind of target can be in question?

Backscattering coefficient of the target is 0 dB, what kind of target can be in question?

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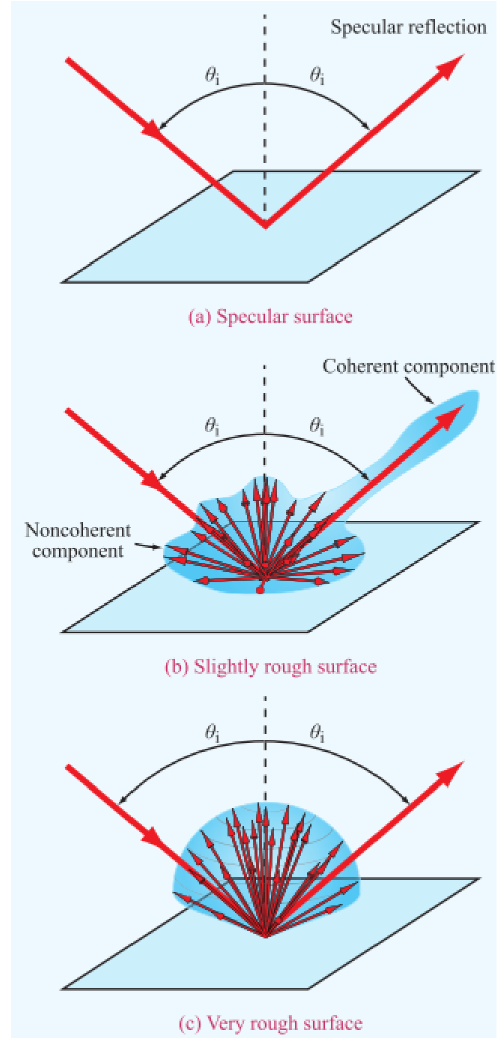
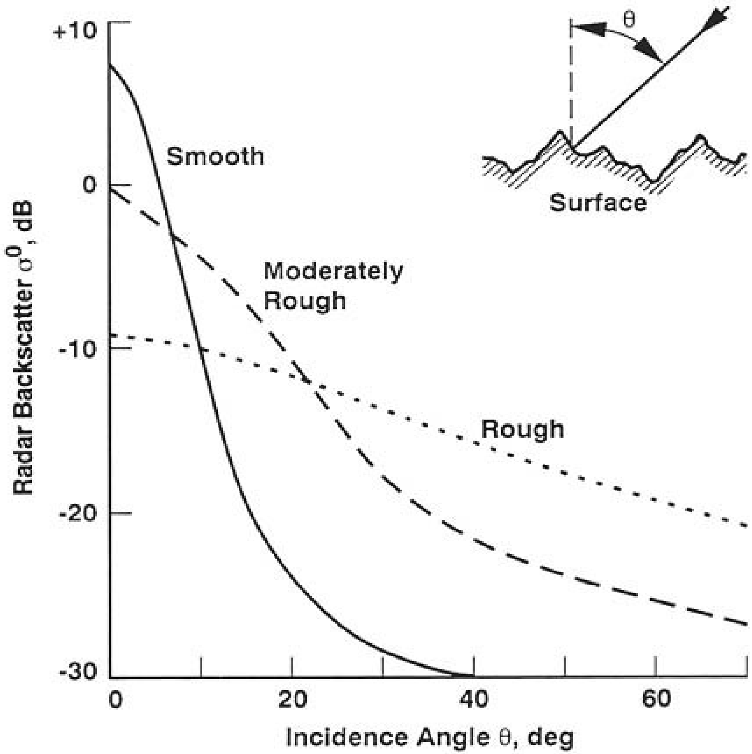
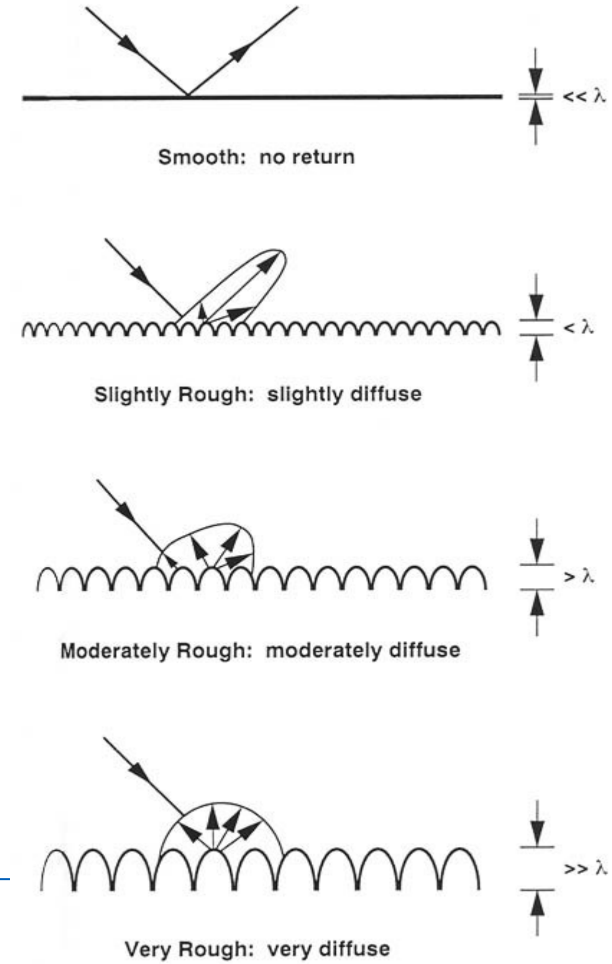
Incidence angle and surface roughness



Incidence angle and surface roughness





http://history.nasa.gov/JPL-93-24/ch5.htm
NASA: Guide to Magellan Image Interpretation
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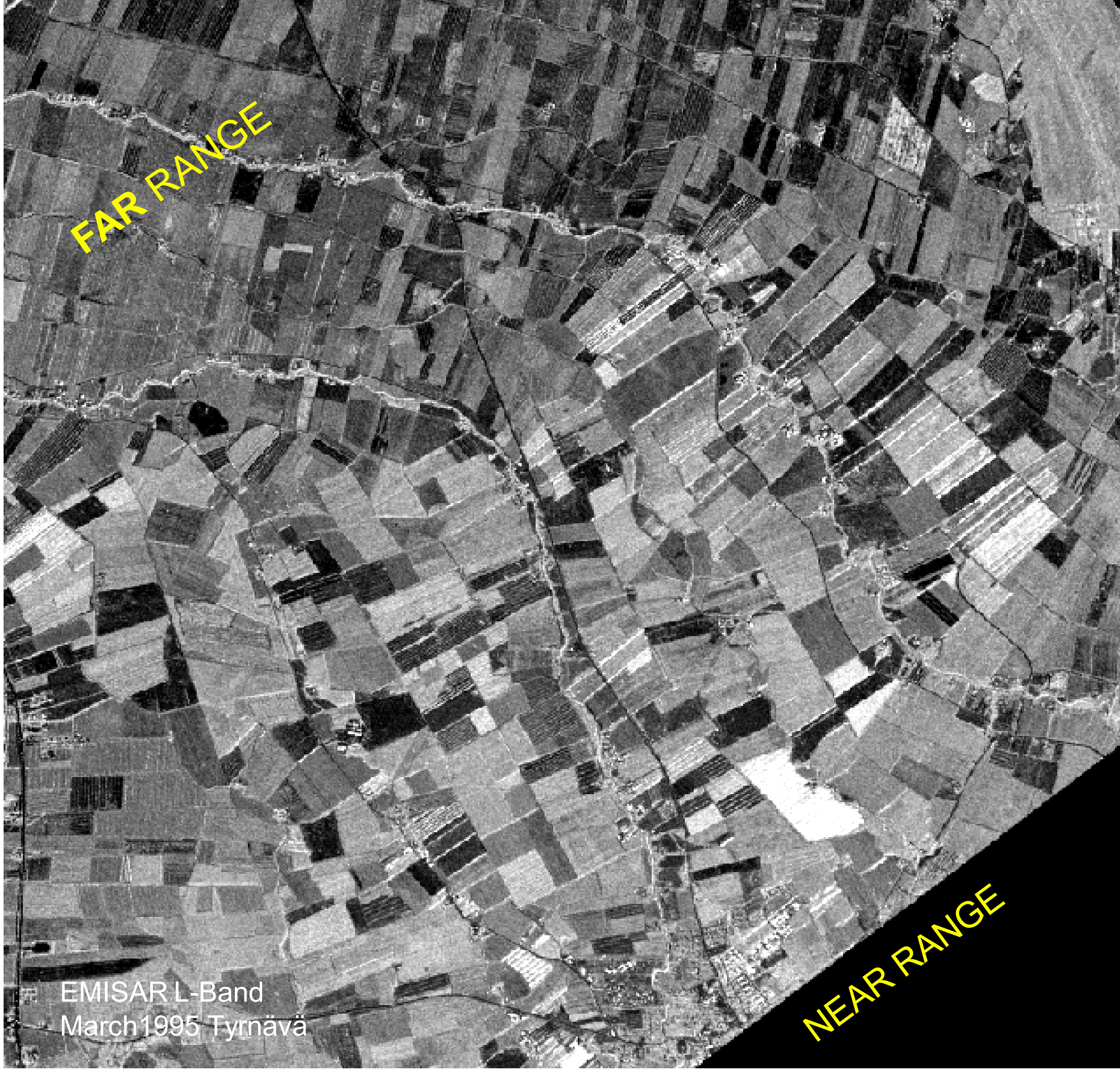
Tom G. Farr

Far range
Near range

Smooth and moderalетly rough surfaces are brighter in near range due to steep incidence angle.

For volume scatterers (forest) incidence angle effect is not noticeable.



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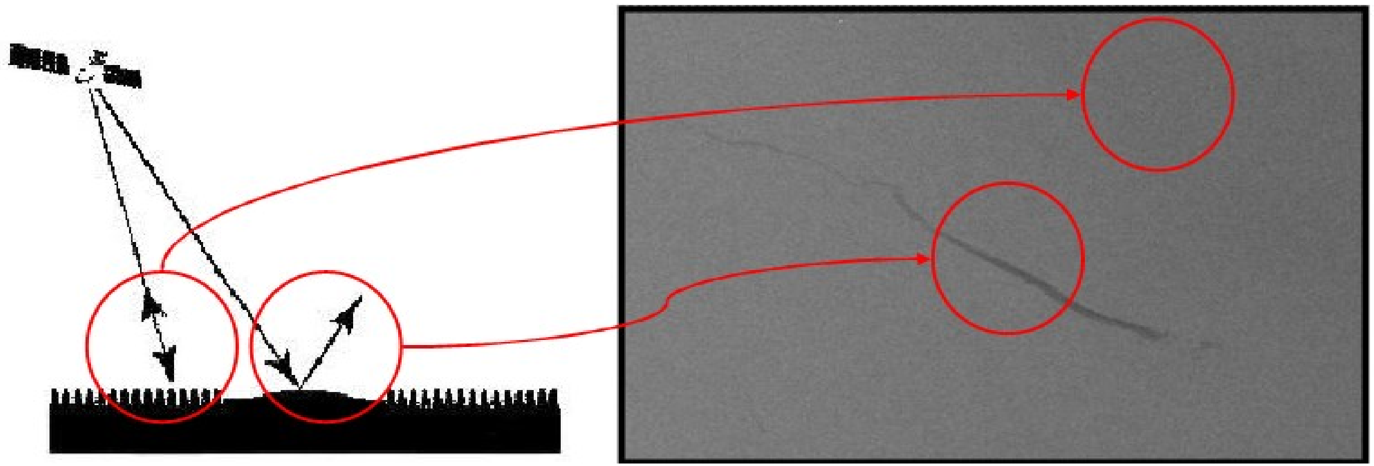
Q?

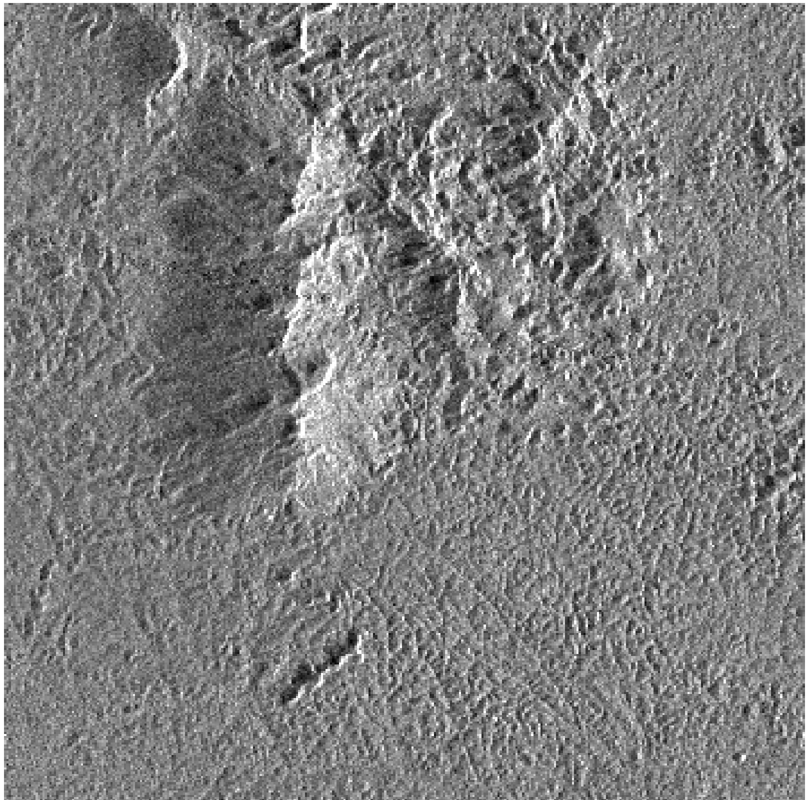
How surface roughness affects SAR refelction?
How roughness affects different SAR bands?

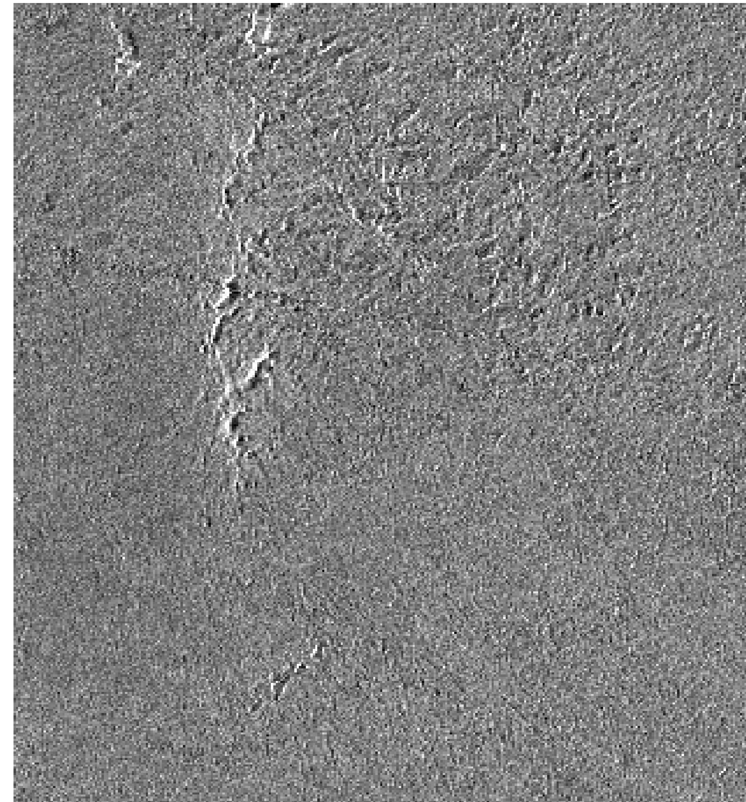
- Oil smooths out the small wind wrinkle on the water surface. The surface becomes better reflector which reflects SAR beam away from the sensor.



Kati Tahvonen

SAR image topography correction

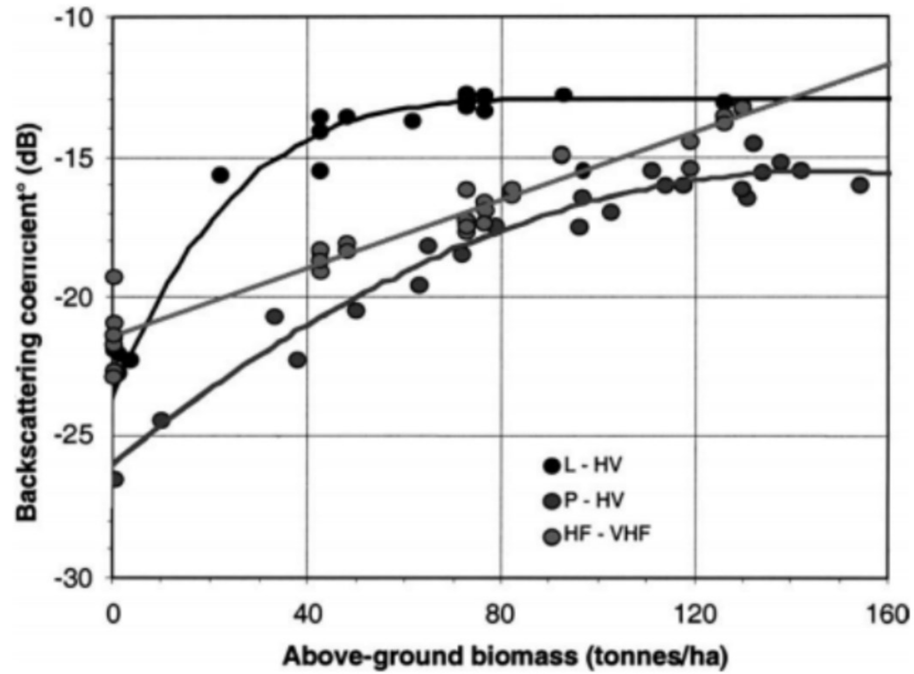




Example of uncorrected and DEM-corrected SAR imagery.

Backscattering vs biomass (forest roughness)

Figure 9. Saturation of SAR at High Forest Biomass



Note: This graph shows the saturation of SAR backscatter from the L-band (dark line, top), P-band (gray, bottom), and VHF-band (light gray, middle) over a forest in Landes, France. In this study, L- and P-band sensitivity to increasing biomass is limited after 100 Mg/ha; other studies have achieved higher sensitivity by combining polarizations.
Source: Le Toan et al. 2004.

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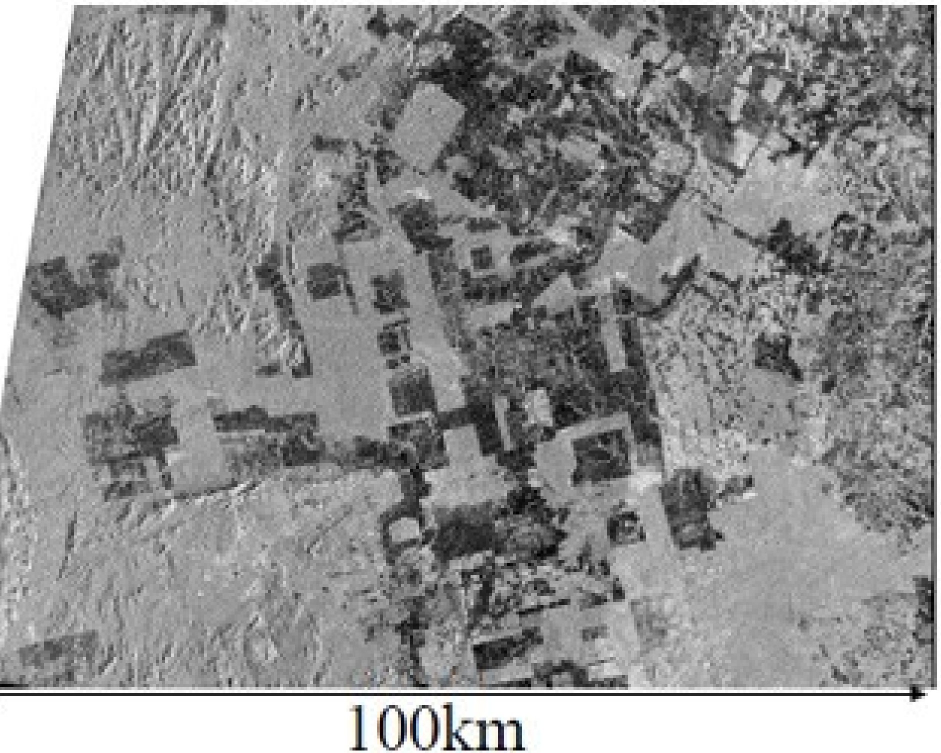
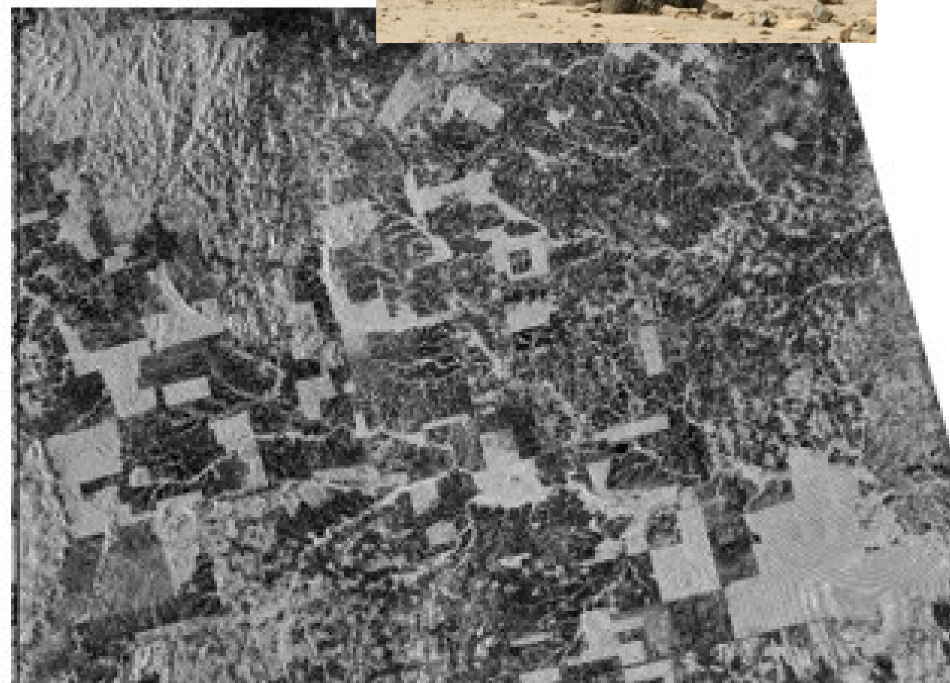
Deforestation detection



October 1996 (JERS-1)



June 2006 (PALSAR)

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Other SAR image peculiarities

SAR and moving targets

Moving targets are displaced and blurred in SAR images, because they alter the SAR signal dopler frequency

SAR based traffic monitoring algorithms are developed

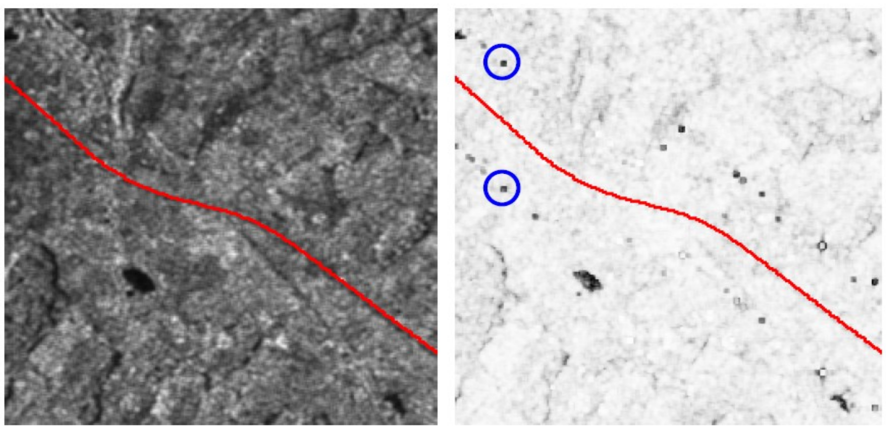


Figure 9: SRTM/X-SAR amplitude (left) and coherence (right) of German motorway A9

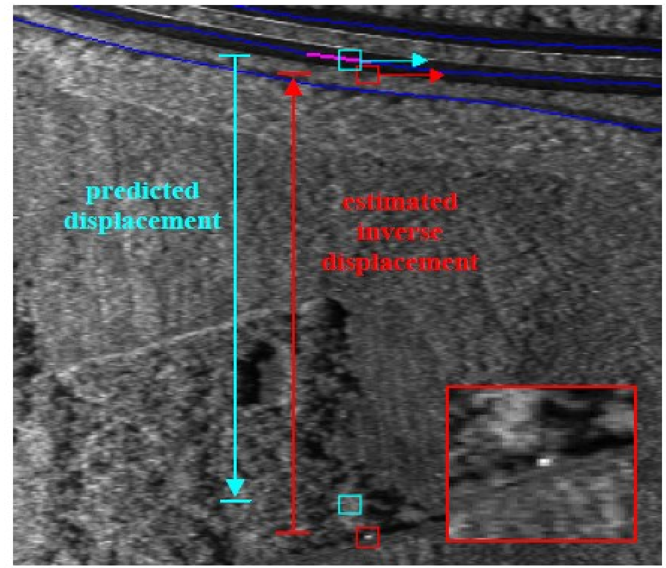
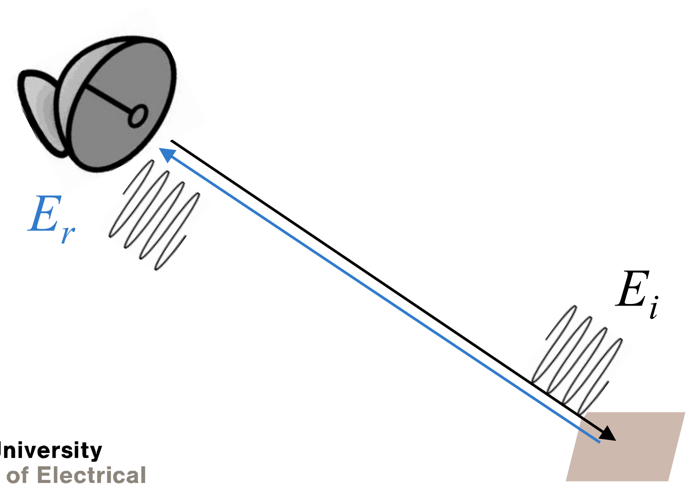


Figure 7: Evaluation of cars on public roads in SAR images

©DLR www.ipi.uni-hannover.de/html/publikationen/2005/workshop/082-suchandt.pdf

SAR pixel is a complex number

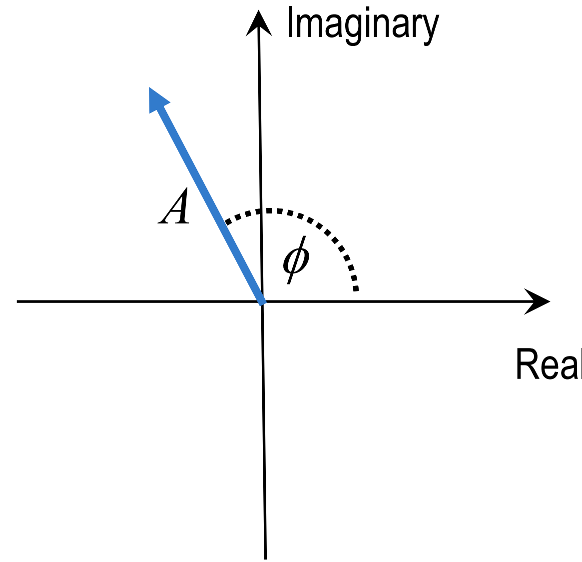
- Each pixel of the SAR image is a complex value
  - It has real and imaginary parts
  - Or, equivalently, amplitude (modulus) and phase
- What is the meaning of such complex numbers?
  - They correspond to the ratio of the received electrical field (received signal) over the field incident to that location on Earth



$$\rho = \frac{E_r}{E_i} = a + jb = Ae^{j\phi}$$

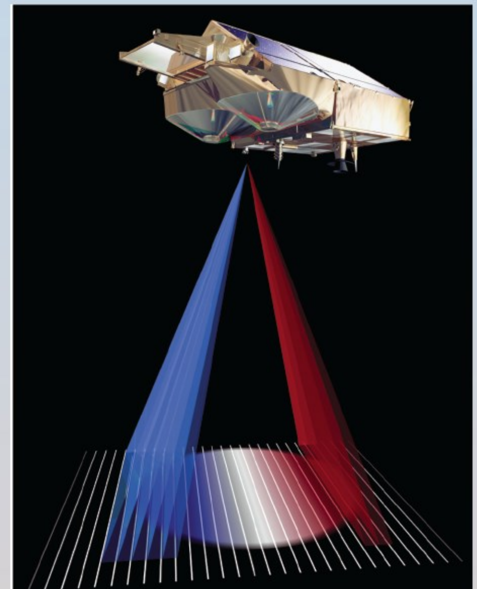
SAR pixel is a complex number

- Phase of single pixel can be random
- Expectation value of random complex value is 0
- Complex pixels cannot be just averaged
- Image geocoding and manipulation does not preserve phase information (polarimetry and interferometry)



- Ulaby
- Long
- Blackwell
- Elachi
- Fung
- Ruf
- Sarabandi
- Zebker
- Van Zyl

Microwave Radar and Radiometric Remote Sensing




F-SAR DLR

Q?

What does the histogram tool in SNAP tell you about statistical variables?

Q?

Why SAR and SLAR look to the side?

Q?

What is the main difference between real aperture and synthetic aperture radar?

Can one use the same hardware for both?

END