Synthetic Aperture Radar Principles

Carlos López-Martínez

SAR Polarimetry Tutorial
Ahmedabad, India

Universitat Politècnica de Catalunya – UPC
Signal Theory and Communications Department – TSC
Remote Sensing Laboratory - RSLab., Barcelona, Spain
carlos.lopez@tsc.upc.edu

Carlos LÓPEZ-MARTÍNEZ, PhD
Associate Professor

Departament de Teoria del Senyal i Comunicacions
UNIVERSITAT POLITÈCNICA DE CATALUNYA

Technical University of Catalonia UPC
Signal Theory and Communications Department TSC
Remote Sensing Lab. (RsLAB)

Jordi Girona 1-3, Campus Nord
Bldg. D3, Room 203
08034 Barcelona
SPAIN

Telephone: +34 93 401 6785
Email: carlos.lopez@tsc.upc.edu
Web Site: http://www.tsc.upc.edu/sar/

Schedule

Time slot	Topic	Faculty
DAY – 1 (Dec 3, 2019)		
1000 - 1130	Registration and Inauguration, Introduction of the Faculty and Participants	
1200 - 1330	Basics of PolSAR, image formation, errors and corrections, current sensors and imaging modes, polarimetric matrices, data types and availability	CLM
1430 - 1600	PolSAR Speckle Filtering and Matrix Estimation	CLM
1630 - 1800	PolSAR Decomposition Theory (part-1)	CLM
DAY – 2 (Dec 4, 2019)		
1000 - 1130	PolSAR Decomposition Theory (part-2)	CLM
1200 - 1330	Review of Applications of POLSAR Decomposition	CLM
1430 - 1600	PolSAR Classification	CLM
1630 - 1800	PolSAR Applications	CLM
DAY – 3 (Dec 5, 2019)		
1000 - 1130	Polarimetric SAR Interferometry (part-1)	KP
1200 - 1330	Polarimetric SAR Interferometry (part-2)	KP
1430 - 1600	Polarimetric SAR Tomography	KP
1630 - 1800	Concluding Session	

CLM= Carlos Lopez-Martinez; KP= Konstantinos P. Papathanassiou
Tea/Coffee: Morning 1130-1200, Afternoon 1600-1630; Lunch: 1330-1430

Outline

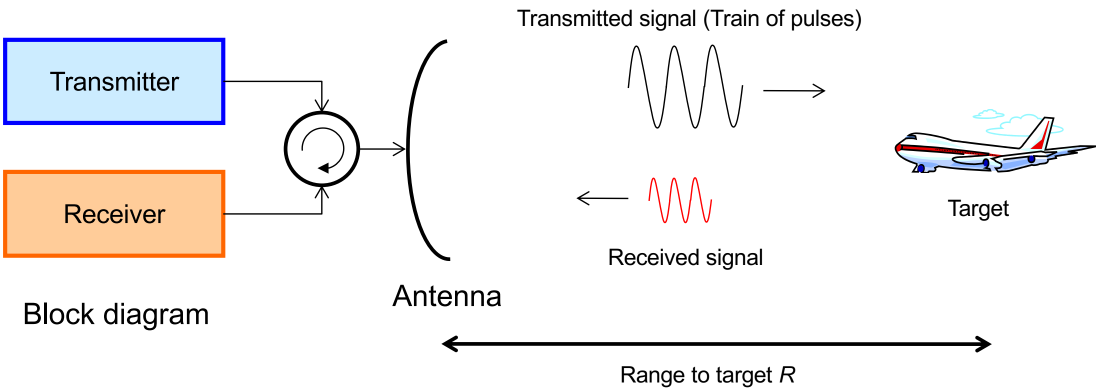
- Real Aperture Radar & Range Imaging
- Synthetic Aperture Radar

Real Aperture Radars & Range Imaging

Range Imaging

A radar is an electromagnetic system for the detection and location of reflecting objects as aircrafts, ships, spacecrafts, vehicles, people and the natural environment

Radar: **RA**dio **D**etection **a**nd **R**anging



The analysis of the received signal allows to detect and locate the target under study but also to infer certain of its properties

A radar is an active system as it provides its own illumination source

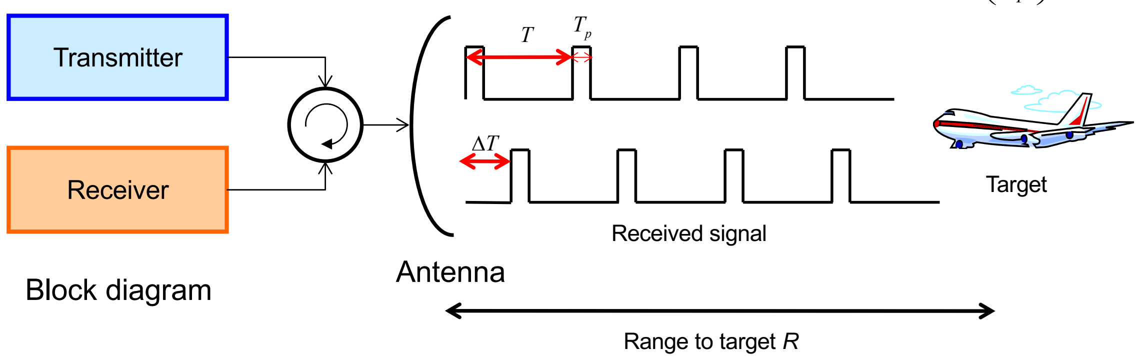
UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH
Department of Signal Theory and Communications

Range Imaging

Analysis of the range dimension. Location of a single target

Transmitted signal (Train of pulses)

$$s_t(t) = \sum_k p(t - kT) \qquad p(t) = \Pi\left(\frac{t}{T_p}\right) e^{j\omega_0 t}$$



Estimated distance $R = \dfrac{c\Delta T}{2}$

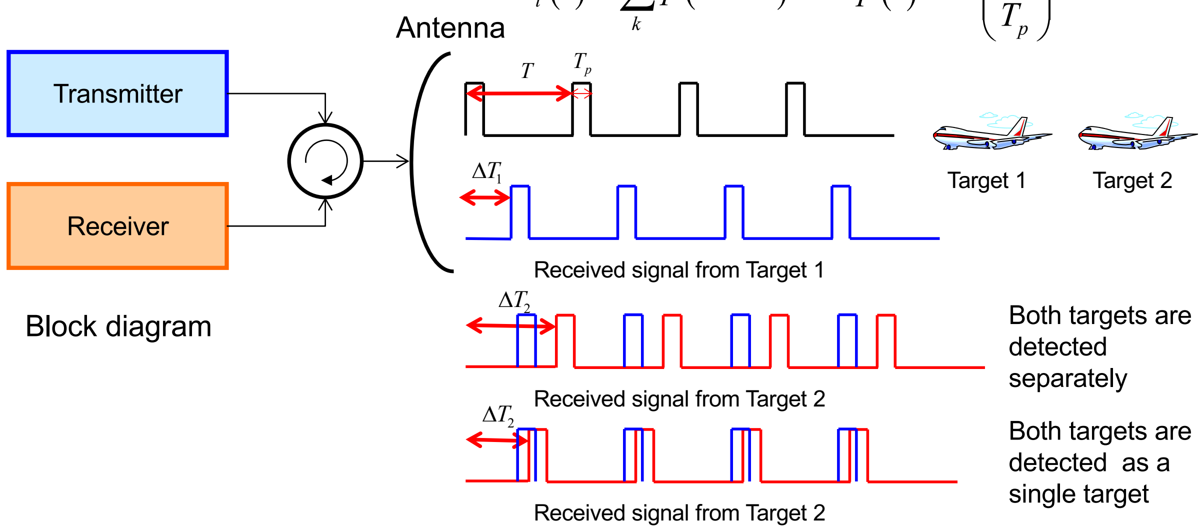
Synthetic Aperture Radar Principles

Range Imaging

Analysis of the range dimension. Location of multiple targets

Transmitted signal (Train of pulses)

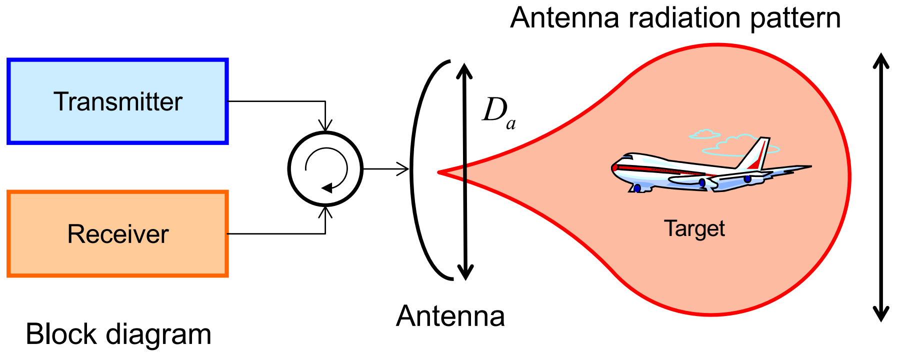
$$s_t(t) = \sum_k p(t - kT) \qquad p(t) = \Pi\left(\frac{t}{T_p}\right) e^{j\omega_0 t}$$



Minimum separation $(\Delta T_1 - \Delta T_2)_{\min} = T_p$ Range resolution $\delta R = \dfrac{cT_p}{2} = \dfrac{c}{2 f_p}$

Range Imaging

Analysis of the azymuth or cross-range dimension. Location of multiple targets



Azimuth angular spread

$$\theta_a \propto \frac{\lambda}{D_a}$$

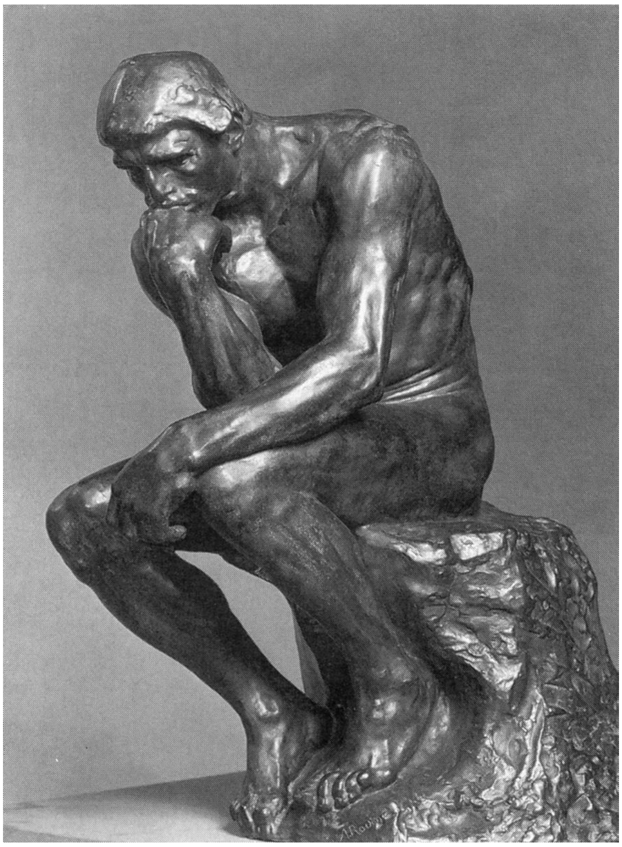
Azimuth resolution

$$\delta_a = R\theta_a = R\frac{\lambda}{D_a}$$

The signal received by the radar systems depends on the targets covered by the antenna radiation pattern and the transmitted pulse

$$s_r(t) = f\left(\sigma_l, p(t)\right)$$

σ_l Radar Cross Section (RCS) of the target



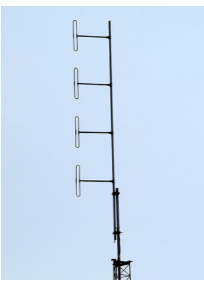
Synthetic Aperture Radar

Synthetic Aperture Radar Principles

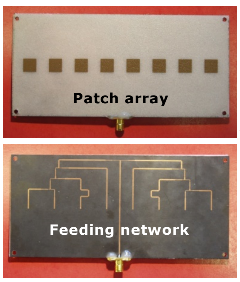
Synthetic Aperture Imaging

The problem of Real Aperture Radars was the poor azimuth spatial resolution due to the antenna footprint. Synthetic Aperture Radars solve this problem based on the following idea:

- Radiation patterns of single-element antennas are relatively wide
- Antennas with narrow radiation may be obtained by
  - Enlarging the dimensions of the radiating element
    - Appearance of multiple side lobes and technologically inconvenient shapes and dimensions
  - Constructing the antenna as an assembly of individual radiating elements in a proper electrical and geometrical configuration, i.e., Antenna Array, where the total field is the vector superposition of the fields radiated by the individual elements

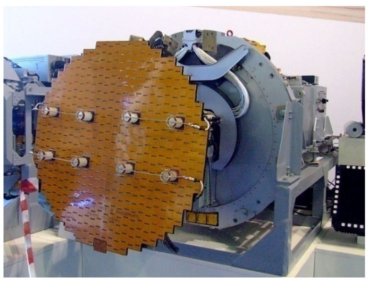


Dipoles array



[Photo courtesy of LEMA-EPFL]

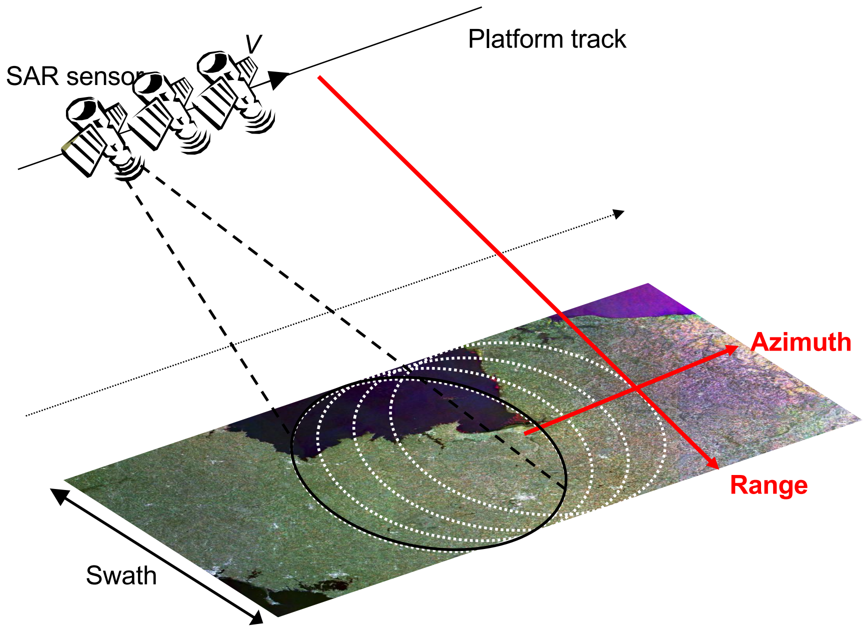
Microstrip patches



Slots array

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
Department of Signal Theory and Communications

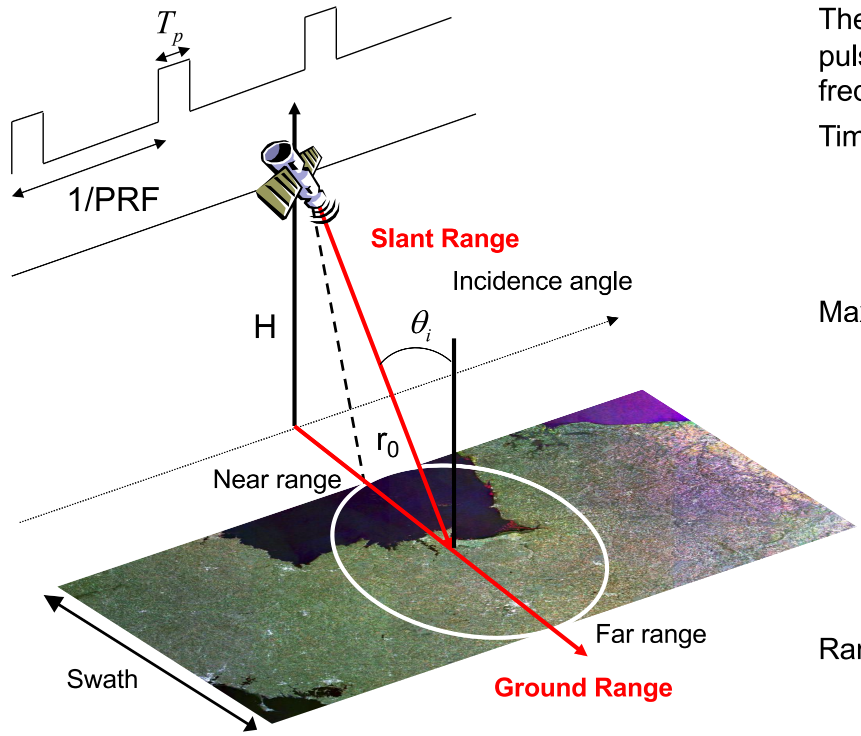
Synthetic Aperture Radar Principles



- Side looking geometry
- Two-dimensional imaging system: Range vs. Azimuth
- Different imaging modes. Compromise between resolution and swath coverage
  - Stripmap
  - Scansar
  - Spolight
- SAR images present a complex nature

Range Analysis

In range a SAR system operates as a conventional radar



The SAR system transmits pulses of duration T_p at PRF frequency

Time delay

$$t_d = \frac{2r_0}{c}$$

Maximum swath

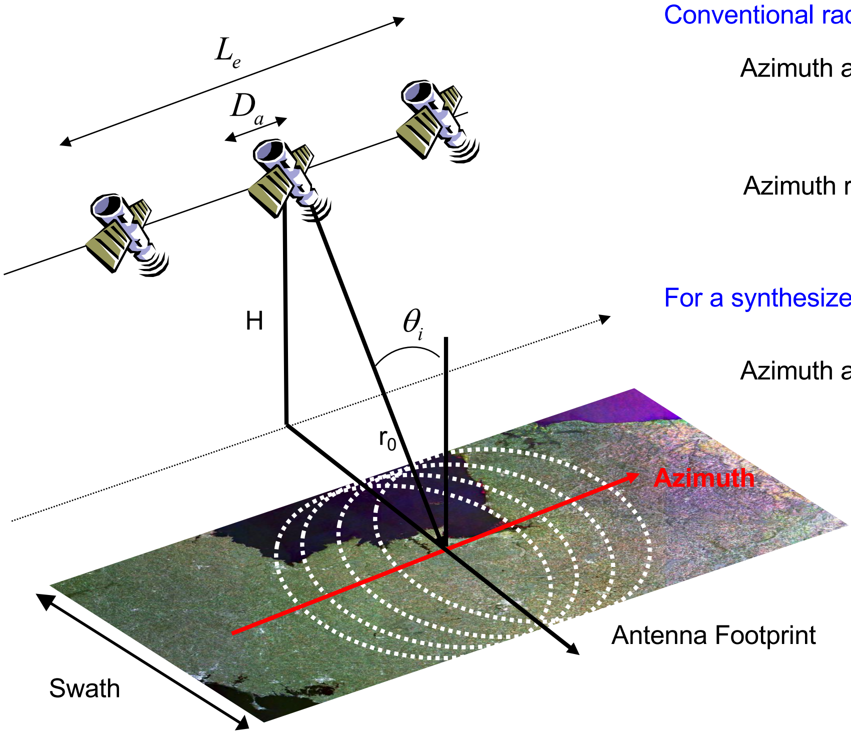
$$SW_{\max} \approx \frac{c}{2\,PRF\,\sin(\theta_i)}$$

$$\theta_i \in \left[20^0..60^0\right]$$

Range resolution $\delta R = \frac{cT_p}{2} = \frac{c}{2f_p}$

Azimuth Analysis

Difference between SAR system and conventional radars. Geometric approach



Conventional radar

Azimuth angular spread $\theta_a \propto \frac{\lambda}{D_a}$

Azimuth resolution $\delta_a = r_0\theta_a = r_0\frac{\lambda}{D_a}$

For a synthesized aperture

Azimuth angular spread $\theta_{sa} \propto \frac{\lambda}{2L_e}$

Two-way

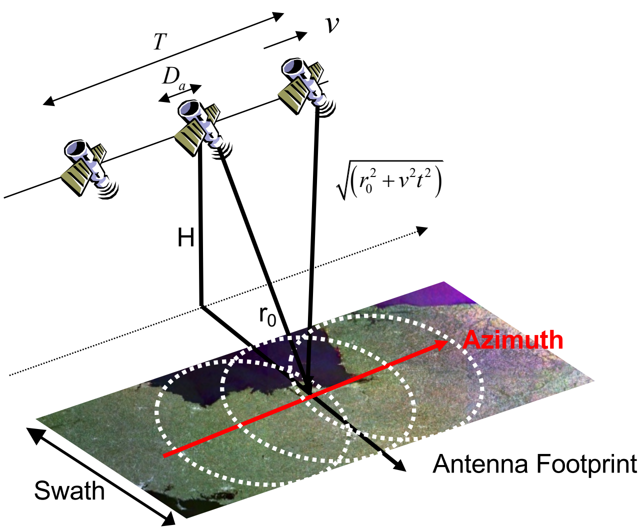
Azimuth resolution $\delta_a = r_0\frac{\lambda}{2L_e}$

$L_e < \frac{\lambda R}{D_a}$ $\qquad$ $\delta_a > \frac{D_a}{2}$

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH
Department of Signal Theory and Communications

Azimuth Analysis

Azimuth processing is based on the fact that a given target is observed all the time that it is within the antenna footprint. The different observation points are labelled through the doppler frequency



Doppler frequency definition $f_{dop} = \frac{1}{2\pi}\frac{d\phi}{dt}$

Instant phase $\phi = \phi_0 + 2\frac{2\pi}{\lambda}\sqrt{(r_0^2+v^2t^2)}$

Doppler frequency $f_{dop} = 2\frac{v^2t}{\lambda r_0}$ $\qquad$ $B_{dop} = 2\frac{v^2T}{\lambda r_0}$

Doppler bandwidth $T \approx R\frac{\lambda}{L_e}\frac{1}{v}$ $\qquad$ $B_{dop} \approx 2\frac{v}{D_a}$

Azimuth resolution $\delta_a \approx \frac{D_a}{2}$

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH
Department of Signal Theory and Communications

SAR Impulse Response & SAR Focusing

Derivation of the SAR system impulse response considering the overall imaging process as a linear process

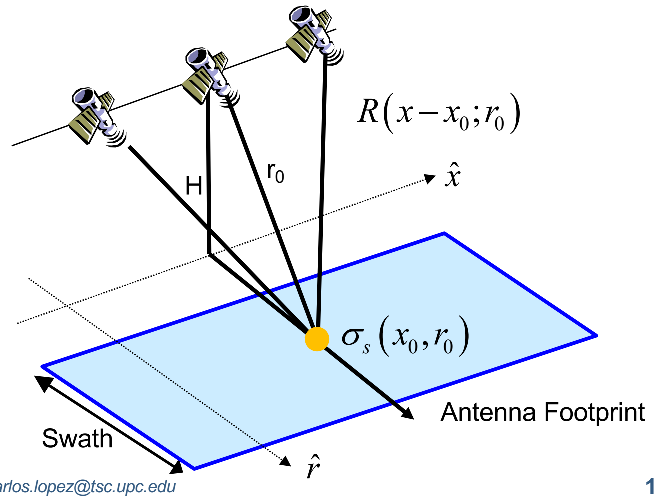
Amplitude and Phase information

$$\sigma_s(x_0,r_0) \longrightarrow \boxed{h(x,r)} \longrightarrow S(x,r)$$

Complex scattering amplitude $\sigma_s(x_0,r_0)=\sqrt{\sigma}e^{j\theta}\delta(x-x_0,r-r_0)$

SAR impulse response or Point Spread Function (PSF)

Complex SAR image

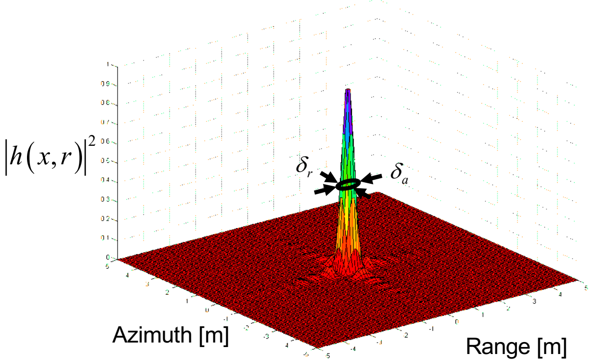


SAR Impulse Response & SAR Focusing

The impulse response of the SAR system embracing the acquisition and the focusing processes is

$$h(x,r)=\exp\left(j\frac{4\pi}{\lambda}r\right)\mathrm{sinc}\left(\frac{\pi r}{\delta R}\right)\mathrm{sinc}\left(\frac{\pi r}{\delta X}\right)$$

- Range resolution: $\delta R=\dfrac{c}{2B}$
- Azimuth resolution: $\delta X=\dfrac{D_a}{2}$



$\delta_a=\delta_r=1m$

Point scatterer

How it appears in the SAR image $s(x,r)$

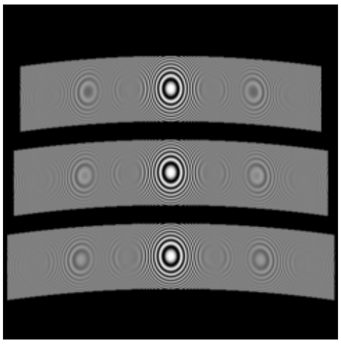
Distributed scatterer

Idea of resolution cell $\delta_a\times\delta_r$

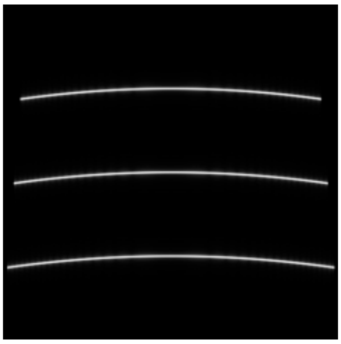
The resolution cell is not the pixel of the SAR image. The pixel properties depend on how the SAR impulse response is sampled. Over sampling induces image spatial correlation.

SAR Impulse Response & SAR Focusing

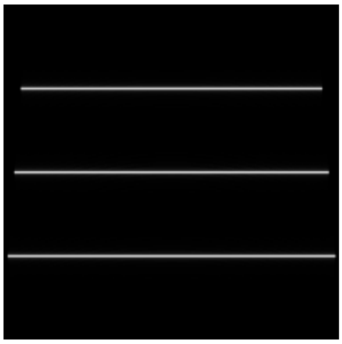
Focusing process of three point scatters varying in range



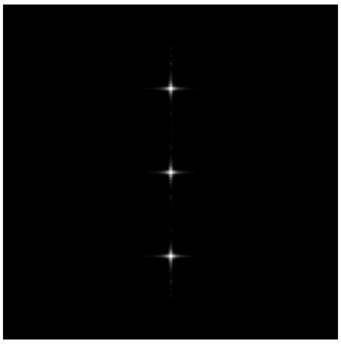
Real part of the raw data



Amplitude of range-compressed data



Amplitude of range-compressed data after RCMC

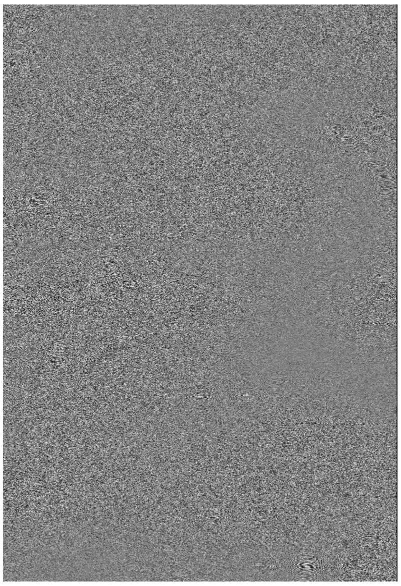


Amplitude of the final compressed image

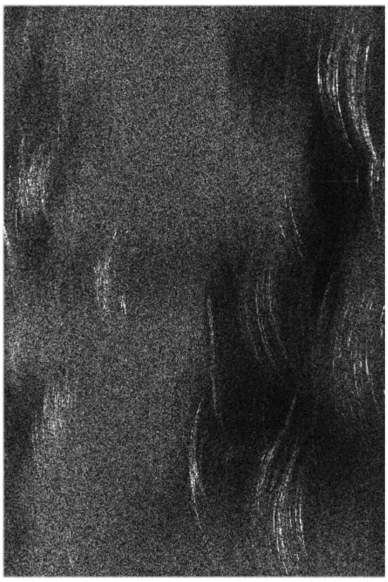
UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH
Department of Signal Theory and Communications

SAR Impulse Response & SAR Focusing

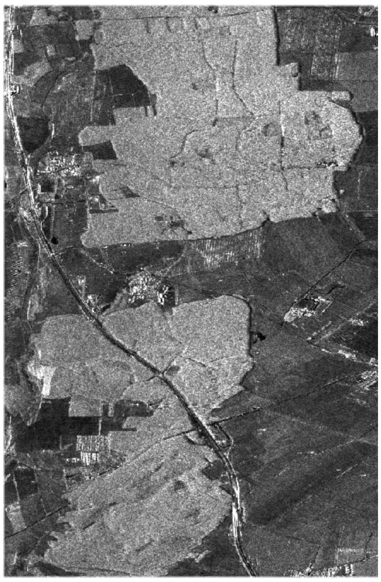
Focusing process of a real SAR image



SAR raw data as measured by the system



SAR data after range compression

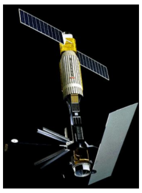


Focused SAR image

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH
Department of Signal Theory and Communications

Platforms

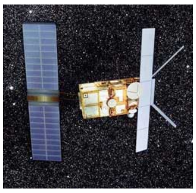
Spaceborne: Orbital systems



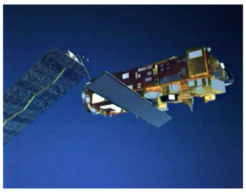
SEASAT
L-band
HH Pol
NASA/JPL (USA)

J-ERS-1
L-band
HH Pol
JAXA (J)

SIR-C/X-SAR
L, C, X-band
C&L FullPol, X VV
NASA/JPL (USA), ASI (I), DLR (G)

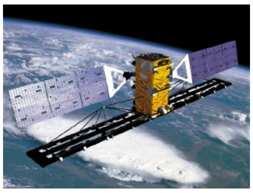


ERS-1/2
C-band
VV Pol
ESA (EU)

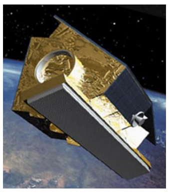


ENVISAT / ASAR
C-band
HH&HV, HH&VV, VH&VV
ESA (EU)

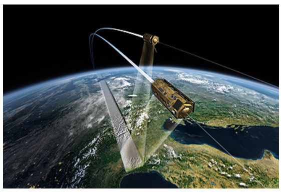
ALOS / PALSAR
L-band
FullPol
JAXA (J)



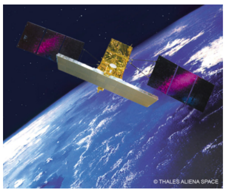
RADARSAT 2
C-band
FullPol
CSA - MDA (CA)



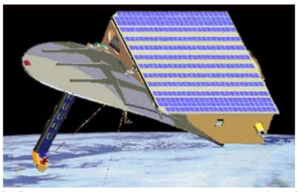
TERRASAR
X-band
FullPol
BMBF / DLR / ASTRIUM (G)



TanDEM-X
X-band
FullPol
BMBF / DLR / ASTRIUM (G)



Cosmo-Skymed
X-band
FullPol
ISA (I)



SAR-Lupe
X-band
BWB (G)

Sentinel-1
C-band
HH&HV, VH&VV
ESA (EU)

Platforms

Airborne: Aerial or UAV systems

AES1
X-Band (HH), P-Band (FullPol)
InterMap Technologies (D)

AIRSAR
P, L, C-Band (FullPol)
NASA / JPL (USA)

AuSAR – INGARA
X-Band (FullPol)
D.S.T.O (Aus)

DOSAR
S, C, X-Band (FullPol), Ka-Band (VV)
EADS / Dornier GmbH (D)

ESAR
C, X-Band (Sngl)
P, L, S-Band (FullPol)
DLR (D)

EMISAR
L, C-Band (FullPol)
DCRS (DK)

MEMPHIS / AER II-PAMIR
Ka, W-Band (FullPol) / X-Band (FullPol)
FGAN (D)

STORM
C-Band (FullPol)
UVSQ / CETP (F)

PHARUS
C-Band (FullPol)
TNO - FEL (NL)

PISAR
L, X-Band (FullPol)
NASDA / CRL (J)

RAMSES
P, L, S, C, X, Ku, Ka, W-Band (FullPol)
ONERA (F)

SAR580
C, X-Band (FullPol)
Environnement Canada (CA)

Platforms

Ground Based: Linear movement

UPC GB-SAR
X-band (FullPol)
PolDInSAR
UPC (SP)

GBInSAR Lisa
LisaLab (I)

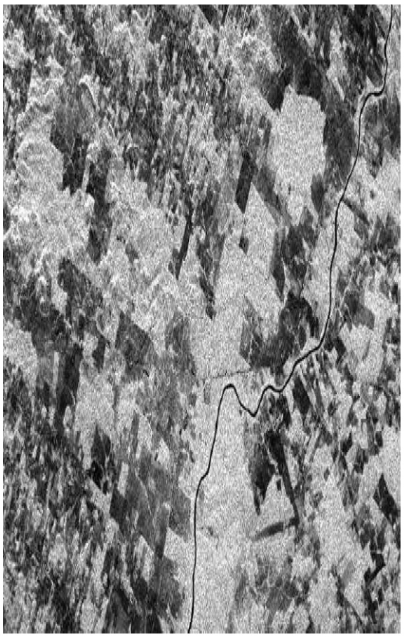
CNEAS Tohoku University GB-SAR
TU (J)

Examples

Amazonian Forest (Brazil)

X-band

C-band



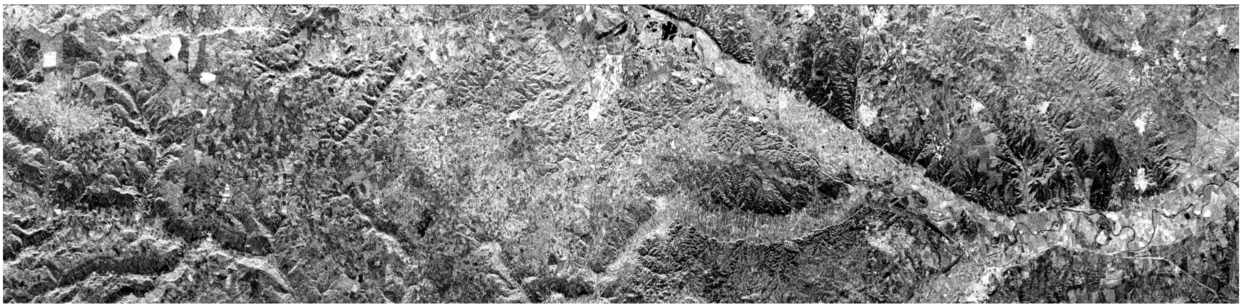
L-band

©DLR SIR-C www.cp.dlr.de/ne-hf/SRL-2/Images-SRL-2.html

Examples

Madrid (Spain). SIR-C Sensor

L-band

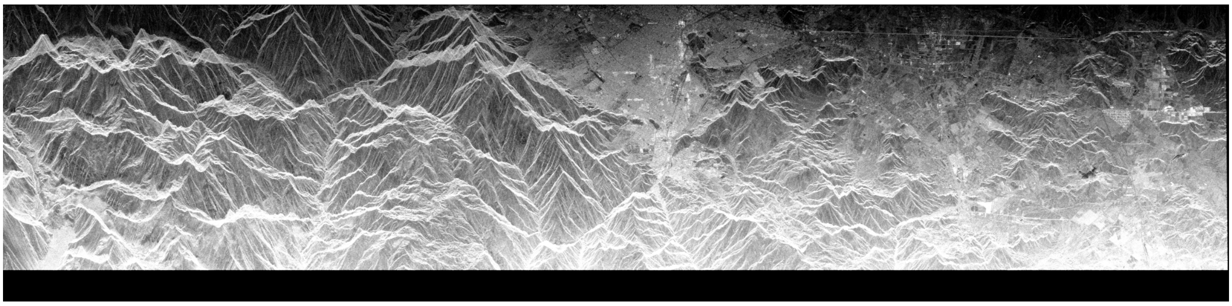


C-band

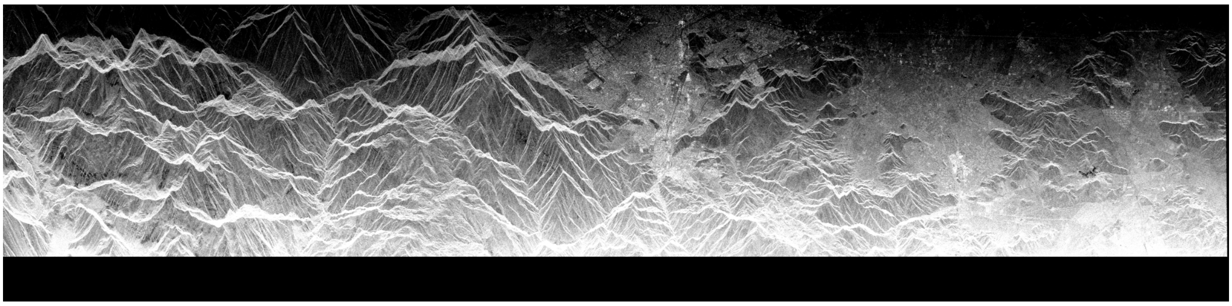
Range x Azimuth resolution: 25 x 25 m
PRF: 1620 Hz
B_w : 12.5 MHz

Examples

Santiago de Chile (Chile). SIR-C Sensor. 19/4/1994



L-band

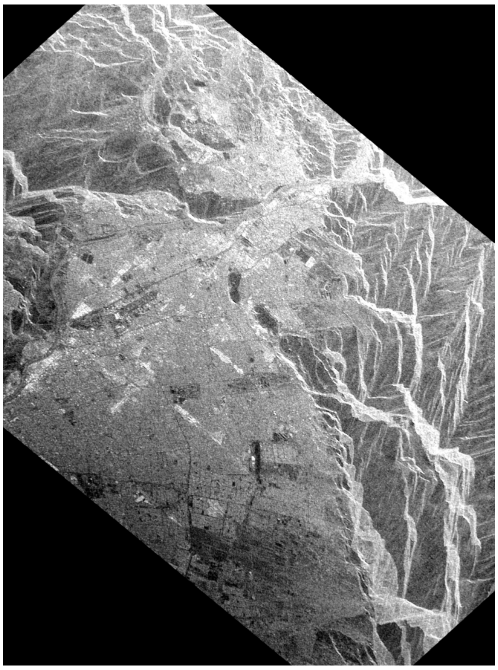


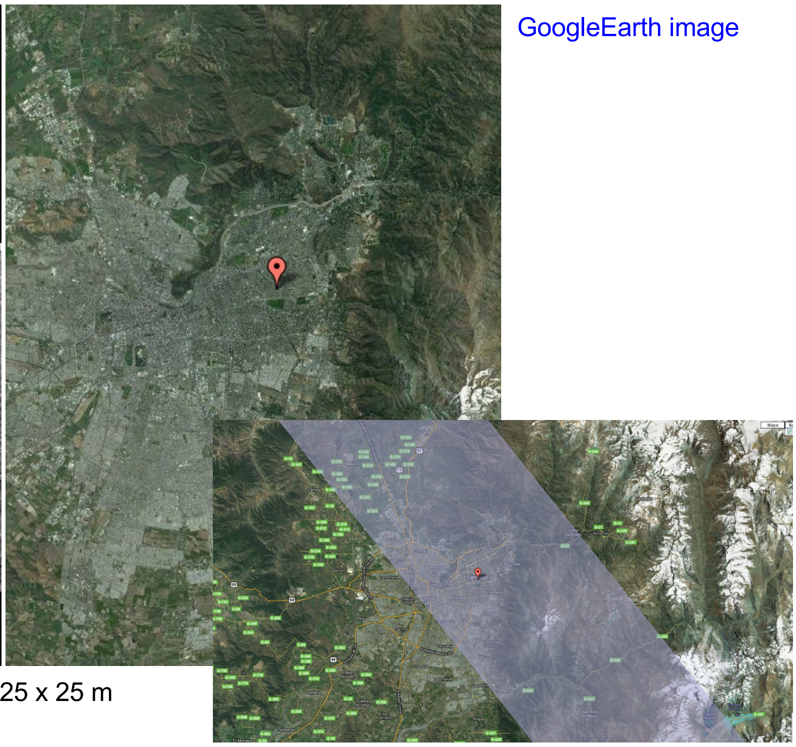
C-band

Range x Azimuth resolution: 25 x 25 m
PRF: 1440 Hz
B_w : 10.4 MHz

Examples

Santiago de Chile (Chile). SIR-C Sensor. 19/4/1994





GoogleEarth image

L-band

Range x Azimuth resolution: 25 x 25 m
PRF: 1440 Hz
B_w : 10.4 MHz

Examples

DLR; July 1, 2007, 23:00 UTC; Resolution: 1 metre
High Resolution Spotlight Mode, Polarisation: HH.

TerraSAR-X

Examples

Sandia National Laboratories

Ka-band (35 HHz) 4 inches spatial resoltuion

Examples

Sandia National Laboratories. Washington DC area

Ku-band (15 MHz) 1 m spatial resoltuion

Examples

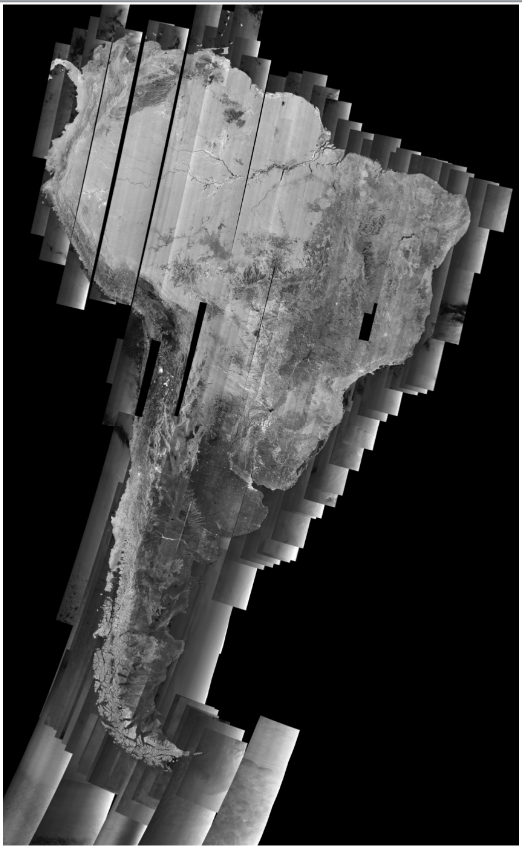
Global coverage by ALOS-PALSAR

ALOS Kyoto & Carbon Initiative

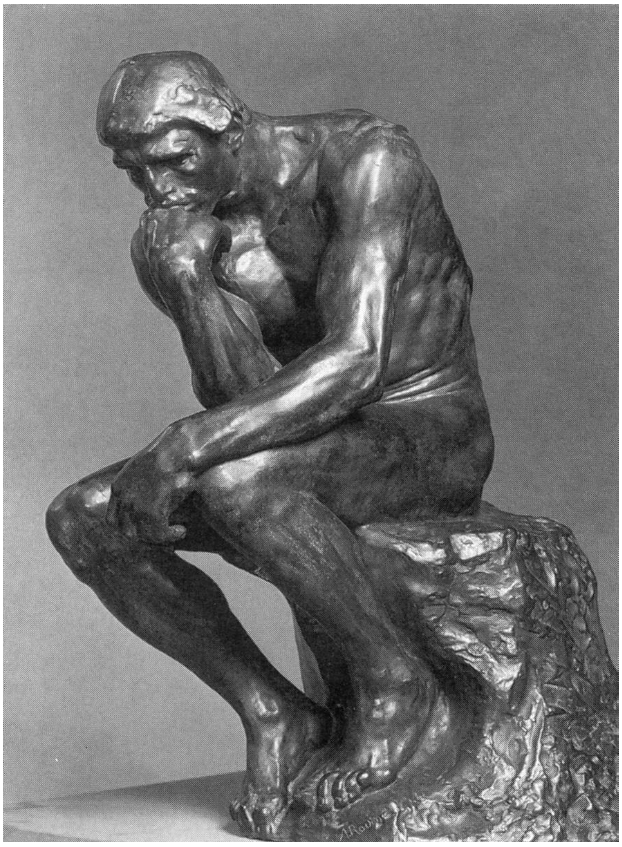
PALSAR 500m Browse Mosaic Product

PALSAR Acquisition Mode: ScanSAR (WB1)

Central Frequency	1270 MHz
PRF	1500 - 2500 Hz (discrete stepping)
range Sampling Frequency	16 MHz
Chirp bandwidth	14 MHz
Polarisation	HH or VV
Off-nadir angle [deg]	20.1-36.5
Incidence angle [deg]	18.0-43.3
Swath Width [Km]	250-350
Bit quantization [bits]	5
Data rate [Mbps]	120 or 240



UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
Department of Signal Theory and Communications



UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
Department of Signal Theory and Communications