Planetary Radars -
International School of Space Science (ISSS) – Course on “Planetary Interiors”
L’Aquila 2016, September 15th

WE LOOK AFTER THE EARTH BEAT

Ornella Bombaci

Ornella.bombaci@thalesaleniaspace.com

16/09/2016

Ref.:

THALES ALENIA SPACE INTERNAL

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83230352-DOC-TAS-EN-001

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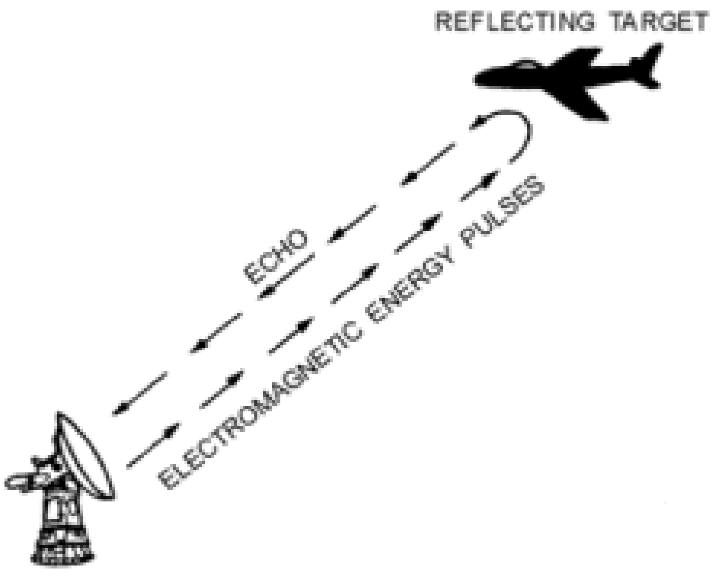
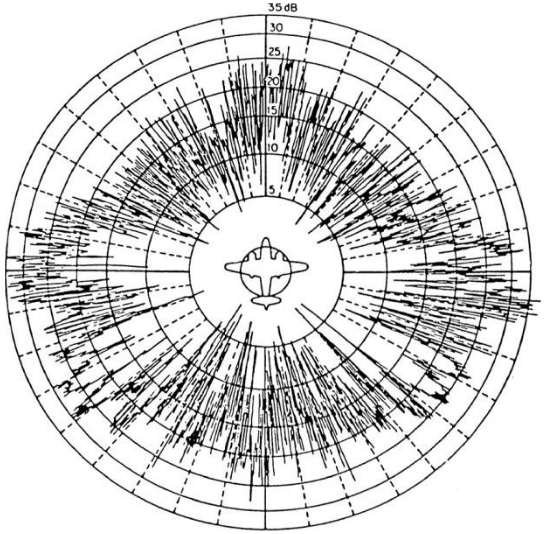
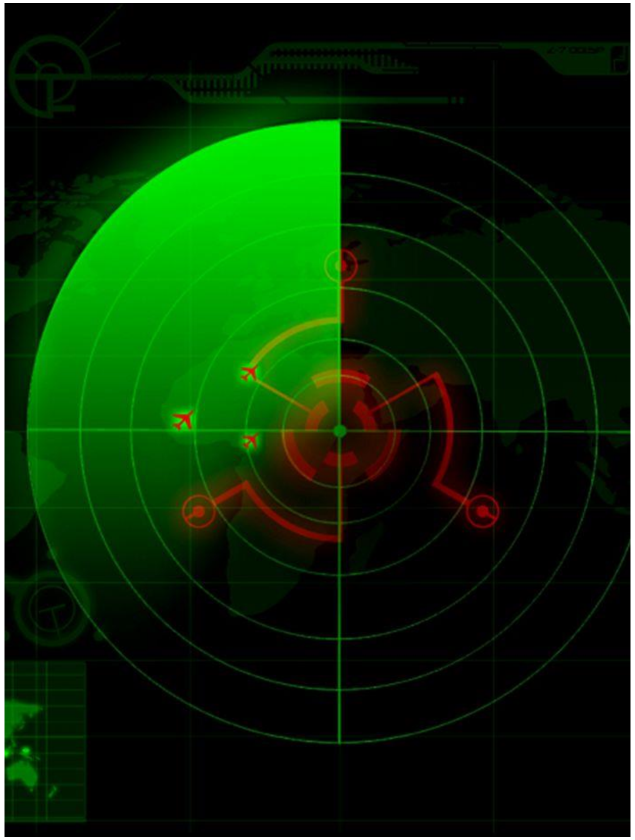
Thales Alenia Space in worldwide Radar Missions
35+ years success record
1995: ERS-2
2nd European Altimeter
1991: ERS-1
1st European Radar Altimeter
CASSINI RADAR
1997: CASSINI
1st multimode Radar : SAR, RA, SAC, MWR
2002: ENVISAT
1st ESA SAR
RA 2nd Gener.
MW Radiometer
2005: MRO
2nd sounder (with JPL)
2007-2010
COSMO-SkyMed
FM-1…FM-4
1st HR SAR
2014 and 2016
Copernicus
Sentinel 1A/1B
2016 -2018 COSMO SG
2018 -2020 Sentinel-1C/1D
2017 -2019 SARah
1991 1994 1995 1997 2000 2002 2003 2005 2007 - 2010 2013 2014 2015 2016
SIR-C
X-SAR
1994: April SRL-1 / October SRL-2
1st European X-SAR
2000: SRTM
1st inteferometric SAR
2003: MARS Express
1st sounder (with JPL)
2007: RADARSAT-2
Canadian Space Agency
2007-2008 : SARLupe
HR SAR Electronics
2013: Kompsat-5
Payload (SAR & PDHT)
2016 EXOMARS RDA
2018 EXOMARS RDA

- Radar:
  - Microwave sensor conceived for providing capabilities of: **detection, ranging and tracking of targets**





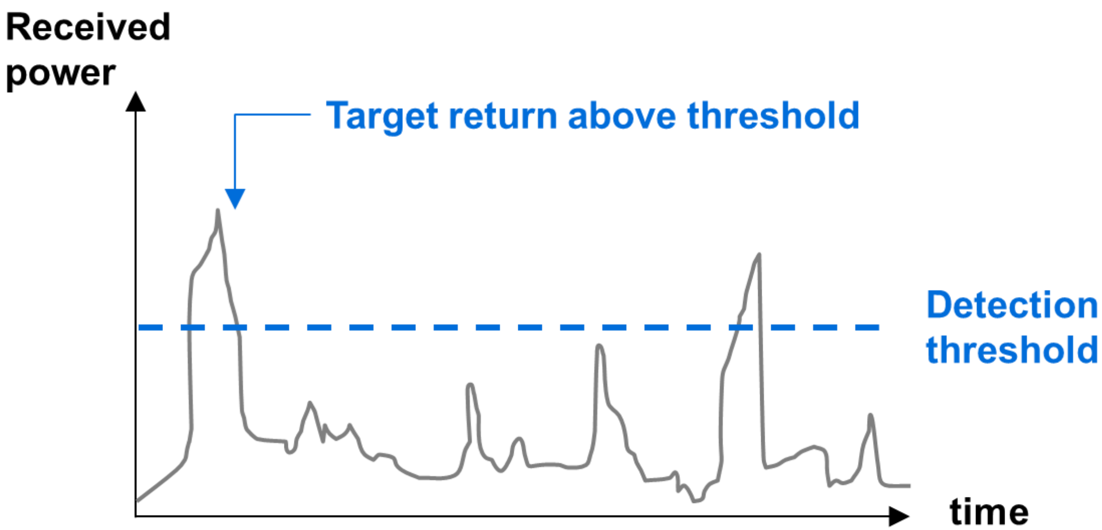


Radars

- The basic **radar concept** involves the transmission of a train of narrow, rectangular pulses which modulates a sine wave carrier
- The echo signal returned by the target is acquired by the radar and evaluated to retrieve the desired information

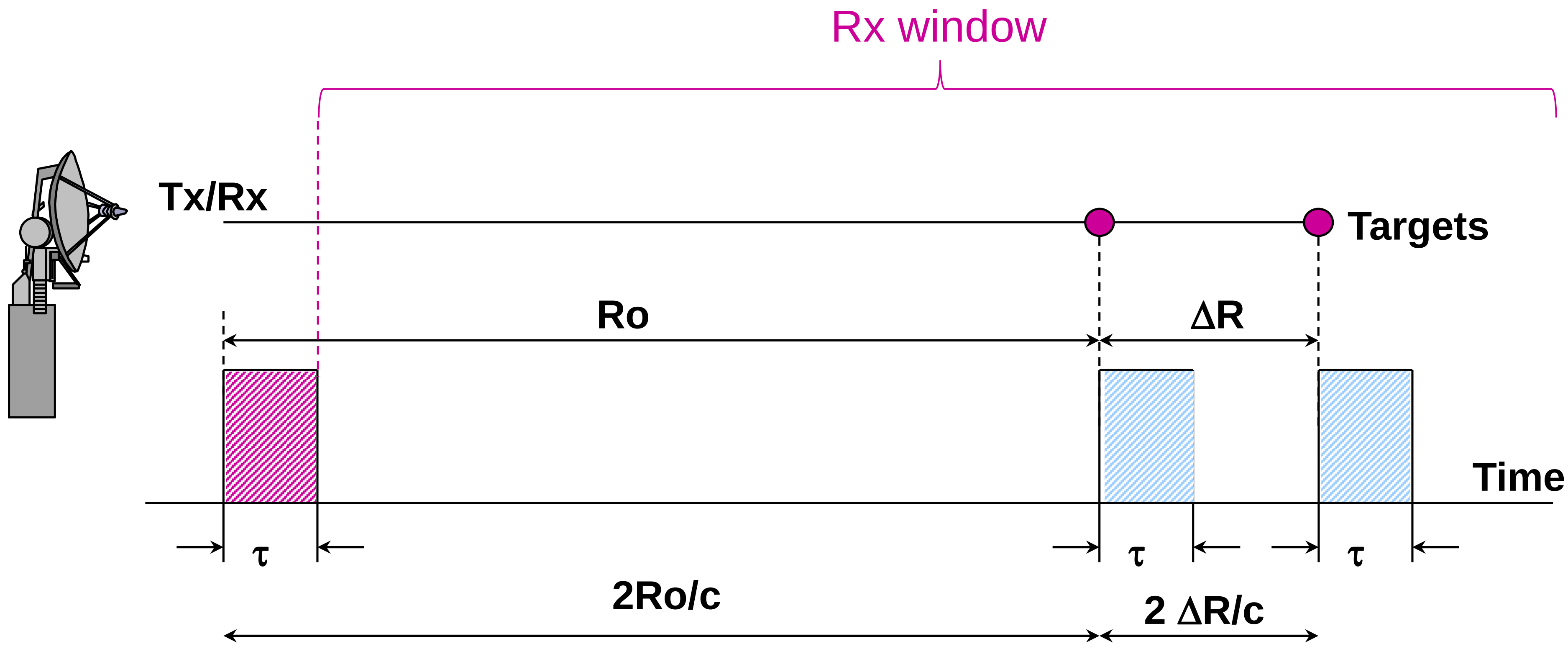
SYSTEM parameters	**SENSOR measurements**
⇨ Backscattering coefficient (time, space, frequency and polarization related)	⇨ Amplitude
⇨ Point target localisation	⇨ Time Delay, Direction of arrival
⇨ Target velocity	⇨ Doppler frequency shift

- **Detection** is the capability to indicate the presence of a target of interest



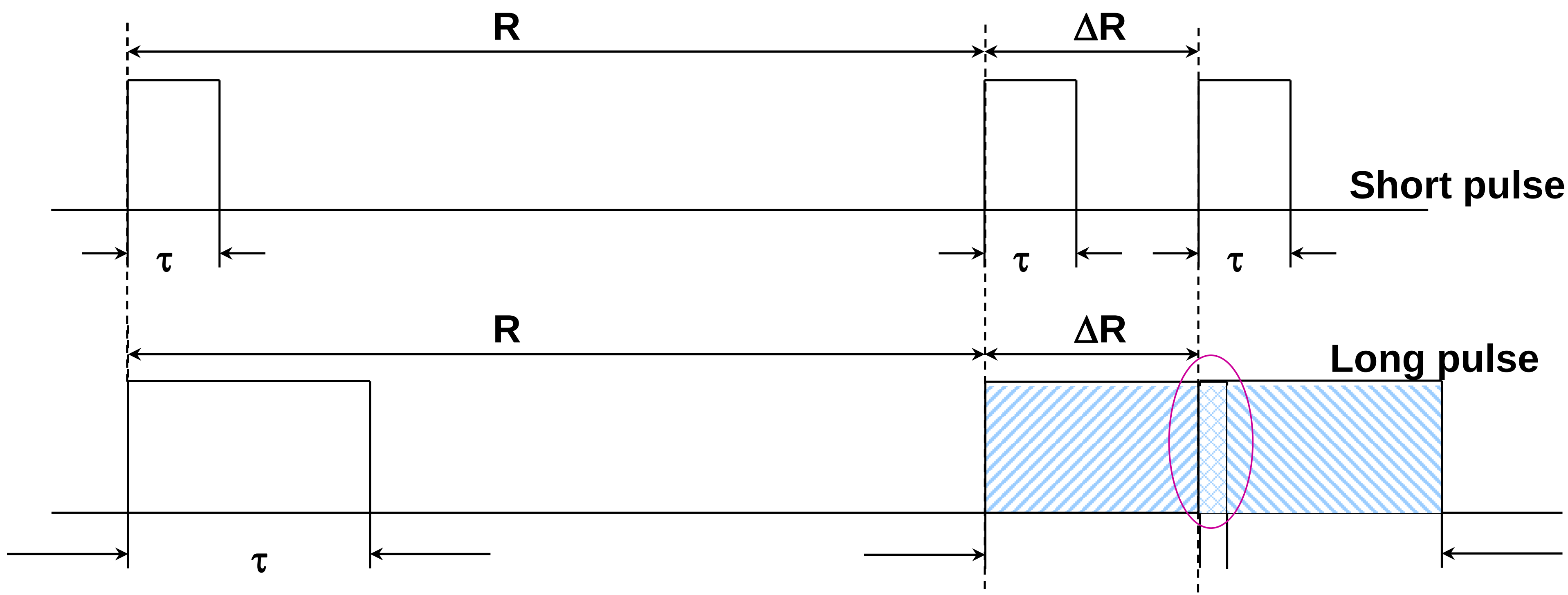
- The radar transmits a pulse and, if a target is present, this target reflects an **echo** of the signal towards the radar itself
- **Noise** corrupts the signal received by the radar, thus the detection problem is based on stochastic principles
  - SNR, probability of detection, probability of false alarm, etc.

Radars: range measurement



Ro: Time delay 2Ro/c

ΔR: Time delay 2ΔR/c



For a long pulse, two targets are no more detectable since the echoes are not separable in the time domain ⇨ **range resolution**

Maximum range resolution ⇔ Minimum measurable range delay

Range Resolution = cτ / 2

Radars: range measurement

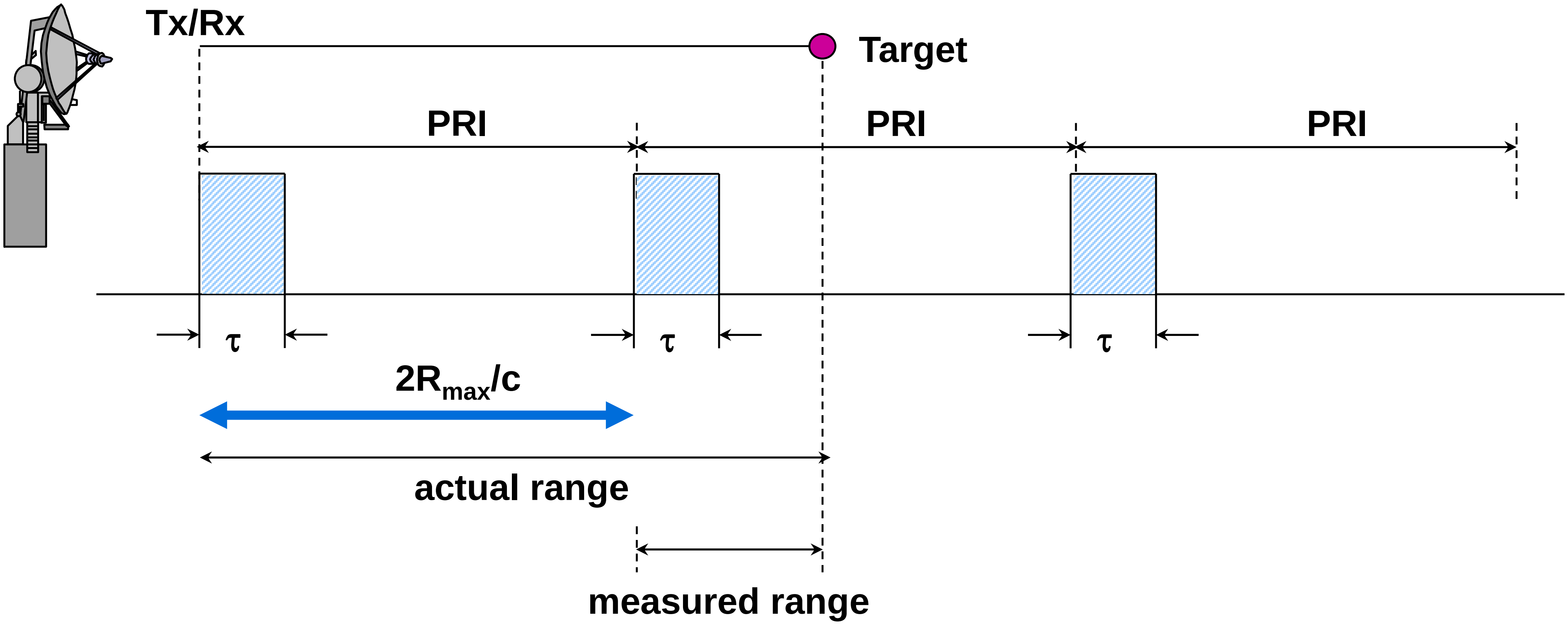
- Range Resolution and engineering aspects:
  - Metrical range resolution should require very short pulses (nanoseconds)
  - To keep an acceptable signal to noise ratio the peak transmitted power would require a very complex and expensive transmitter
  - The use of coded pulses can solve the problem

- Linear Frequency Modulated pulses (**“chirps”**) and **“matched filter”** allow:
  - very good range resolution (depending on the pulse bandwidths)
  - feasible and cost effective transmitters, thanks to the possibility of transmitting long pulses (microseconds)

Radars: range measurement

- The chirp pulse is a rectangular pulse linearly modulated in frequency (LFM)
  - pulsewidth = τ; bandwidth = B; carrier frequency = f_o
- The received echo is compressed by a “matched filter” that **maximise the SNR**, concentrating the energy in the mainlobe
- At the output form the matched filter, the **compressed pulse** length is τ_p=1/B with a resolution gain equal to τ/ τ_p
- The mateched filter maximises the detection probability of the target as well

Radars: range measurement

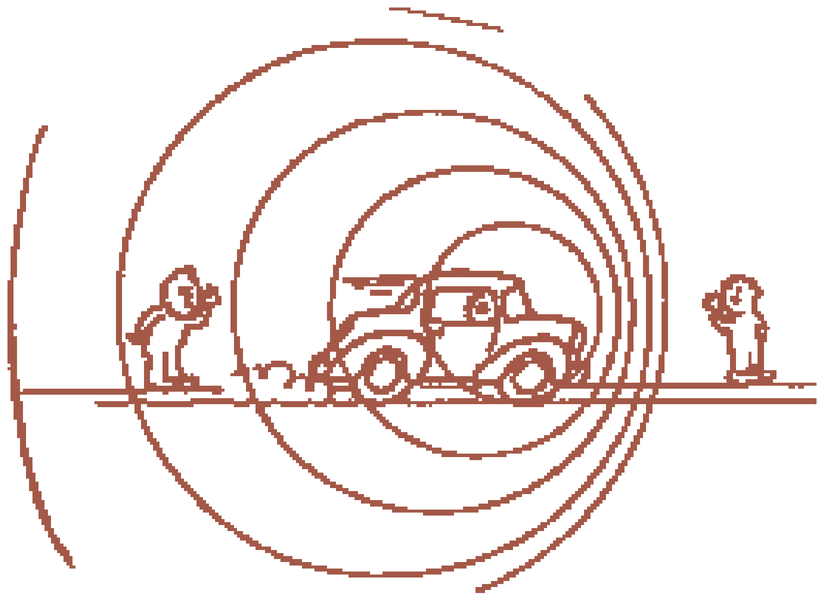


- **Train** of pulses to improve detection capability (SNR)
- A train of pulses involves a **maximum non ambiguous range** (R_{max})
- R_{max} constrained by the **pulse repetition interval** (PRI) or **frequency** (PRF)

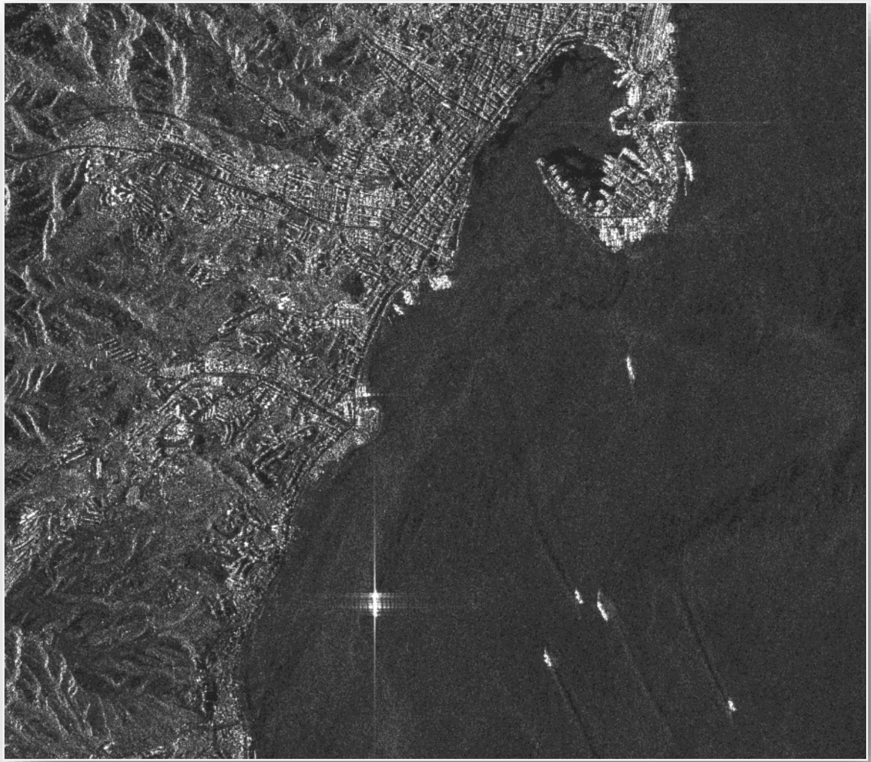
Radars: velocity measurement

- The radial component of the velocity of a target with reference to the radar antenna (v) can be measured by observing the so-called Doppler frequency shift (Δf) of the received echo signals
- The frequency difference Δf between the transmitted signal and the received echo is given by:

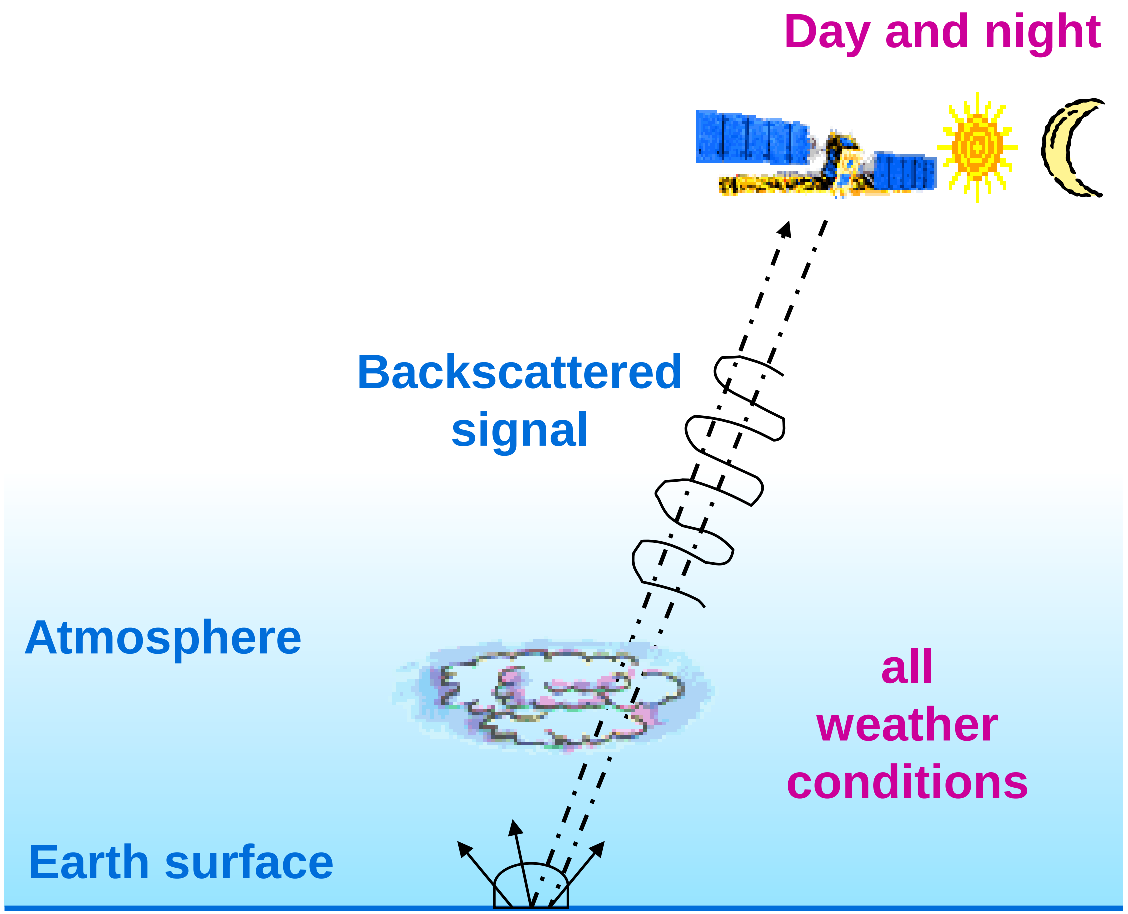
$$f_{Dopp} = \pm \frac{2v}{\lambda}$$



- Imaging Radar:
  - A particular type of radar conceived in order to capture **microwave images** (maps of the reflectivity function of the observed scene)



Imaging Radars



- Microwave sensors are “active” systems, as they do not exploit external sources of radiation, thus they provide **day-and-night** observation capability
- Operating in the microwave frequency band, their performance are **weather-independent**

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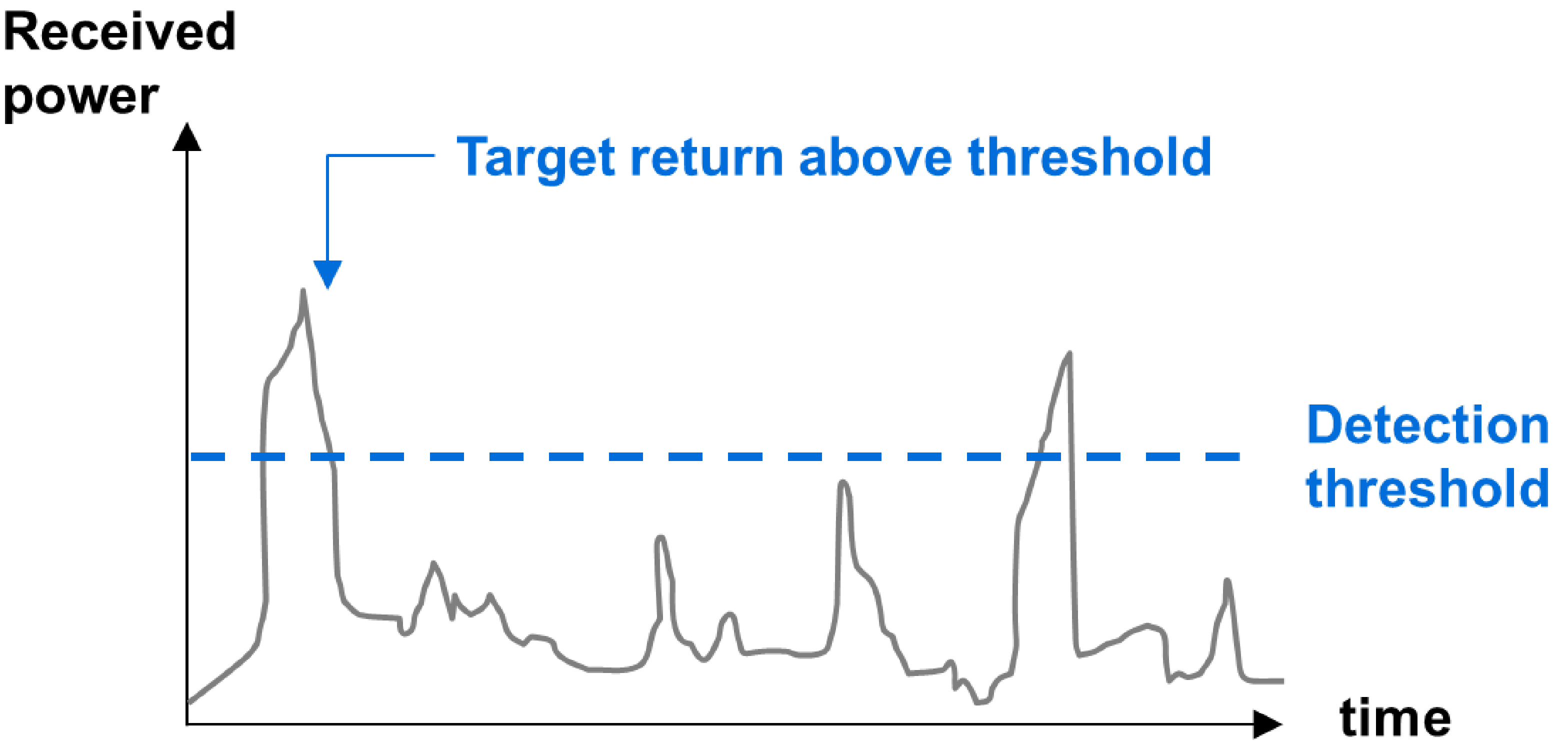
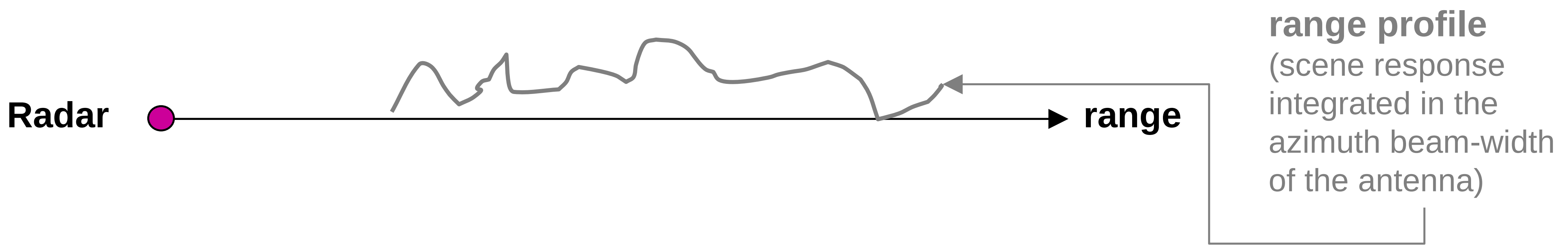
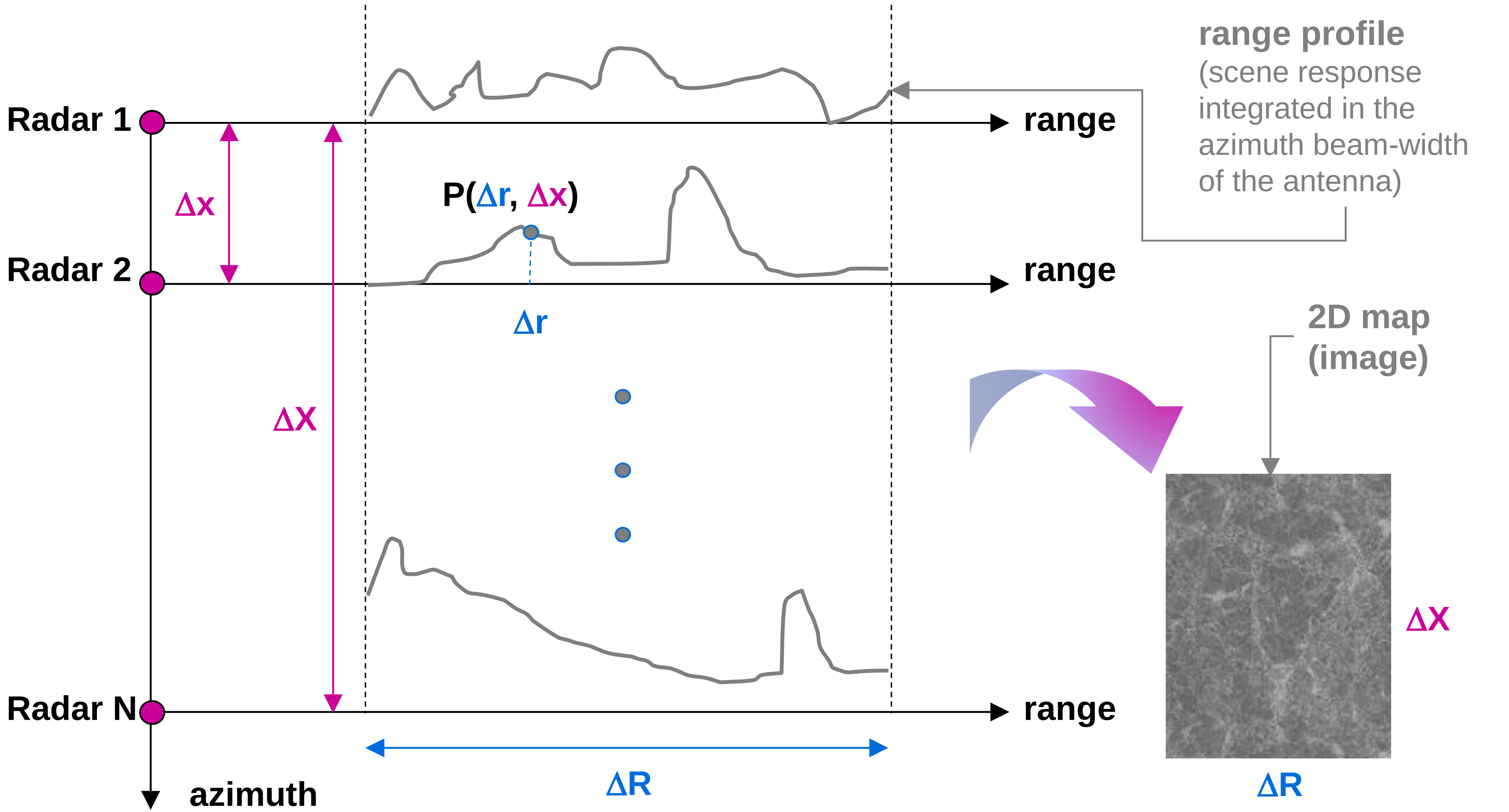

Received power
Target return above threshold
Detection threshold
time

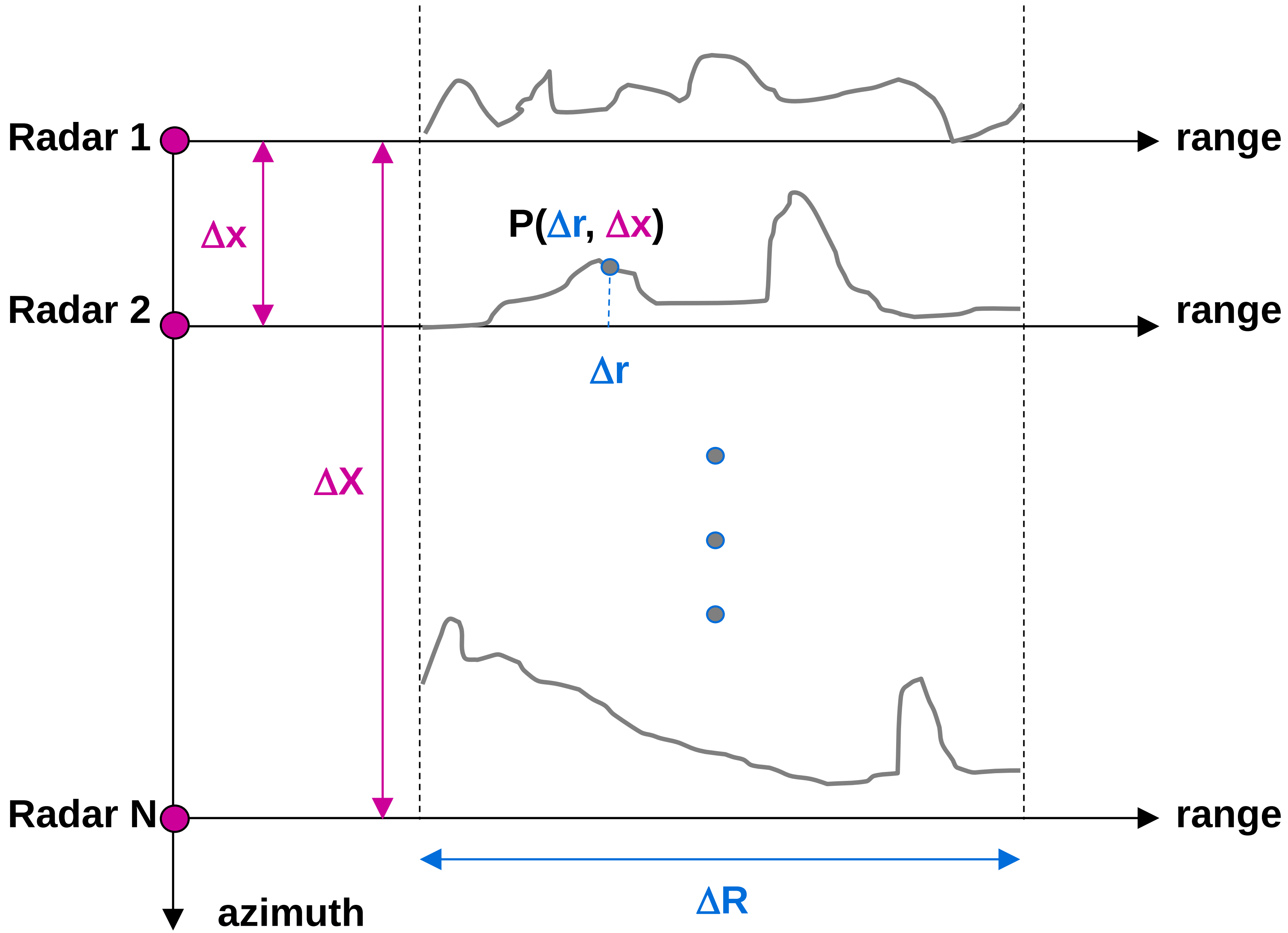
Imaging Radars



Imaging Radars



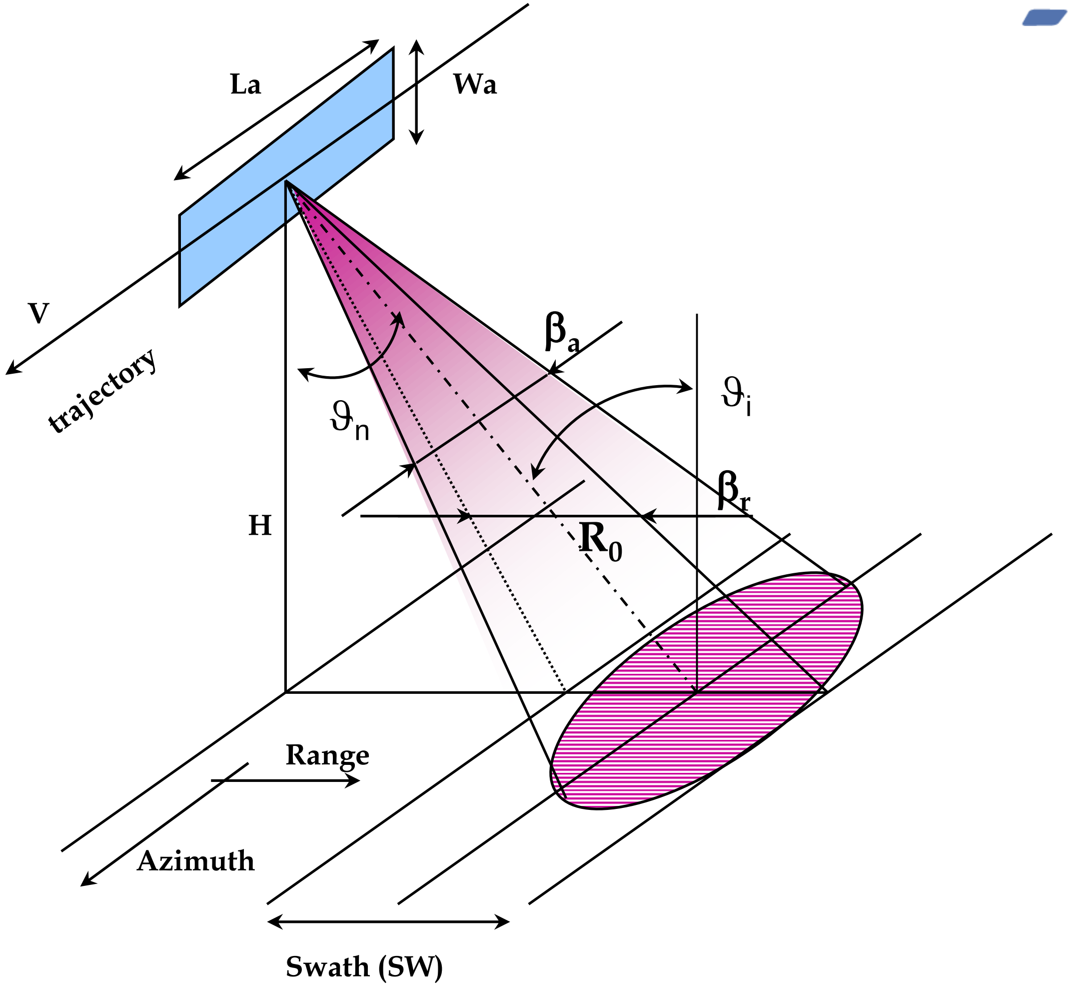
Imaging Radars



An array of radars, or a radar embarked on a moving platform (a satellite?!), to capture a microwave image

Imaging Radars

Satellite

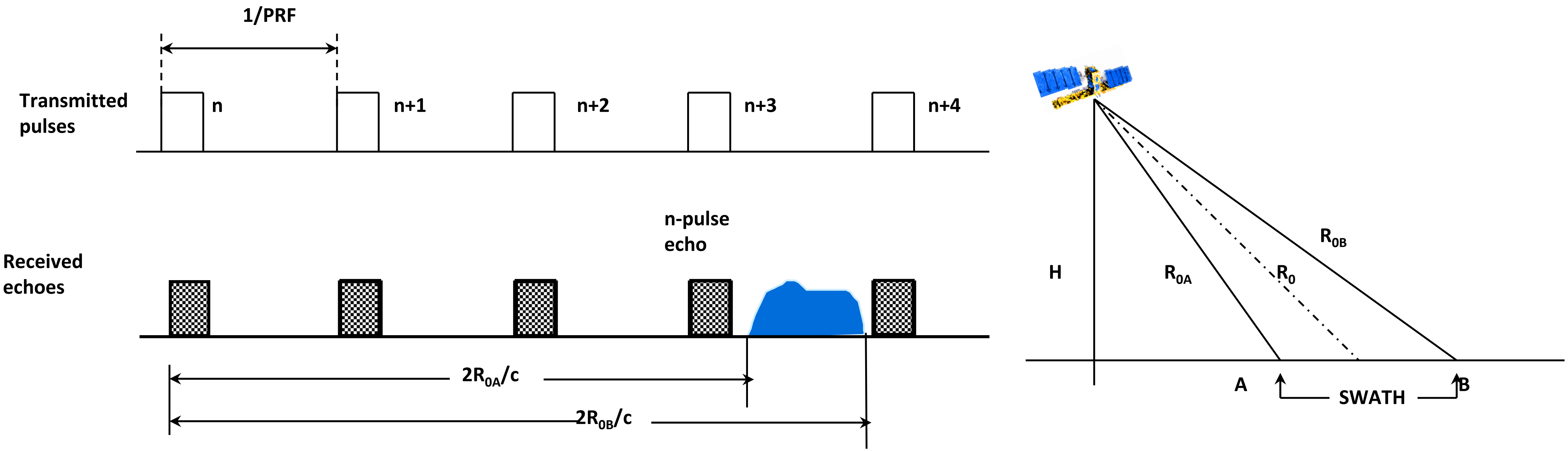


Geometrical parameters:

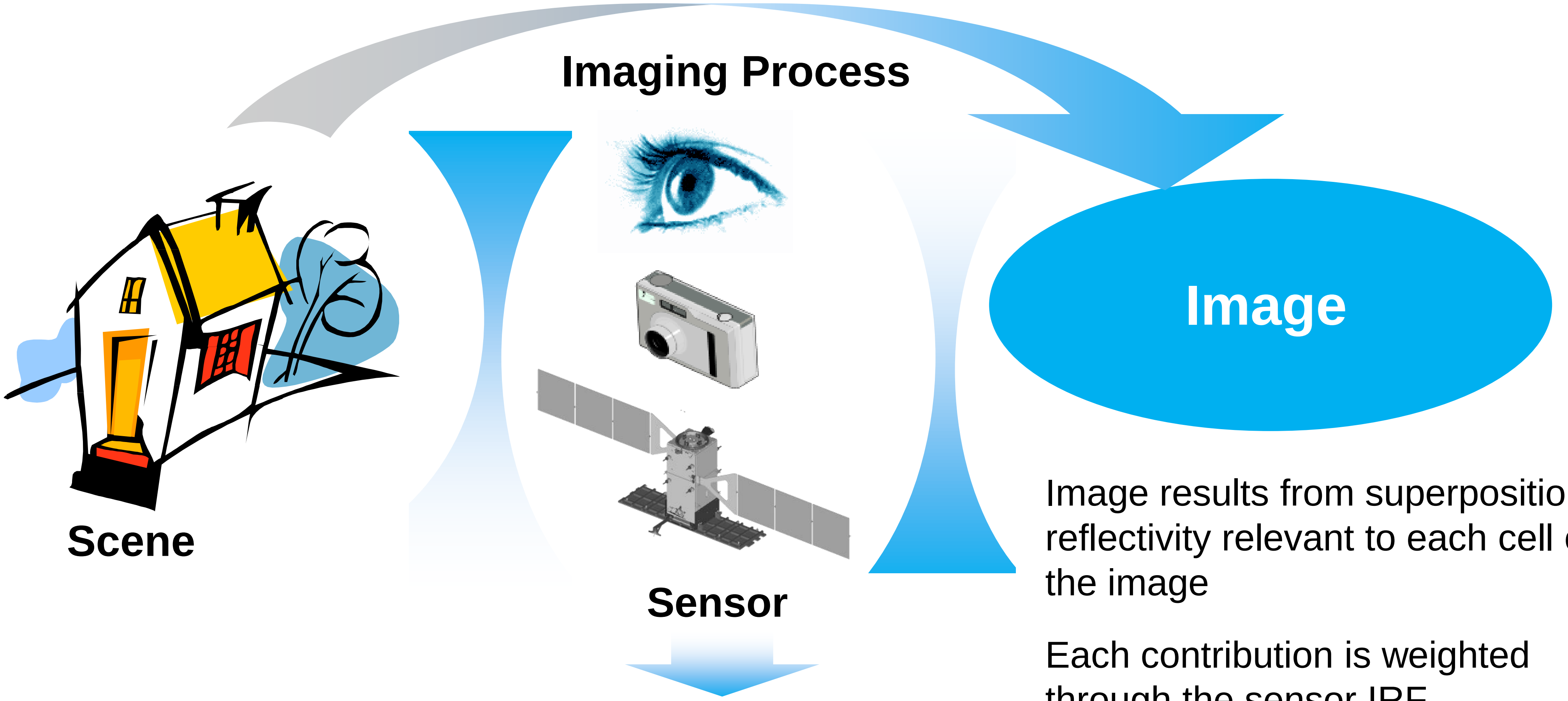
- V satellite velocity
- L_a, W_a antenna dimensions
- H satellite altitude
- R_0 slant range (center swath)
- ϑ_n off-nadir angle
- ϑ_i incidence angle
- λ wavelength
- $\beta_a = \lambda / L_a$ azimuth beamwidth
- $\beta_r = \lambda / W_a \cos(\vartheta)$ elevation beamwidth

Imaging Radars

- The **maximum length of the image** in the range coordinate (**“swath”**) depends on the antenna elevation beam-width and is constrained by the PRI
  - The received echo shall not overlap with the transmitted pulse



Imaging Radars



Mathematical Model:
Impulse Response Function (IRF)

Image results from superposition of reflectivity relevant to each cell of the image

Each contribution is weighted through the sensor IRF

Image quality is specified by IRF

CASSINI MISSION
the first step in ASI/NASA &TASI/JPL cooperation

- Cassini Mission is a co-operative mission between NASA, ESA and ASI to study the physical structure and chemical composition of Saturn as well as all its moons.

- The program started in early nineties and the “Italian Flight Hardware” has been delivered to NASA/JPL in 1996.

- The spacecraft of Cassini Mission has been launched towards Saturn on October 1997.

Alenia SPAZIO
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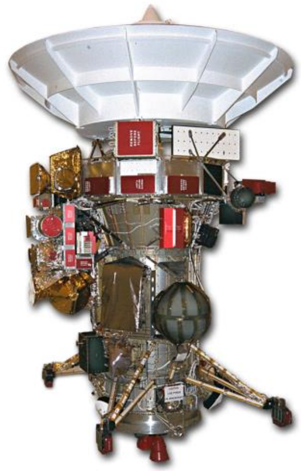
NASA

JPL

asi agenzia spaziale italiana



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Planetary Exploration ---- CASSINI RADAR & HG ANTENNA

October 26t … n Surface

CASSINI Multimode Radar

- **Hi-Res SAR**

  Altitude 1000-1500 km, Resolution 380 (azim.) x 600 (range) m

- **Low-Res SAR**

  Altitude 1500-4000 km, Resolution 600 x 2500 m

- **Hi-Res Altimetry**

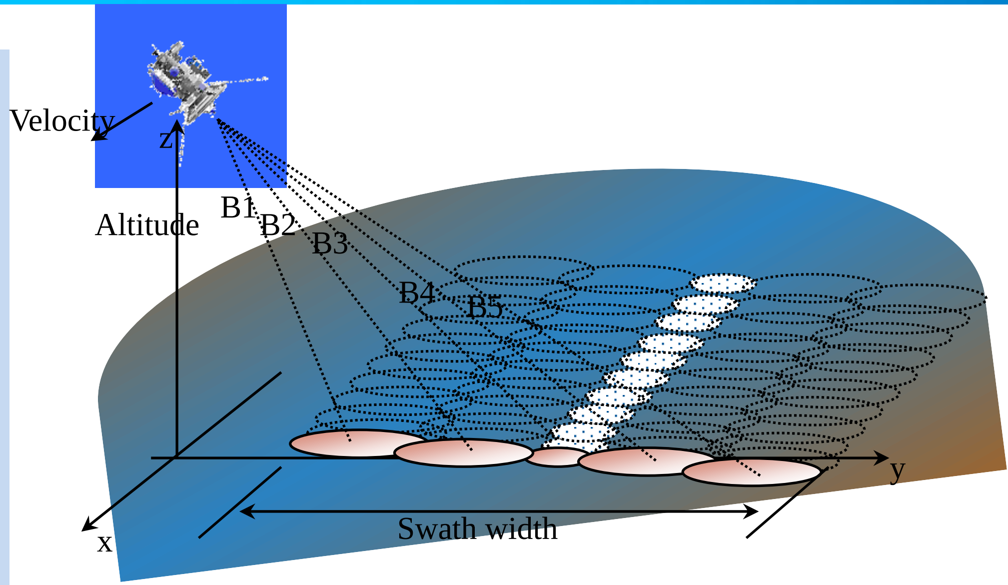
  Altitude 4000-9000 km, Footprint few tens of km, Vertical resolution 35 m

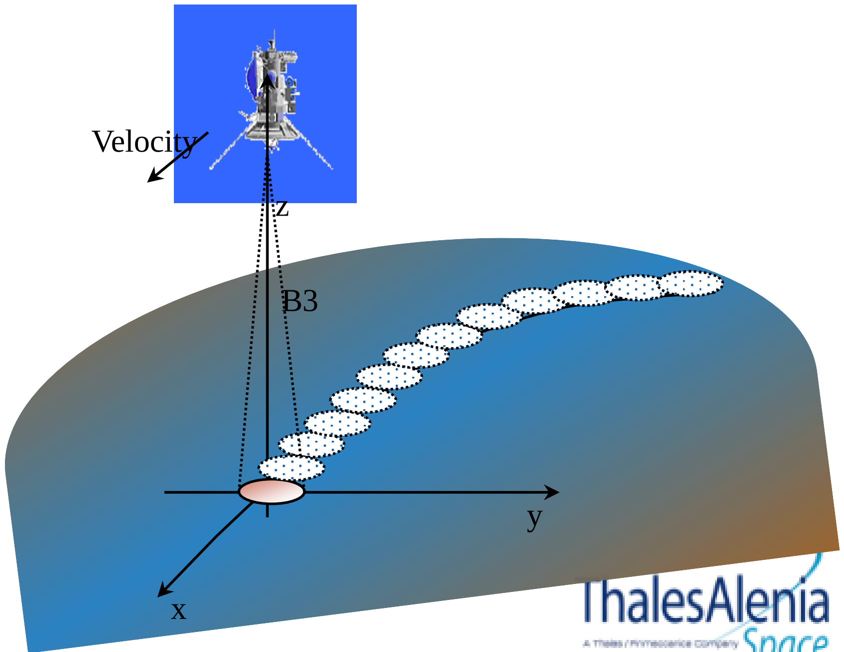
- **Low-Res Altimetry (Scatterometry)**

  Altitude 9000-22500 km, Footprint hundreds of km, Vertical resolution 1415 m

- **Radiometer**

  Altitude 1000-100000 km, 1-sec 1-σ noise = 0.025 K, Half power beamwidth 0.35 deg





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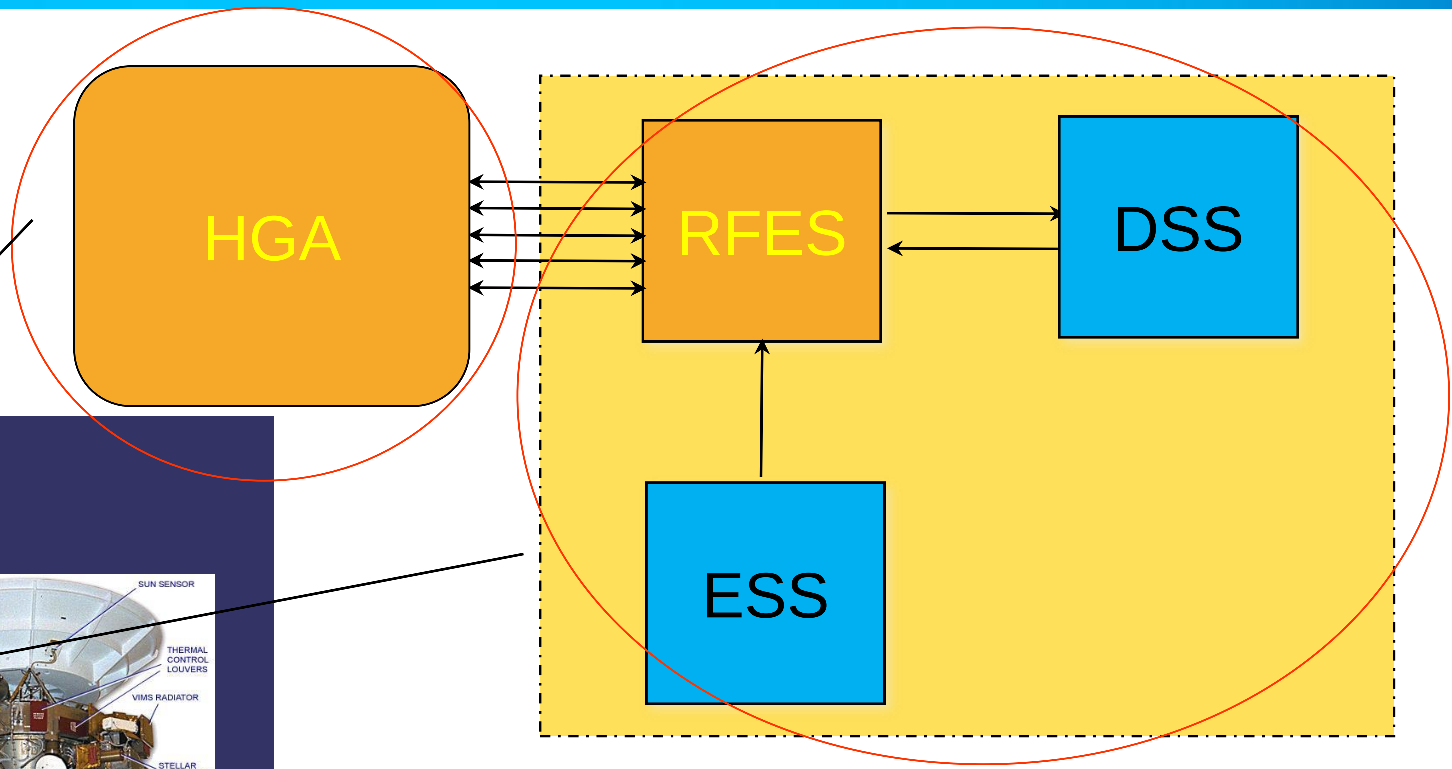
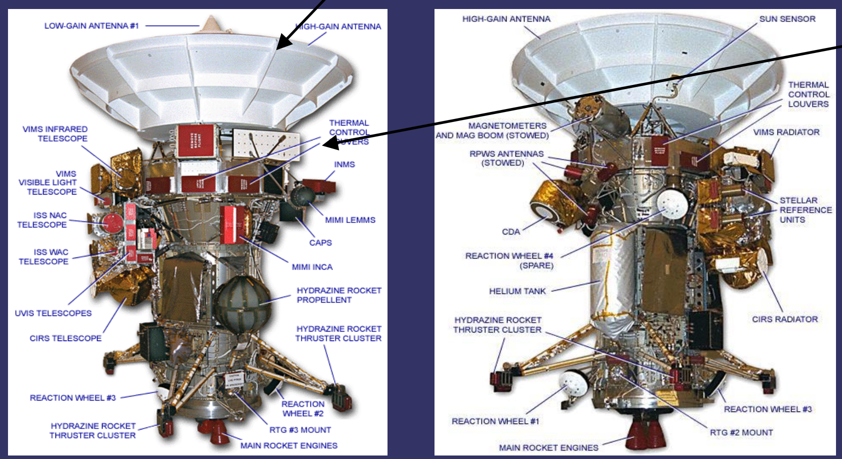
Cassini Radar Architecture



Cassini Spacecraft



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ANT = Antenna

RFES = Radio Frequency Electronic Subsystem

JPL

DSS = Digital Subsystem

ESS = Energy Storage Subsystem

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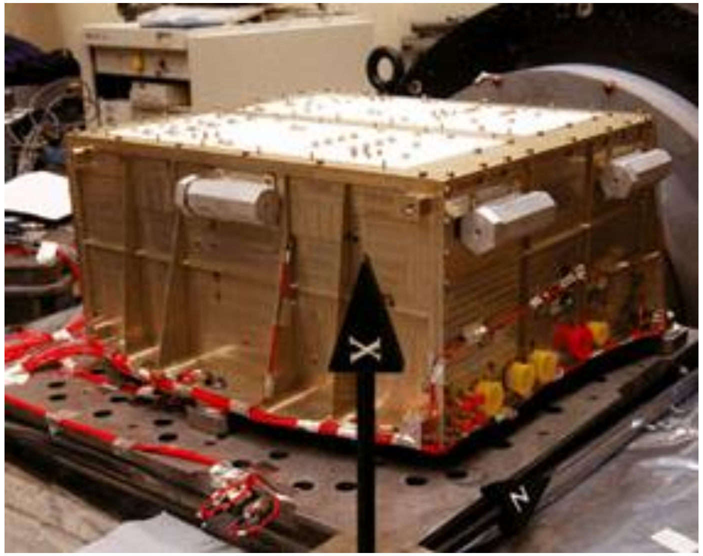
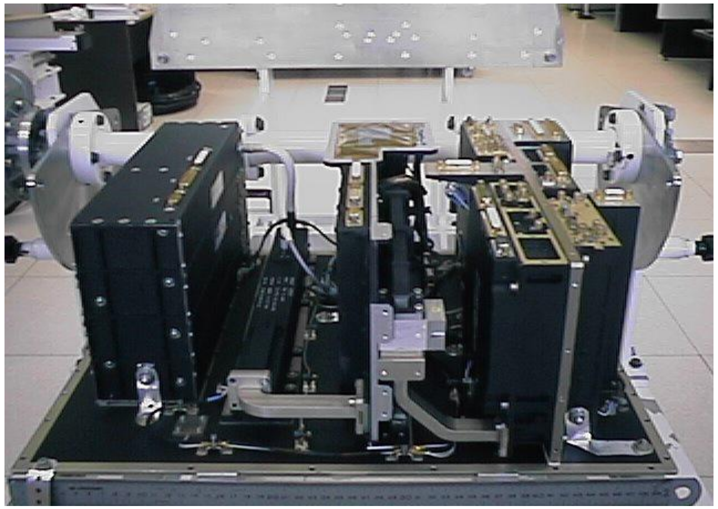
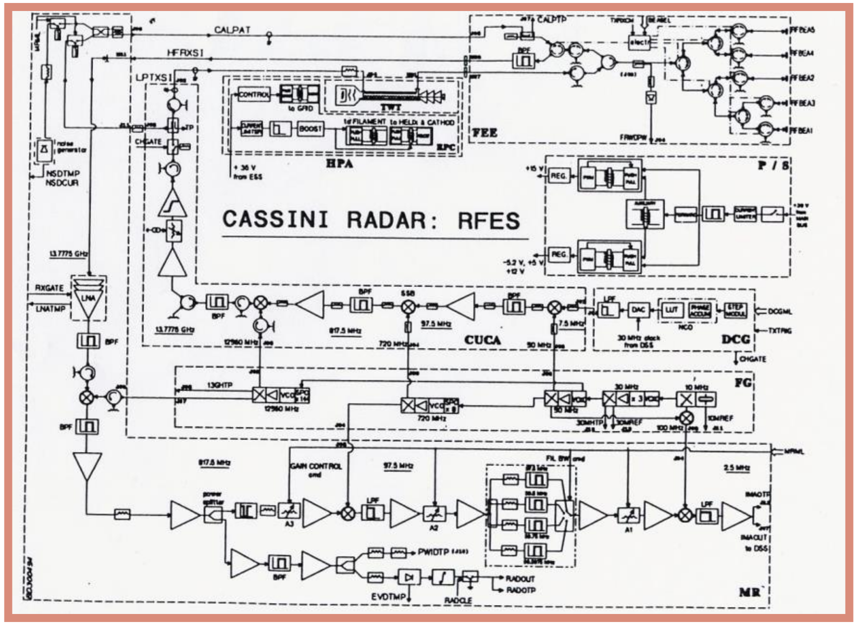
Radio Frequency Electronics Subsystem (RFES)





- The Radio Frequency Electronics Subsystem (RFES) has three principal functions:
  - Transmission of high-power frequency-modulated and un-modulated pulses
  - Reception of both reflected energy from the target and passive radiometric data
  - Routing of calibration signals.
- The RFES electronics units are individually enclosed and are mounted to the RFES housing wall opposite the wall that mounts to the spacecraft.



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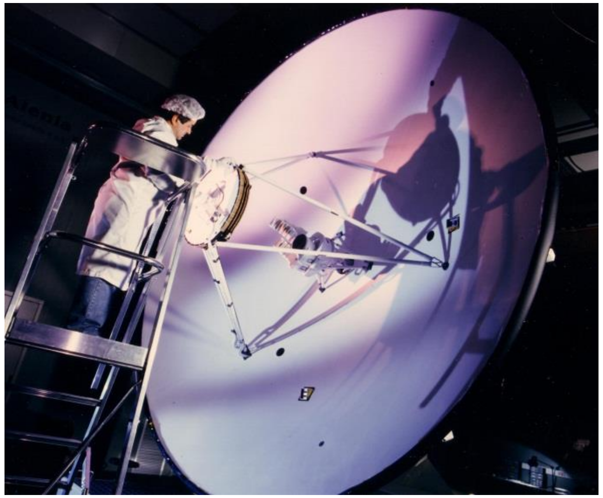
High Gain Antenna (HGA)



The Antenna

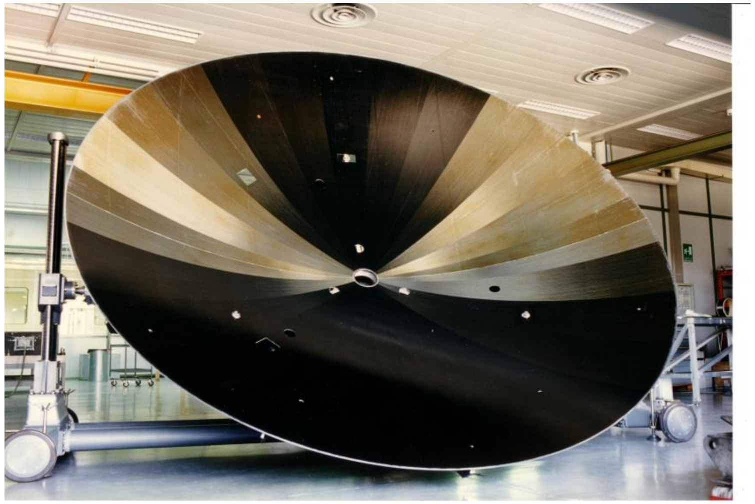
Antenna	Band	Freq. (MHz)	Function	Mode	Polarisation
HGA	S	2040 ± 5	Probe Relay	R	LHCP
	S	2098 ± 5	Probe Relay	R	RHCP
HGA	S	2298 ± 5	Radio Science	T	RHCP
HGA	X	7175 ± 25	Telecom.	R	Dual Circular
	X	8425 ± 25	Telecom.	T	Dual Circular
HGA	Ku	13776.5 ± 100	Radar-SAR	T & R	Linear
HGA	Ka	32028 ± 100	Radio Science	T	Dual Circular
	Ka	34316 ± 100		R	Dual Circular
LGA1	X	7175 ± 25	Telecom.	R	Dual Circular
	X	8425 ± 25	Telecom.	T	Dual Circular

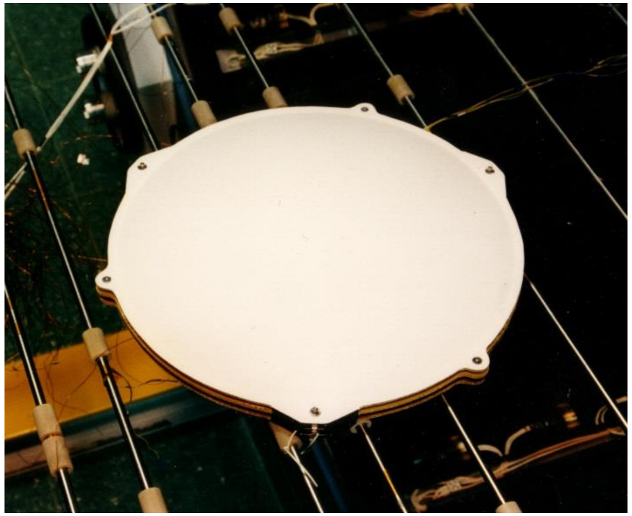
Dichroic Subreflector

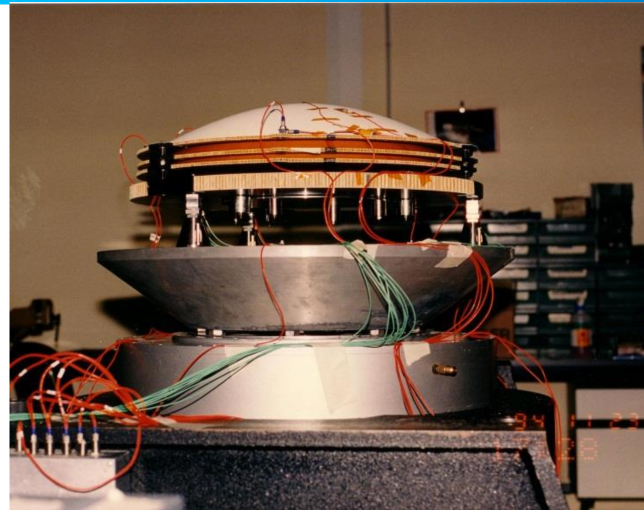
X-Ku-Ka Feed & Ku-Band Array

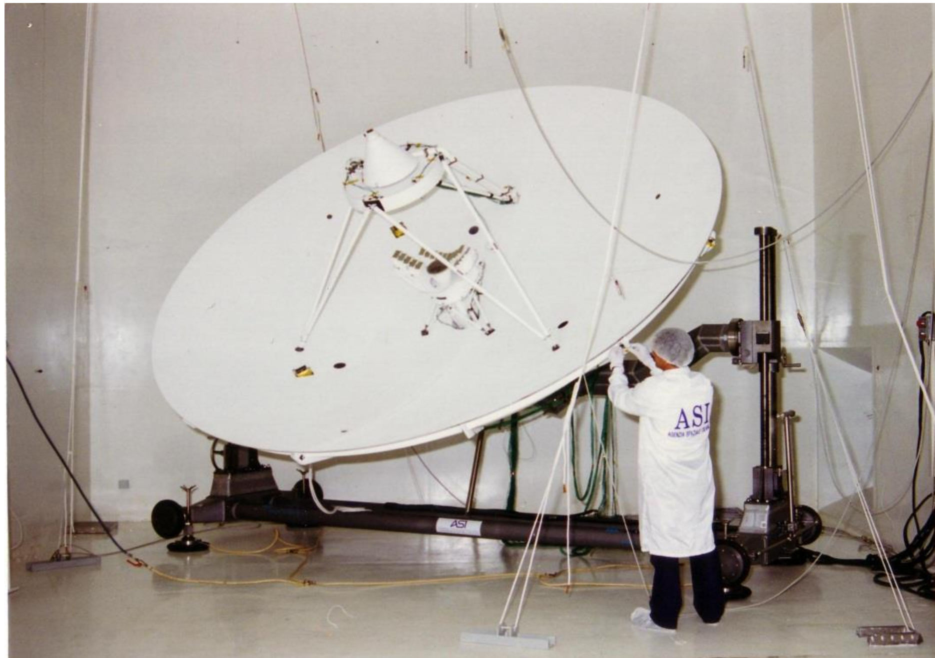
Ku-Band WR62 I/F

HGA Development and Testing









Planetary Exploration ---- MARSIS/SHARAD

Storie vere La conquista dello spazio cominciata negli anni Sessan

«IL MIO ROBOT HA SCOPERTO L'ACQUA S

Giovanni Picardi ha ideato lo strumento che, tramite le ond

SCIENZIATO MARZIANO Roma. Da un decennio Giovanni Picardi (70 anni), professore ordinario di Sistemi di telerilevamento a La Sapienza di Roma, coordina il gruppo di scienziati che, con i suoi studi, ha permesso di scoprire tracce d'acqua nel sottosuolo marziano.

Stefano Lo Cicero Vaina
Roma - Novembre

C'è acqua su Marte? «Sì», ha rivelato la Nasa a giugno. La sonda *Phoenix*, atterrata sul pianeta rosso il 25 maggio scorso, ha fotografato un materiale riflettente sparito dopo quattro giorni. Secondo gli scienziati dell'agenzia americana «è un comportamento compatibile solo con l'evaporazione di ghiaccio d'acqua». Ma ora che Phoenix si è spento, ibernato dai -95 gradi dell'inverno marziano, l'unico occhio disponibile è quello dei due radar *Marsis* e *Sharad* progettati per scandagliare il sottosuolo del pianeta.

La tecnologia è di concezione italiana

E se entrambi i radar sono stati "imbarcati" su sonde internazionali (*Marsis* su *Mars Express* dell'Agenzia Spaziale Europea e *Sharad* su *Mars Reconnaissance Orbiter* della Nasa), le onde emesse parlano italiano. Sono stati costruiti con la supervisione del professor Giovanni Picardi, ordinario di Sistemi di telerilevamento alla Sapienza di Roma, insieme col suo team composto da cinque giovani ricercatori e dal professore Roberto Seu, responsabile di *Sharad*.

Professore Picardi, perché tanto interesse per l'acqua?

«Perché è la condizione essenziale per la vita. I primi microorganismi terrestri sono nati proprio in acqua, quindi se vogliamo scoprire forme viventi extraterrestri dobbiamo inseguire quest'elemento così essenziale, scoprirne le tracce per trovare la vita».

Cosa fanno i suoi radar?

«Innanzitutto direi che sono frutto della collaborazione internazionale. Noi abbiamo fornito la nostra competenza in materia di telerilevamento. Sia *Marsis* che *Sharad* sono stati costruiti in Italia e montati sulle sonde orbitanti per cercare l'acqua nel sottosuolo marziano».

Come funzionano?

«Inviano onde radio a bassa frequenza. Una volta incontrata la superficie di Marte, penetrano nel sottosuolo fino a raggiungere profondità diverse. Il modo in cui queste onde tornano indietro fino al radar ci permette di definire gli strati di sedimenti sotto la superficie, rilevando quindi acqua o ghiaccio».

Come fate a capire che si tratta proprio di acqua?

«Effettivamente, presumiamo che sia acqua sulla base del segnale ricevuto. Le onde vengono riflesse dal materiale sotterraneo e l'indice di riflettività, chiamato "permettività", ci dice di cosa è composto il sottosuolo. Se c'è acqua liquida, questo indice ha un valore più elevato corrispondente a 80. Sulla Terra, a questo valore corrisponde la presenza d'acqua».

Così avete riscontrato lo stesso "numero" su Marte?

«Esatto. Pensiamo che sia acqua o comunque un liquido composto d'acqua. Ci vuole ancora del tempo per avere la certezza».

Il modo più sicuro sarebbe andare su Marte e scavare con le mani...

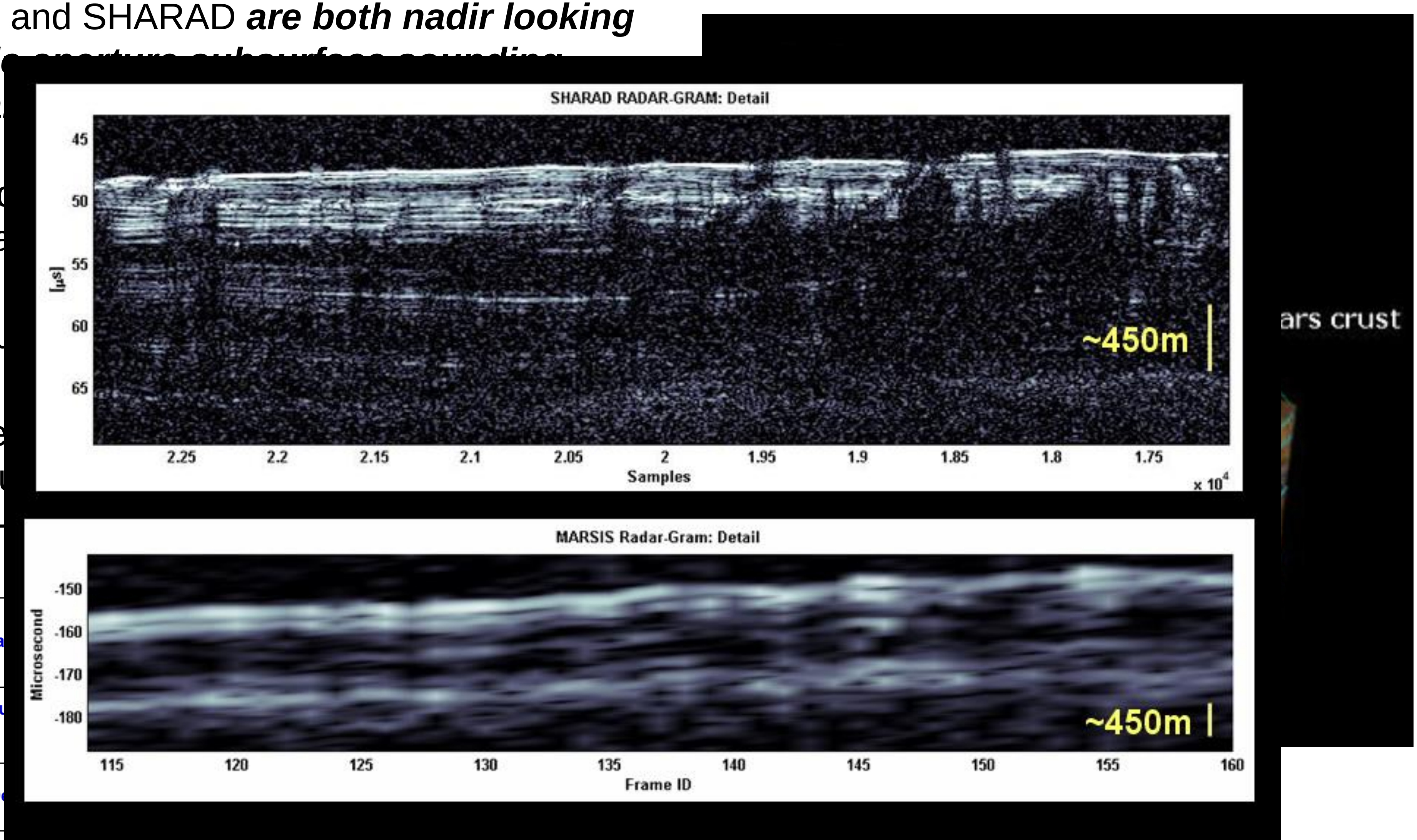
«Eh, magari! Ma per ora è impossibile sia per le condizioni atmosferiche estreme sia per i costi enormi che comporterebbe una missione sul pianeta rosso».

Qual è la differenza tra *Marsis* e *Sharad*?

mars_express.mpeg

MARSIS & SHARAD Description

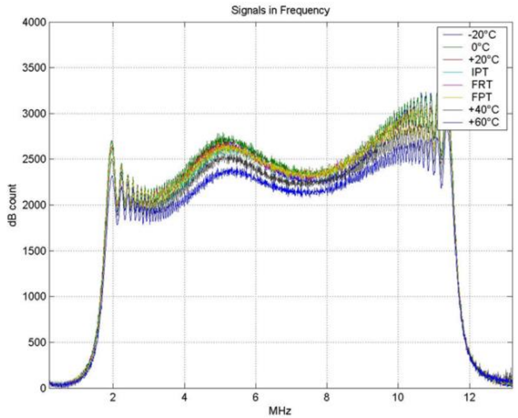
- MARSIS and SHARAD ***are both nadir looking synthetic*** ***radars a***
  to detect
  liquid and
  of the Ma
- MARSIS
  isolate su
- MARSIS
  ionosphe
  the subsu

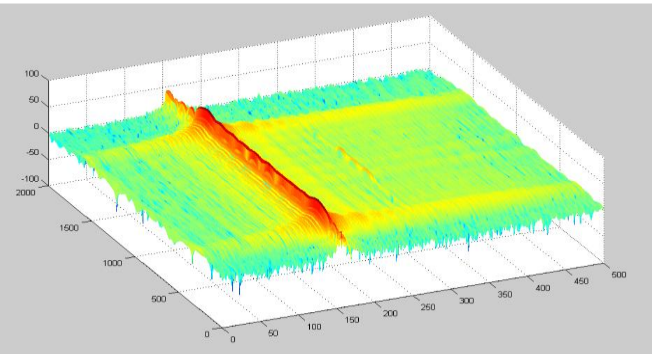


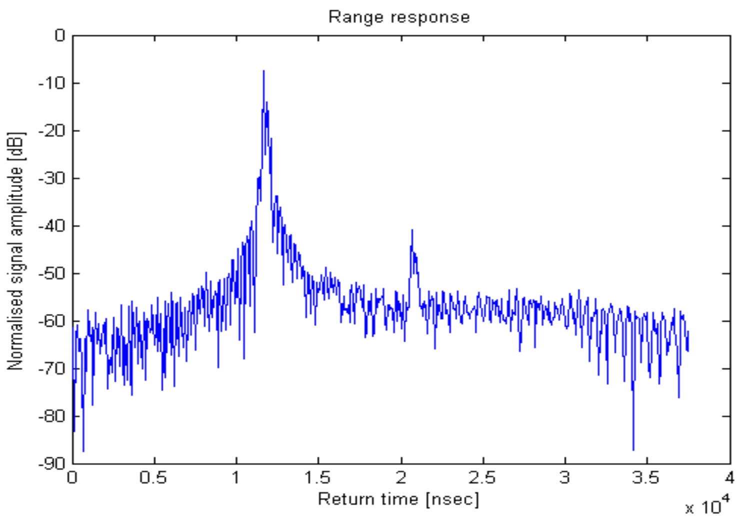
Frequency Ba		
Vertical Resolu ($\varepsilon/\varepsilon_0$ = 5)		
Penetration D		
Horizontal Resolution (along-track x cross-track)	5-9 km x 15-30 km	0.3-1 km x 3-6 km

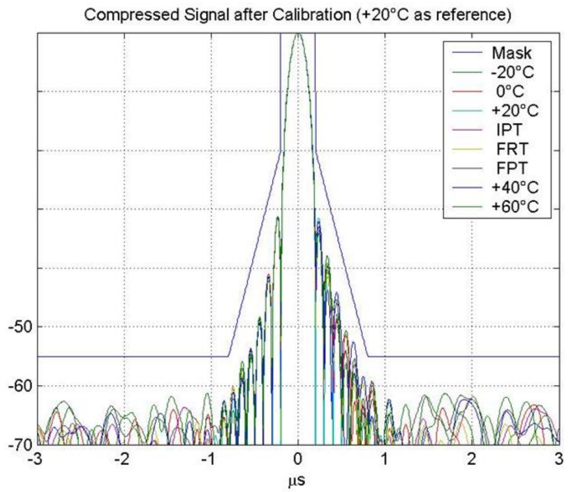
Sounders key constraints and challenges

- Low mass HF foldable antenna
- Antenna matching network
- Transmitter efficiency
- Control of signal quality
- On Board Processing
- Testing tools capable to simulate the «unknown scenario»





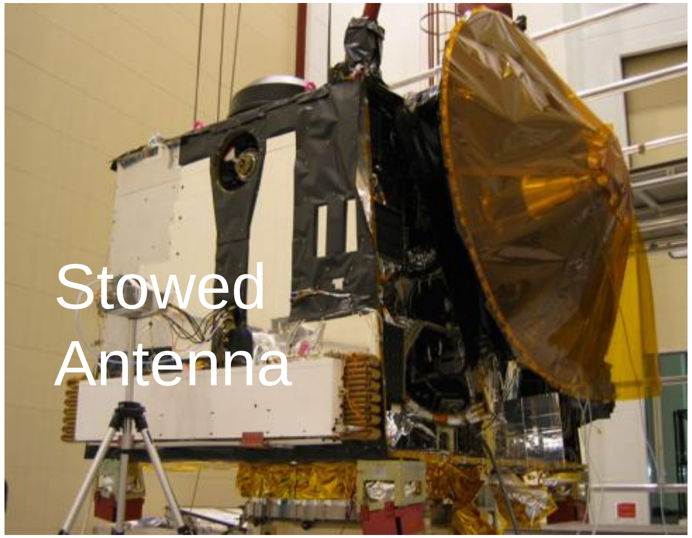


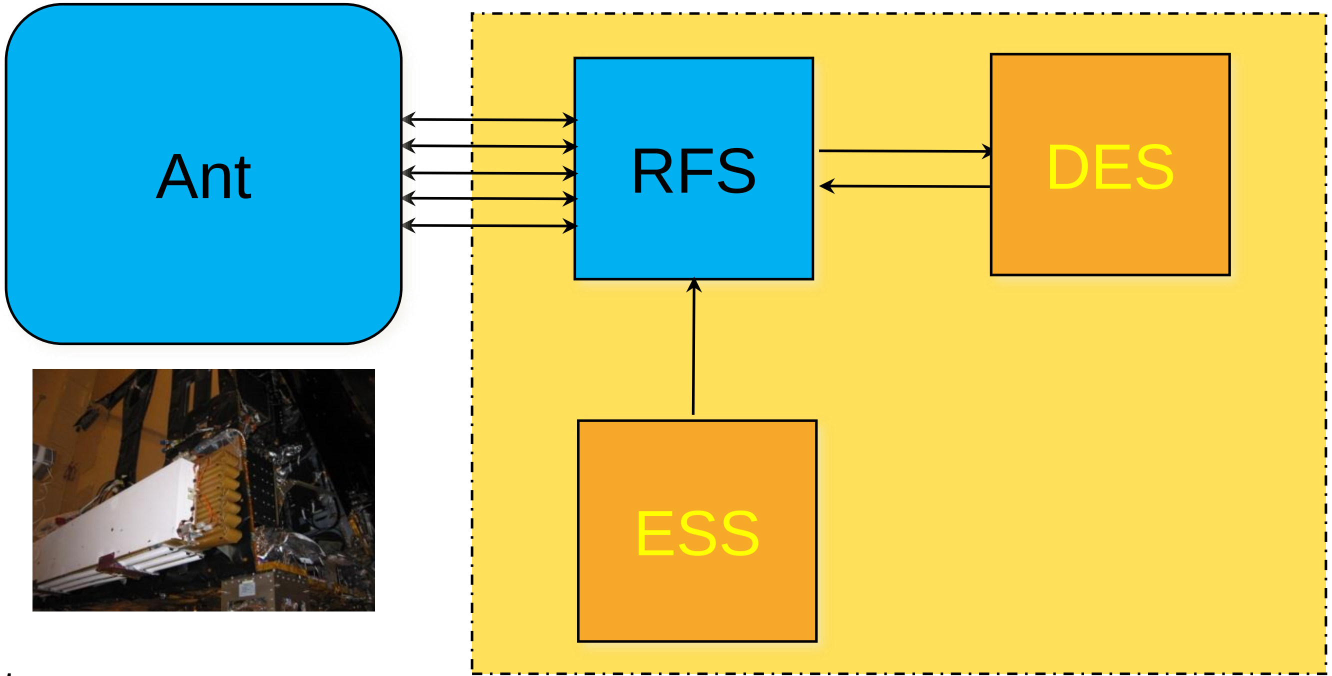


MARSIS Background

- MARS EXPRESS is the European contribution to the Mars exploration program and is headed by ESA.
- It has been launched in June 2003.
- One of the seven instruments on Board Mars Express is MARSIS (Mars Advanced Radar for Subsurface and Ionosphere Sounding)
- The radar MARSIS is a co-operative project funded by NASA and ASI whose technical leadership is co-shared between Thales Alenia Space Italia and JPL.
- **Thales Alenia Space is the design authority for the Digital Control and Processing Subsystem (DES)** of the radar and retains the **coordination of AIV/AIT activities of the overall instrument that has been integrated in ThalesAlenia Space Rome plant.**
- ThalesAlenia Space has the **responsibility of the In-flight instrument commissioning and of the End to End Instrument Operations**
- In this frame ThalesAlenia Space designed, developed and realized the **MARSIS Operation Center (MOC).**

MARSIS: Instrument Description





JPL/Univ of IOWA

ANT = Antenna

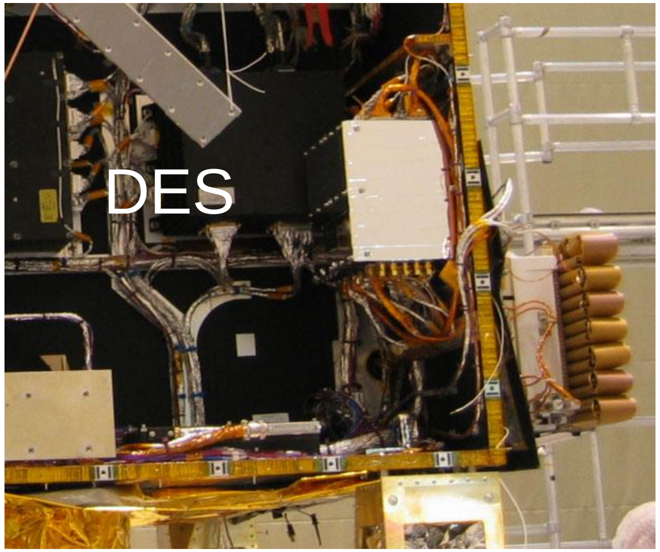
RFS = Radio Frequency Subsystem

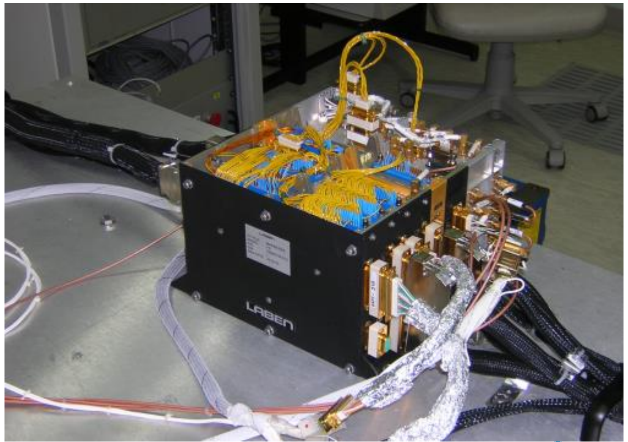
Thales Alenia Space

DES = Digital Electronic Subsystem

ESS = Energy Storage Subsystem

	SUBSURFACE	IONOSPHERIC
TX Signal:	Chirp	Sweep of CW Signals
Bandwidth:	1 MHz	Na
Center Frequency:	1.8, 3, 4, 5 MHz	From 0.1 to 5.5 MHz
Pulsewidth:	250μs (baseline)	91.43μs
PRF	130 Hz	130 Hz
Received Echoes per PRI	Up to Four	80





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MARSIS Design Key Issues

- Very large fractional bandwidth of the treated signals
  - 1 MHz of BW w.r.t. 1.8 MHz (worst case)
- On Board Processing (performed in real time by DES)
  - Range Compression (Matched Filter using 512 points FFT/IFFT)
  - Real time Ionospheric correction (estimation of plasma frequency and reference function pre-distortion)
  - Doppler processing & Multilook (up to 5 filters)

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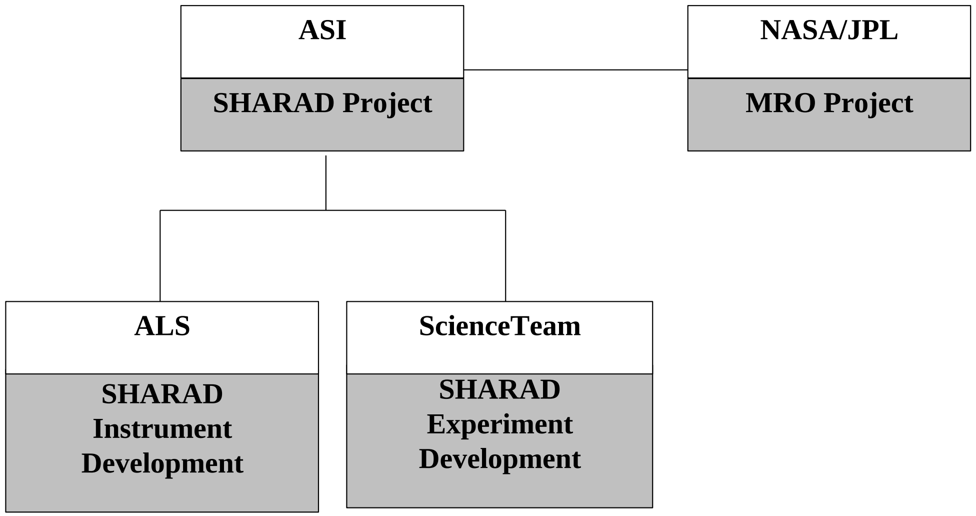
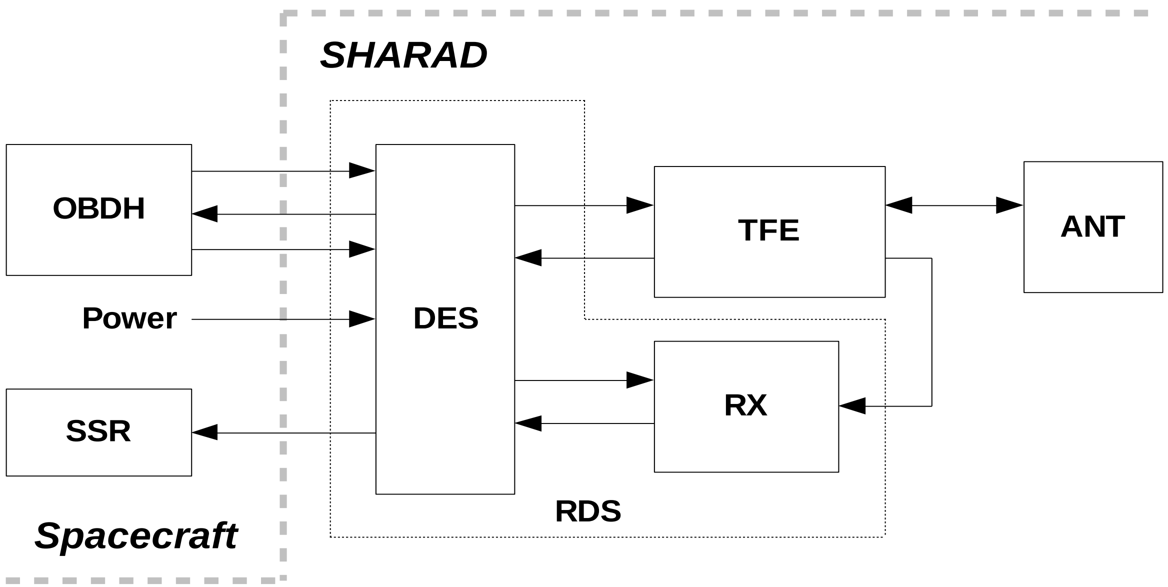
ThalesAlenia Space contribution to MRO: SHARAD

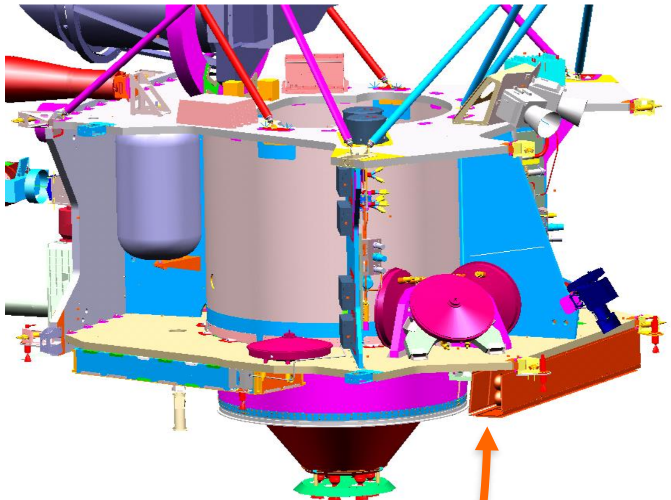


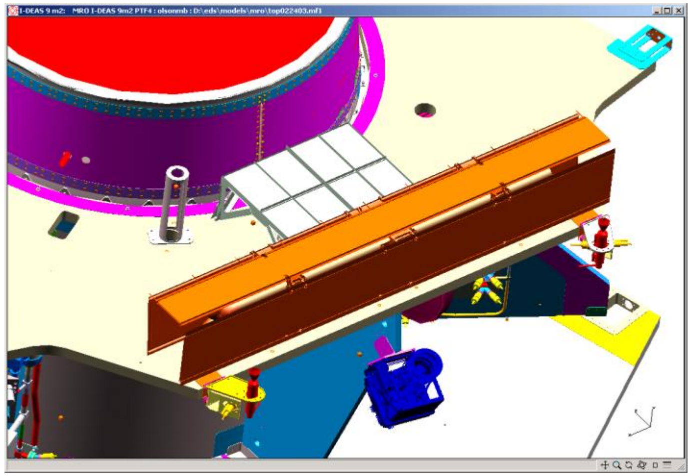


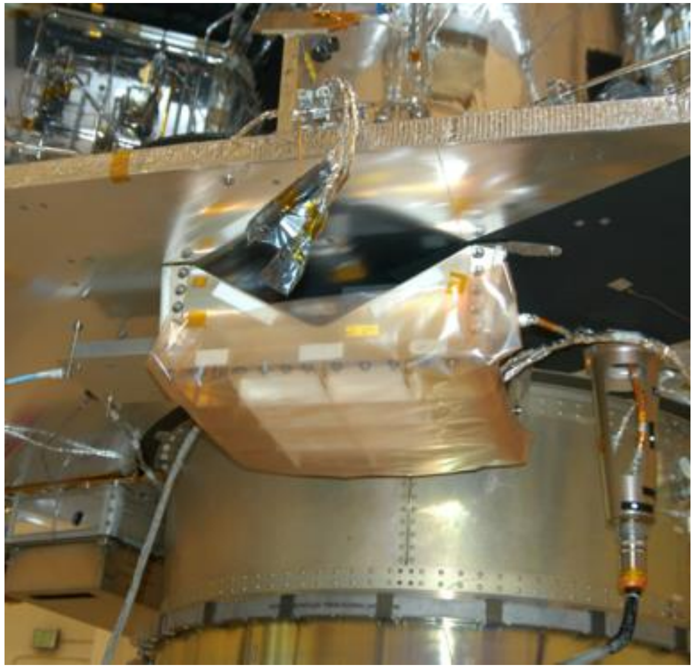
- ALS (now TAS-I) was the prime contractor of the SHARAD Instrument.
- It had the responsibility of the In-flight instrument commissioning and of the end-to-end instrument operations
  - In this scope it designed, developed and realized the SHARAD Operation Center (SHOC).

- Antenna Efficiency: > 10%
- Centre Frequency: 20 MHz
- Radiated Peak Power: 10 W
- Pulse Length: 85 us
- Pulse Bandwidth: 10 MHz
- Pulse Repetition Frequency: 700 Hz, 670Hz, 775 Hz (350, 335, 387.6 Hz)
- alternate PRF added to cope with orbital extreme during extended phase (including topography margin)
- Receive window: 135 us
- A/D Resolution: 8 bits
- Downloaded sample bits 8 (default), 6, 4
- A/D frequency: 26.67 MHz
- Maximum Data Rate: 20.16Mbit/s (@ 700 Hz) 22.32 (@ 775 Hz)

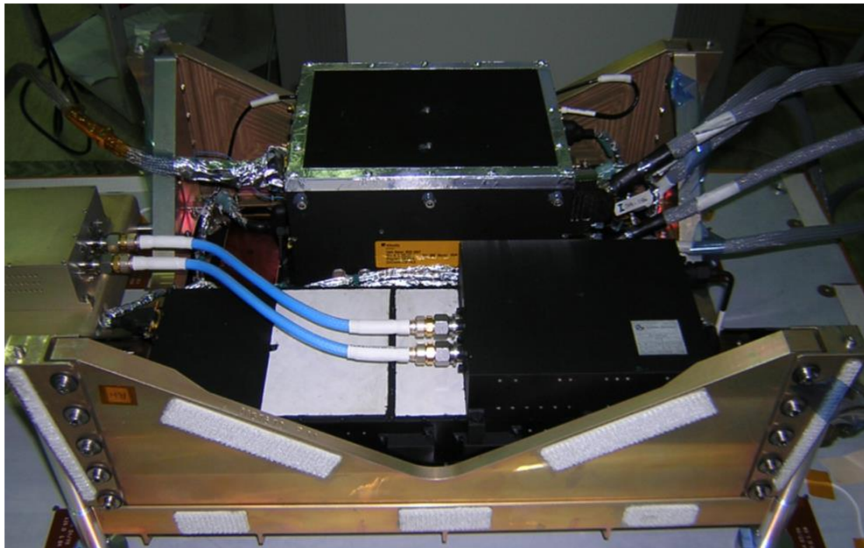
SHARAD on MRO







SHARAD



Recent developments: EXOMARS Radar Doppler

- The EXOMARS Radar Doppler (RDA) will support the Entry Descent and Landing Demonstration Module during the landing phase on the Mars surface in 2016/2020 Missions

- It is designed and manufactured by Thales Alenia Space Italia (TAS-I) under the responsibility of the European Space Agency (ESA).

- The design of the RDA is driven by *challenging constraints* on mass, volume, power consumption and specific operational and environment requirements related to the Mars landing conditions.

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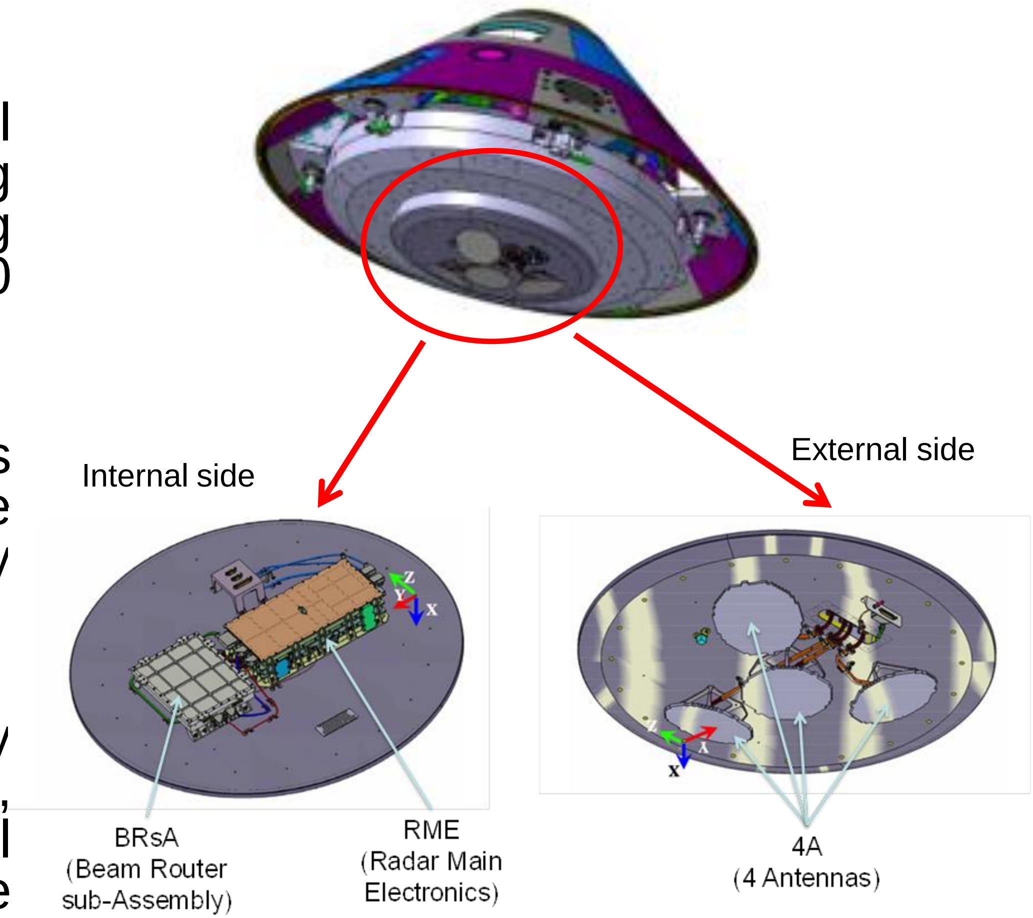

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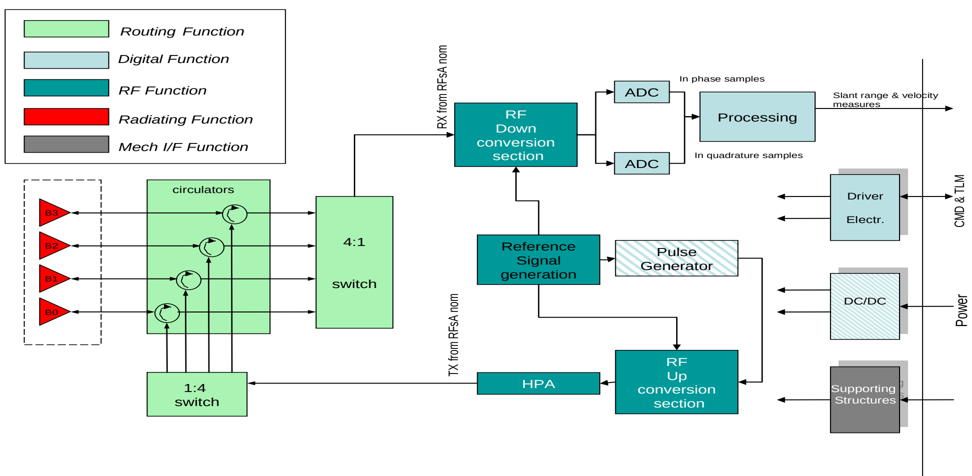
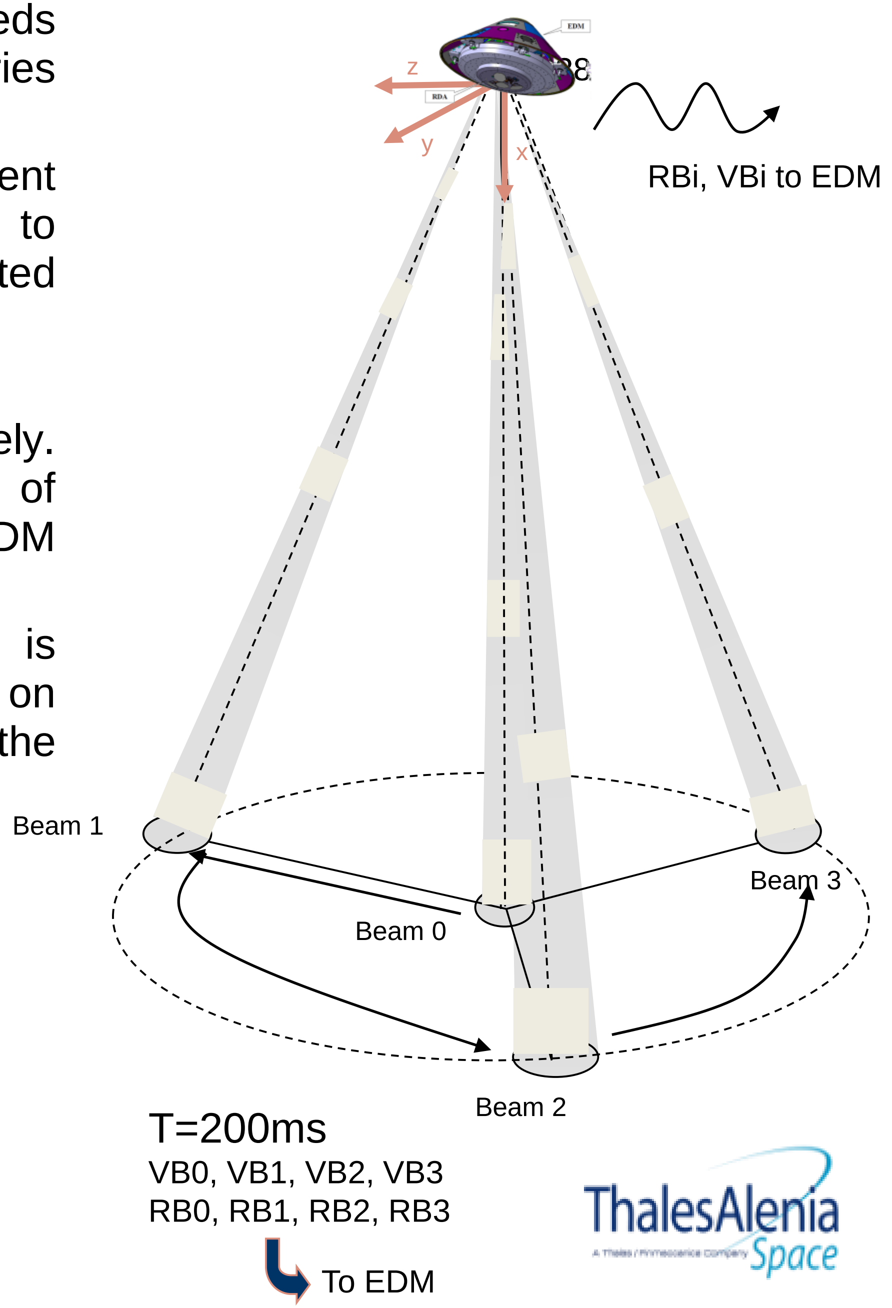
RDA Architecture And Functional Description

- The Architecture design has been driven by the System level needs @ GNC level, where at least three different acquisition geometries have been requested, this to ensure a position reconstruction.
- The proposed solution has included four independent measurements, to guarantee at least three measurements and to ensure an higher accuracy considering every time a beam pointed toward nadir.

- Access to each single beam happens in time-division iteratively. According to a fixed refresh rate (20 Hz) a new measurement of range and of velocity values along one beam are provided to EDM GNC.
- The measurement is independent from the previous and is conducted using a dedicated antenna, with a whole refresh time on each antenna of 200 ms (time between two measurement on the same antenna.)





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Radar Doppler Operational reqs >> Performances&Budget

Operational Requirement	Value
Altitude envelope	*10m < H < 6500 m (2500 m [1])*
Velocity envelope	*0 m/s < V (vertical) < 115 m/s (90 m/s [1])*
Acceleration	*ax < 9.3 m/s2; ay, az < 2.65 m/s2*
Jerk	*jx < 93 m/s3; jy, jz < 26.5 m/s3*
Off-nadir angle range	*± 45° (vehicle pointing variation)*

[1] Range in which the performances are requested
[2] 4 beams are implemented for the actual application which ask for 4 independent measures.

Design Parameters	Value
Carrier Frequency	*F0 = 35.76 GHz*
Antenna Beams	*4* [2]
TX Peak Power	*1 W*
TX BW	*200 MHz*
Pulse width	*20 ÷2560 ns*
PRI	*10 ÷ 240 usec*
RX signal BW	*50 MHz*
Antenna Directivity	*>34 dB*
Antenna sidelobe level	*<-35 dB*
Antenna beam aperture	*< 3 deg*

Qualified Performances [3]	Value
Measure Refresh rate	***20 Hz (50ms)***
Velocity measurement accuracy	***±0,2m/s + 0,05% of the current velocity***
* ***Altitude measurement accuracy***	***±0,4m + 0,05% of the current altitude***
Dynamic Range	***-95 dBm – 0 dBm***

Budget	Value
Mass	***10 kg*** [4]
Volume	***Ø680 mm x 120mm***
PW consumption	***55W (unregulated bus 22V-36V)***

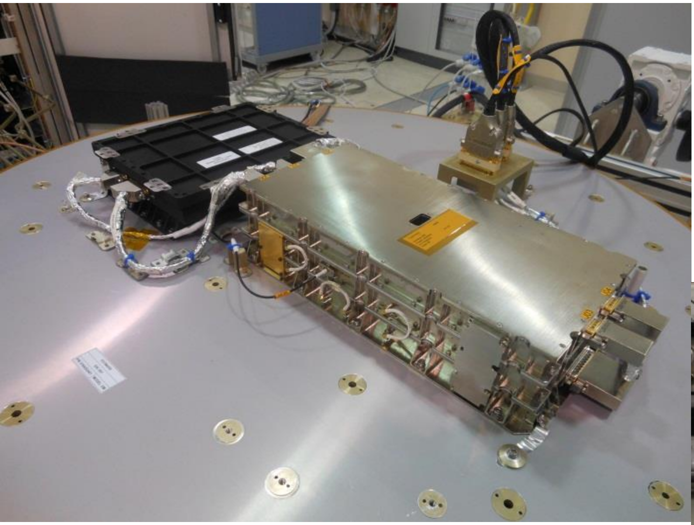
[3] The performances are achieved by each single antenna's measure
[4] In case a single measure is needed the mass can be reduced to 6-7 Kg (no need for beam switch assembly)

Approaching and Landing Radar

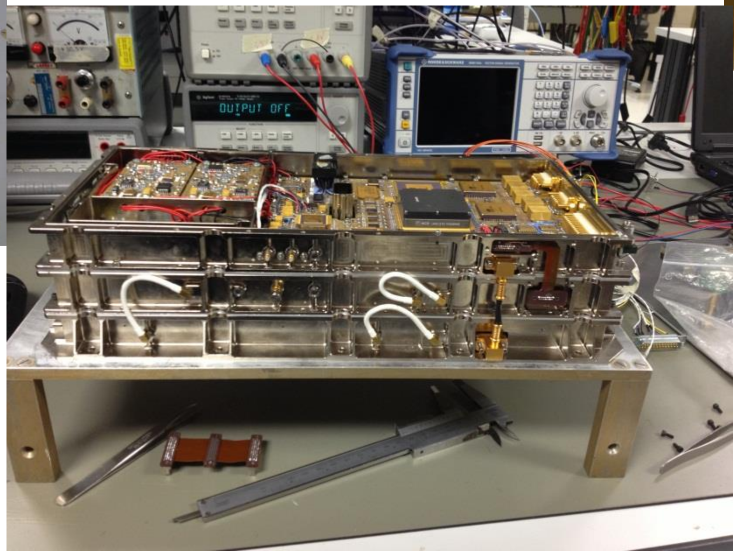
- The Approaching and Landing Radar (ALR) is a Pulsed CW in Ka Band (35,76 GHz)
- It provides highly accurate navigation data (range and velocity) to Guidance and Navigation Control systems, in landing and/or approaching missions.

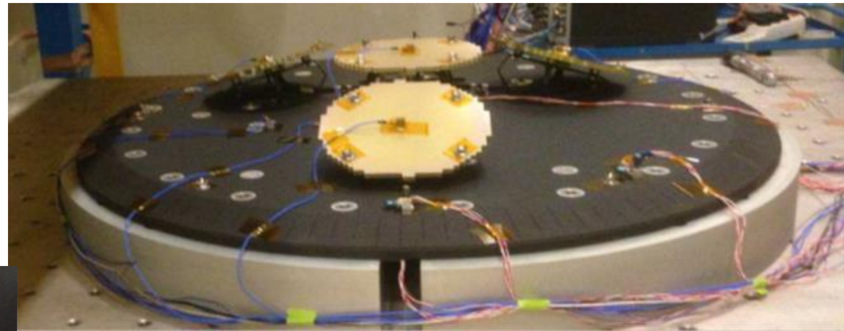
Keywords

- ***Highly accurate nav data***
- ***Low Mass*** and ***Compact Envelope***.
- ***Low Power Consumption***
- The ***multi mission applicability***, thanks to the wide receiver dynamic range.



Ka band electronics





Ka band antennas

On-going development

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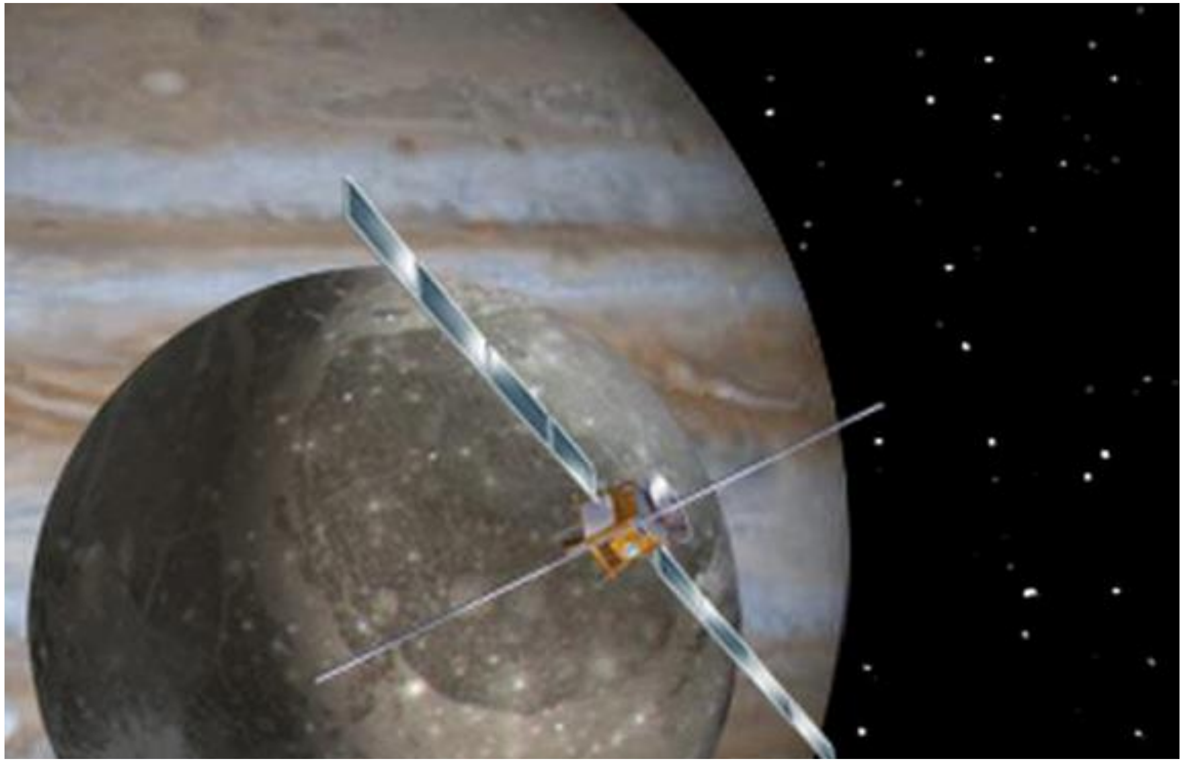
- ESA/JUICE: RIME, Radar for Ice Moon Exploration
  - ➔RIME is a radar sounder (originally referred to as Ice Penetrating) optimized for the penetration of the Galilean icy moons, **Ganymede**, **Europa** and **Callisto**, up to a depth of 9 km. RIME is a key instrument for achieving ground-breaking science on the geology and the geophysics of **Jupiter moons**.



RIME: Instrument Description

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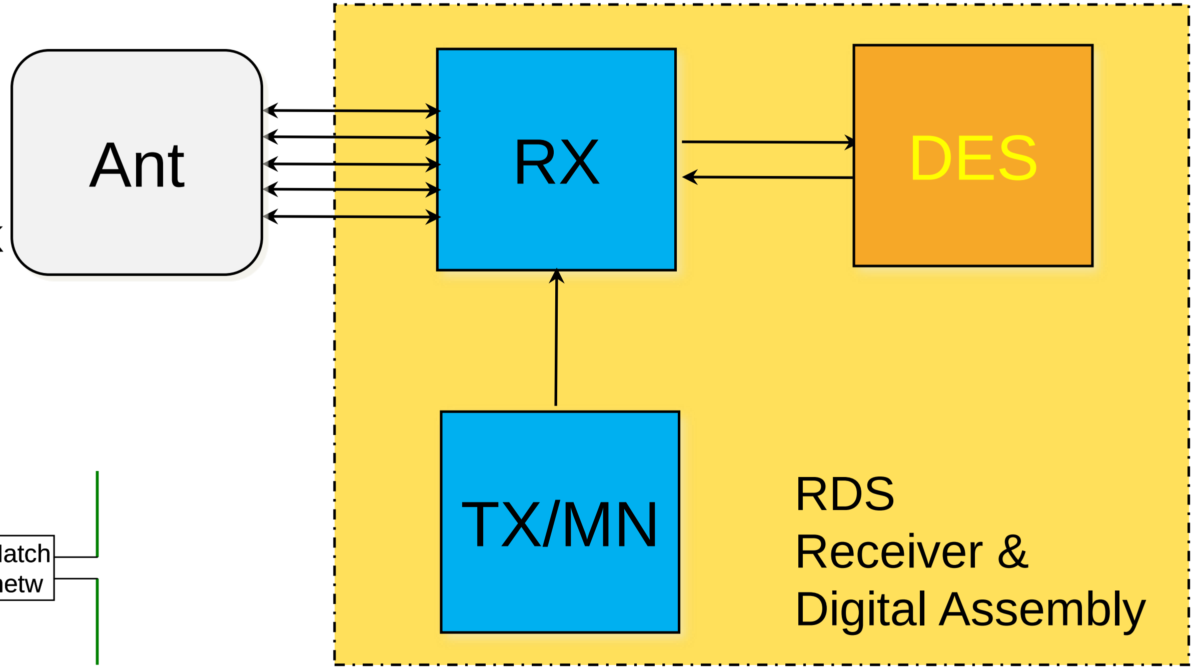
RDS System

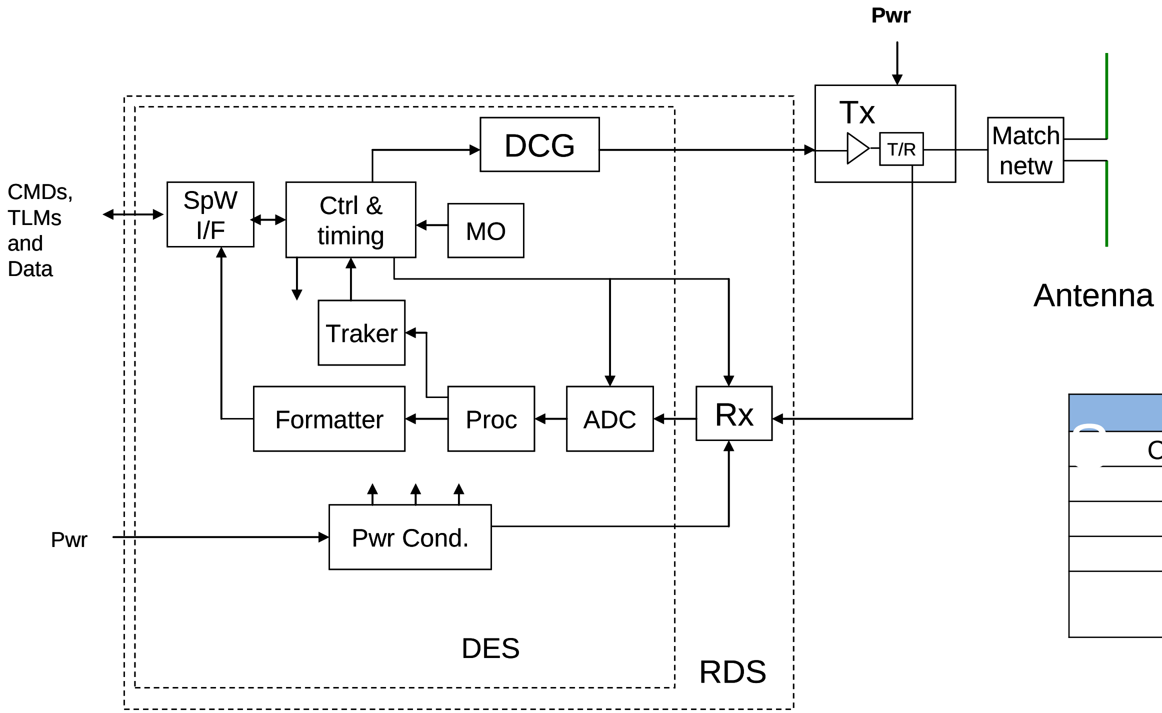
DES = Digital Electronics Subsystem

JPL

TX & MN = Transmitter & Matching Network

RX = RF receiver





Parameter	Value
Centre frequency:	9 MHz
Nominal Bandwidths:	3 MHz, 1 MHz
Tx Power:	10 W
PRF	programmable, 100 Hz to 1 kHz
Pulsewidth	programmable, 50 to 250 usec (100 usec nominal)

Near Future

- NASA/Veritas: VISAR, Radar for Venus Exploration
  - ➔VISAR is a X band interferometer SAR used to map the Venus terrain. VISAR generates a global high-resolution Digital Elevation Model, SAR images with up to 15 m resolution, and surface deformation measurements with 2 mm precision.

VISAR Mission overview and TASI involvement

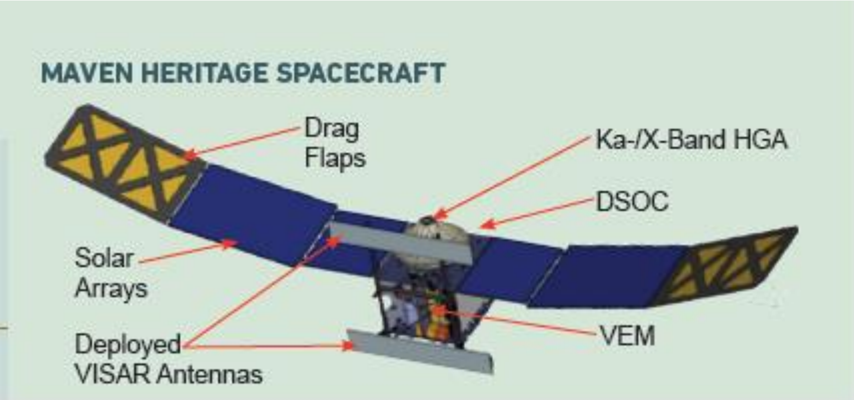
- VERITAS mission is ***currently in the PHASE A*** and our involvement is within the VISAR Instrument.

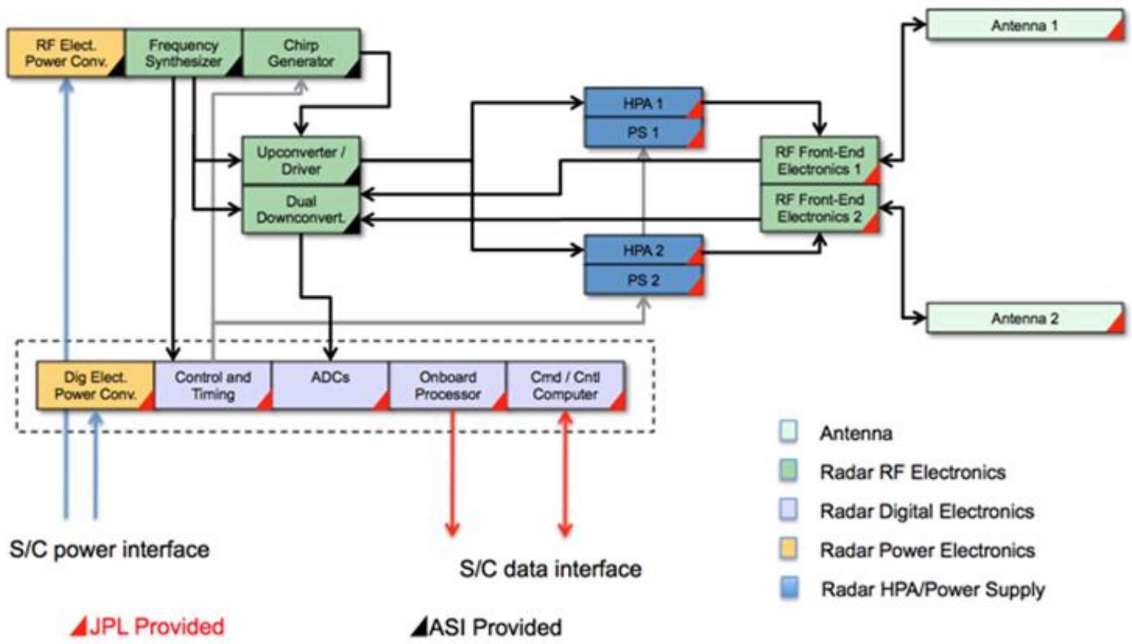
VERITAS builds on proven partnerships

INSTITUTION	RESPONSIBILITY
Jet Propulsion Laboratory (JPL) Suzanne Smrekar, PI Dave Lehman, PM Kirk Breitenbach, PSE	Science leadership; project and payload management: systems engineering; mission assurance; VISAR; mission operations; education and communications
Lockheed Martin (LM)	Spacecraft management, design, assembly, integration, test, and verification, and launch operations; support mission operations
Italian Space Agency (ASI)	VISAR RF electronics; Ka-/X-band transponders
German Aerospace Center (DLR)	VEM; support VISAR data processing algorithms definition in Phase A

- The VISAR is an X band interferometer SAR used to map the Venus terrain with an higher resolution wrt the current data available.

VISAR: Instrument Description



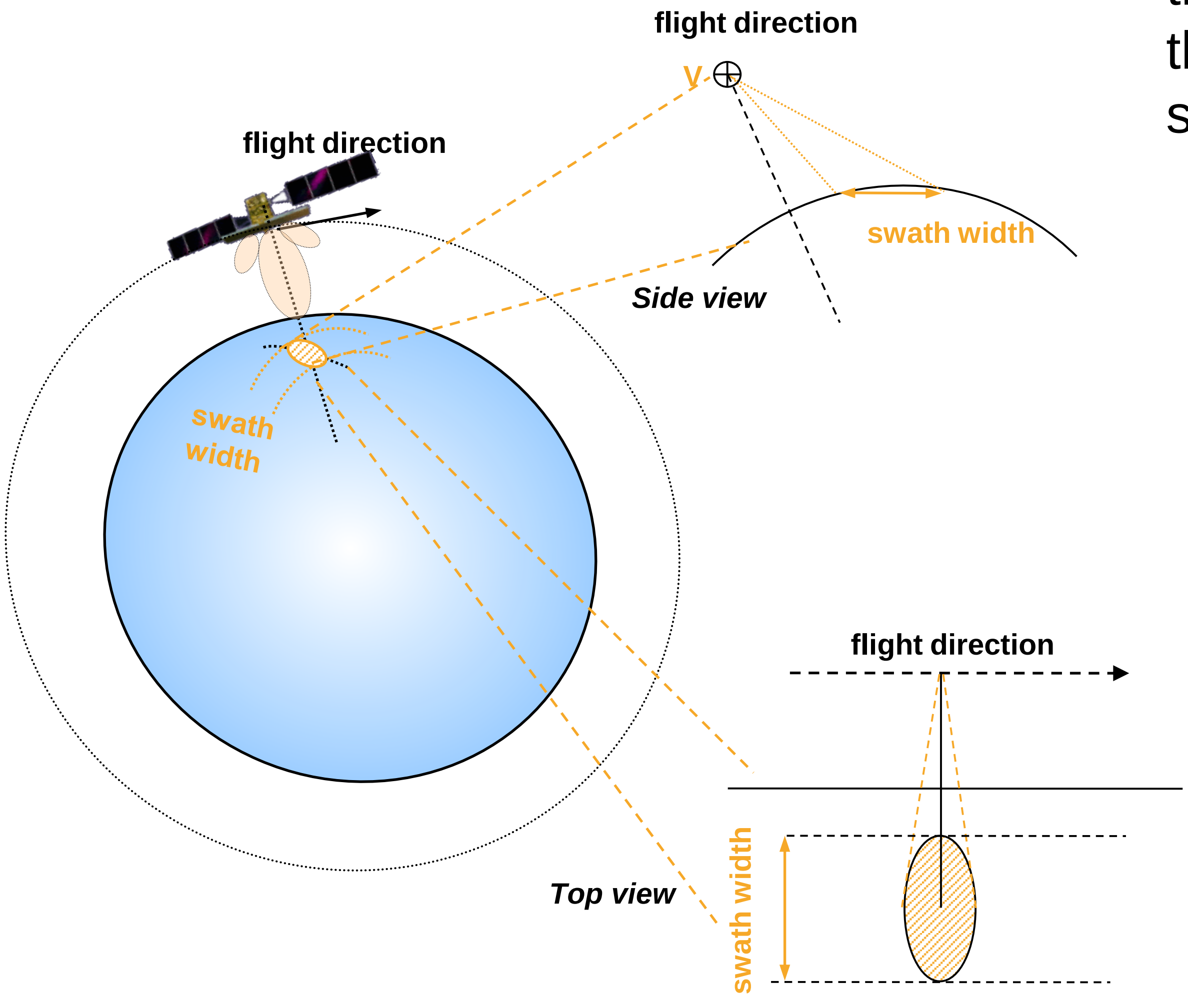


Parameter	Value
Centre frequency:	7,9 GHz
Nominal Bandwidths:	20 MHz
PRF	programmable, max DC = 27%
Pulsewidth	programmable, up to 35 usec

- TAS-I is participating to Phase A as an UniRoma industrial partner

Backup Slides

SAR Acquisition Geometry



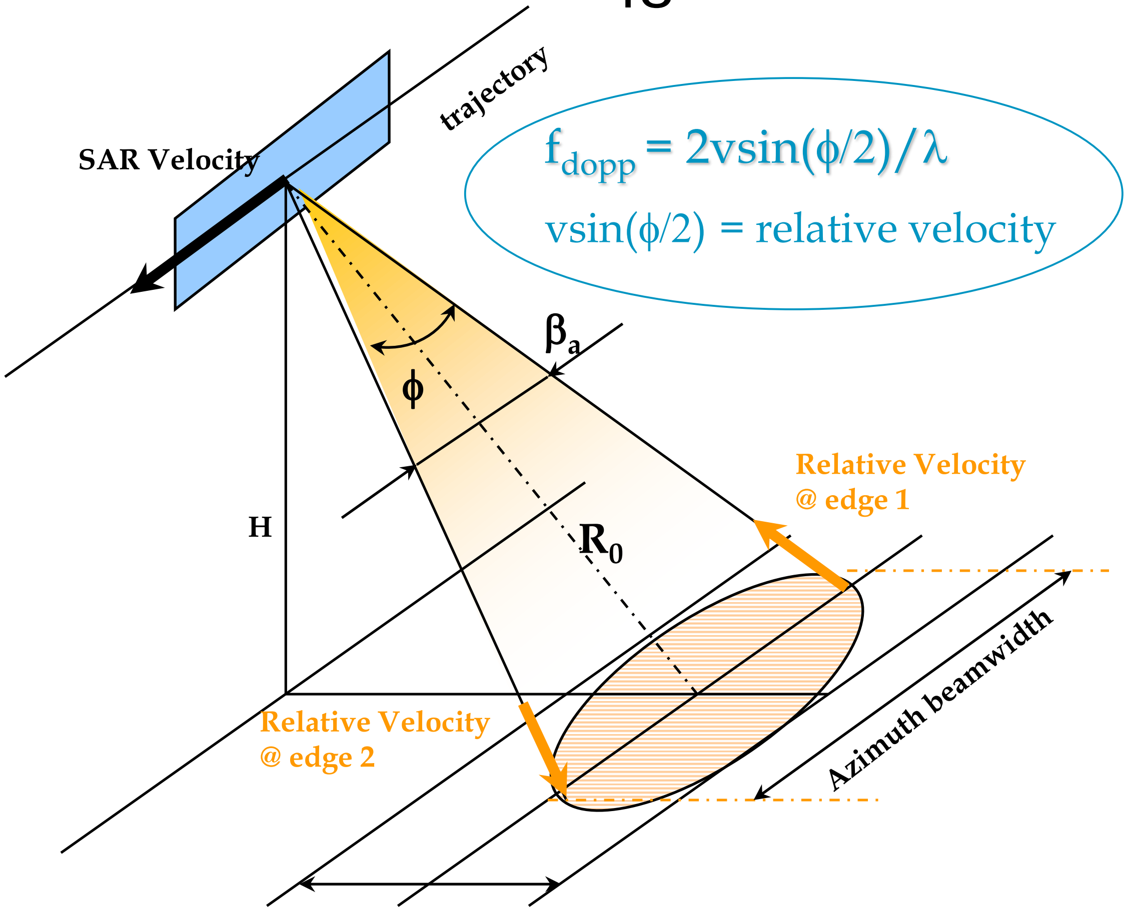
- The area illuminated on ground by the SAR is given by the intersection of the antenna beam with the ground surface (**footprint**):

  - The side view allows to observe the **Range** footprint extension
  - The top view allows to observe the **Azimuth** footprint extension:

PRF and azimuth beamwidth

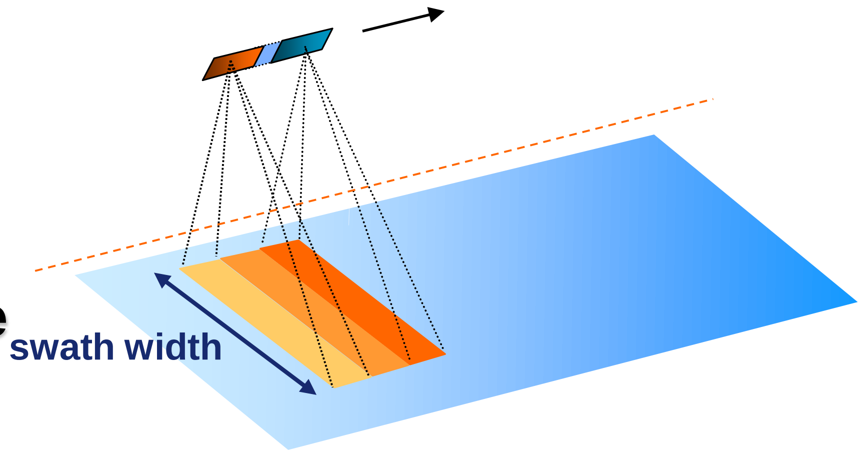
- The relative **SAR-target velocity** induces the Doppler effect.
- The maximum variation of the Doppler frequency over the antenna footprint defines the **Doppler bandwidth** of the system.
- The SAR is a **pulsed system**, which samples the Doppler bandwidth at PRF.
- The sampling frequency (PRF = 1/PRI) shall be selected according to Nyquist.
- With no loss of generality, it can be assumed that the relative SAR-center scene velocity is zero; therefore, the maximum Doppler frequency is defined at the edges of the azimuth footprint.
- The relationship between PRF and Doppler bandwidth (i.e. azimuth beamwidth) is established by:

  → **$PRF \geq B_{dopp}$**



SAR Acquisition Geometry

The antenna footprint of the SAR illuminates a "strip" on ground as the satellite moves along its trajectory.

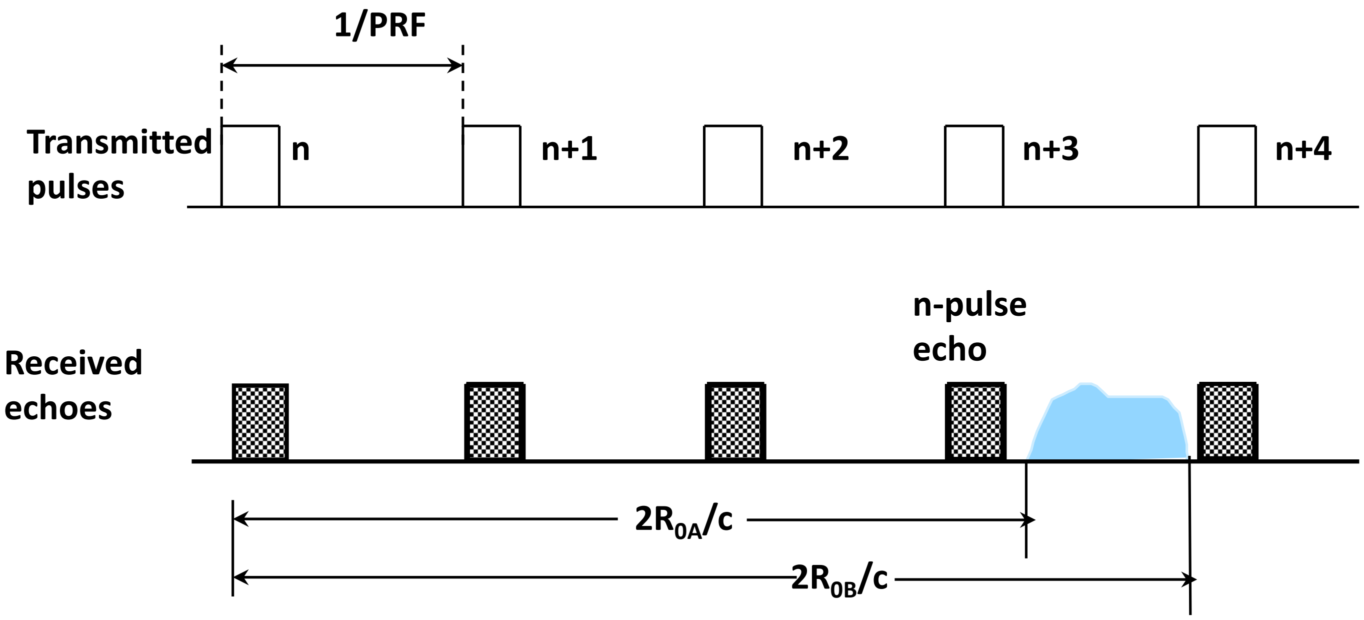


- The strip extension along the azimuth **coordinate** is defined by:
  - ➔ SAR acquisition time
  - ➔ Satellite velocity

- The strip extension along the range **coordinate** (swath) is related to:
  - ➔ Satellite Altitude
  - ➔ Off-nadir angle
  - ➔ Elevation beamwidth
  - ➔ Pulse Repetition Interval (1/PRF)

Swath width

- The instantaneous swath is constrained to the Pulse Repetition Interval duration (PRI = 1/PRF).
- The received echo shall not overlap with the transmitted pulse.



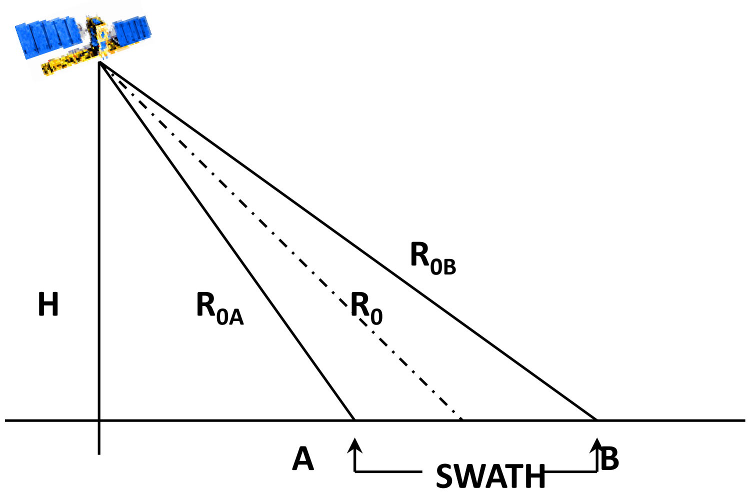


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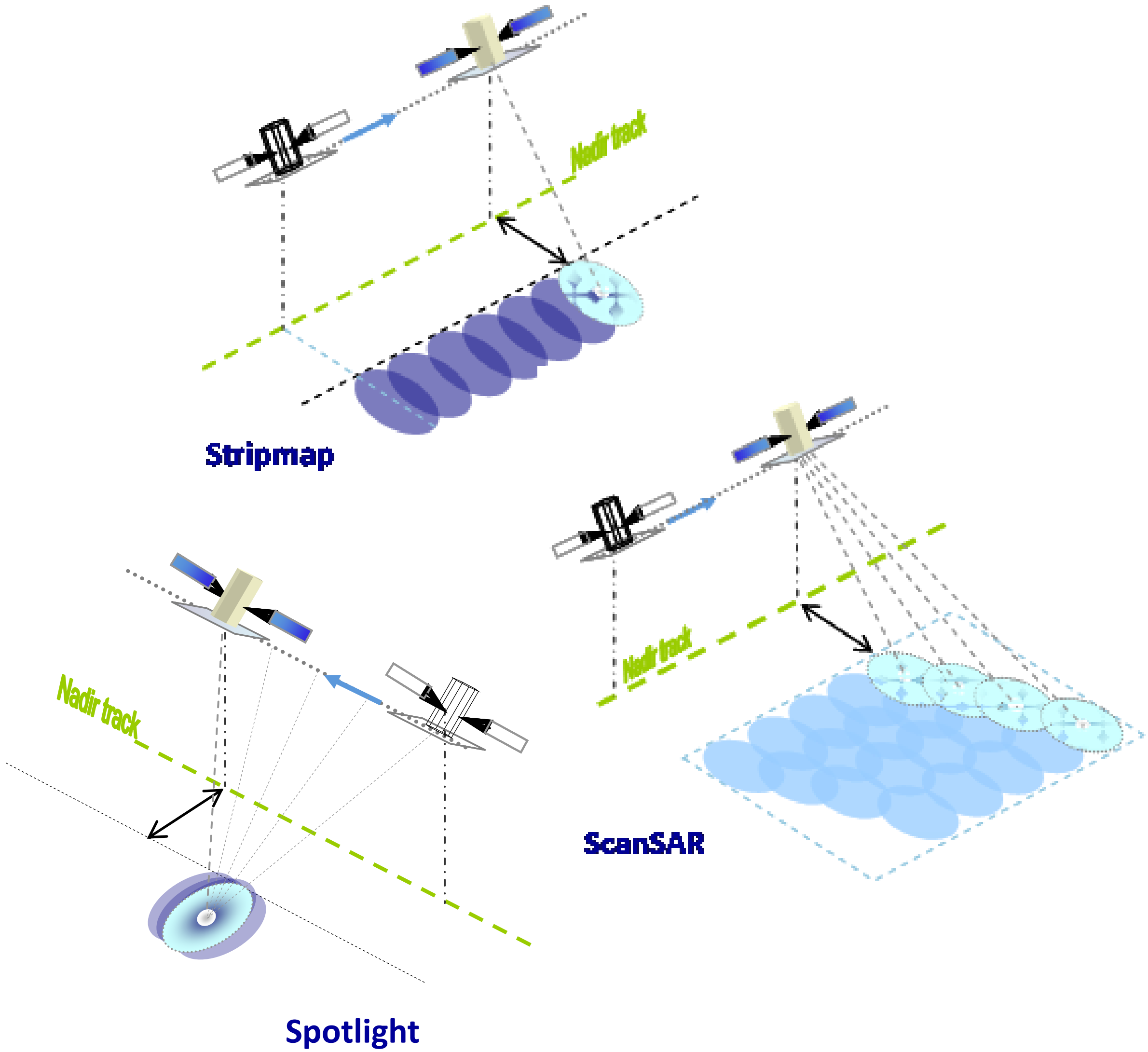
Image Performance: acquisition techniques

- **Stripmap**:
  - is the mode used to achieve medium resolution and wide swath using a single beam acquisition

- **Scansar**:
  - in this mode the antenna beam is scanned in the elevation plane in order to cover a wider swath dimension than the one achievable with a single beam at the expense of the achievable resolution

- **Enhanced Spotlight:**
  - is the mode defined for the acquisition of spot images with a very high resolution



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SAR Performance parameters

- The first level of interest in the Synthetic Aperture Radar design is referred to the:
  - Spatial resolution (azimuth and range)
  - Image size

- The evaluation of the SAR performances is obtained through the several "quality parameters":
  - **Spatial Resolution**
  - Integrated side lobe level (Integrated Side Lobe Ratio – ISLR)
  - Side lobe level (Peak Side Lobe Ratio – PSLR)
  - Ambiguity to Signal Ratio (ASR)
  - Radiometric accuracy
  - **Noise Equivalent σ° (NEσ°)**
  - Dynamic

- The backward activity is to convert the quality parameters to the SAR technical parameters useful for the instrument requirements definition.

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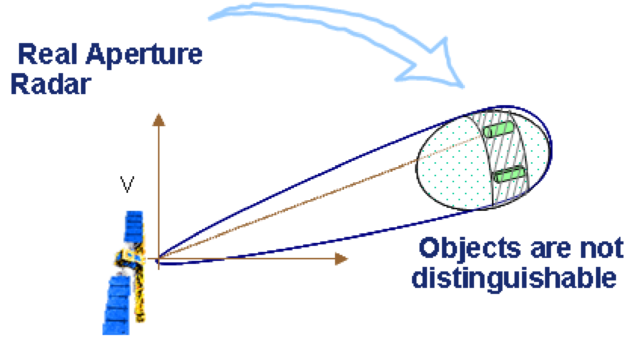
Quality Parameters: Azimuth Resolution

- In “classical” radar the azimuth resolution is related to the azimuth beam-width: the narrower the beam-width the better the azimuth resolution.
- Very **long antennas** shall guarantee a narrow beam and a good resolution (e.g. @ 800km altitude, in L-band an antenna of 20 km shall guarantee 10m spatial resolution). Physical antenna lengths around kilometers are unfeasible.

- The Azimuth resolution has a direct impact on the dimensioning of**:**
  - → antenna length
  - → Pulse repetition frequency (PRF)
  - → Swath width



- SAR fundamental principle:

it is not necessary for the long antenna to be physical,

a “*synthetic*” one shall work as well

- SAR is capable to synthesize very long equivalent antennas allowing azimuth resolution of fraction of meters.

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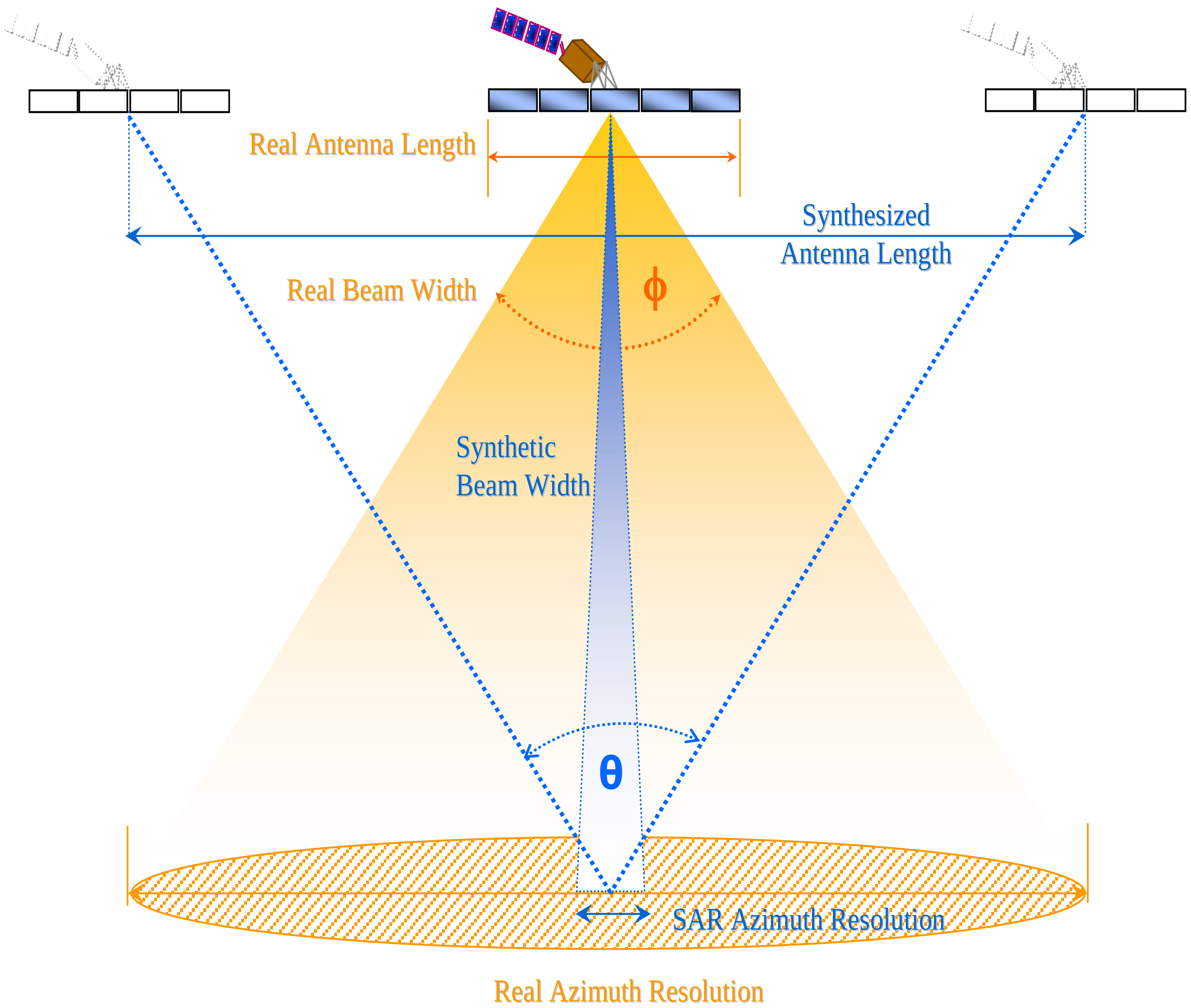
Quality Parameters: Azimuth Resolution

- The **synthetic antenna** has the same length of the beam extension on ground.
- In other words the azimuth resolution is proportional to the **look angle**.
- In STRIPMAP the look angle (θ) coincides with the azimuth antenna beamwidth (ϕ).
- The wider the look angle the better the azimuth resolution:

$$R_{az} = \lambda / (2\theta) = L_a / 2$$

✓ θ = look angle

✓ L_a = antenna length



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Quality Parameters: Azimuth Resolution

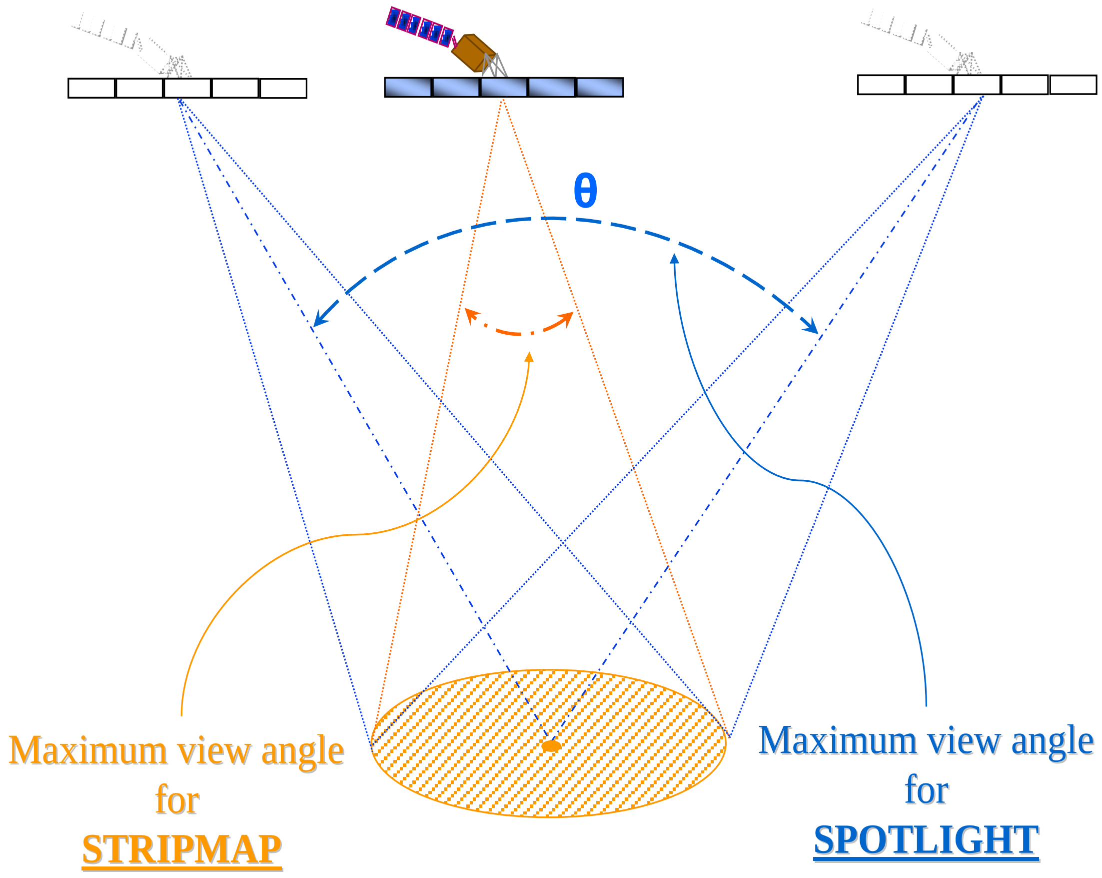
- The antenna dimension cannot be reduced indefinitely to wide the beam-width, due to the maximum PRF available to sample the Doppler bandwidth.

- The azimuth resolution is driven by the look angle:

$$R_{az} = \lambda/(2\theta)$$

***the azimuth resolution can be improved by re-pointing the antenna on the useful spot* (SPOTLIGHT)**

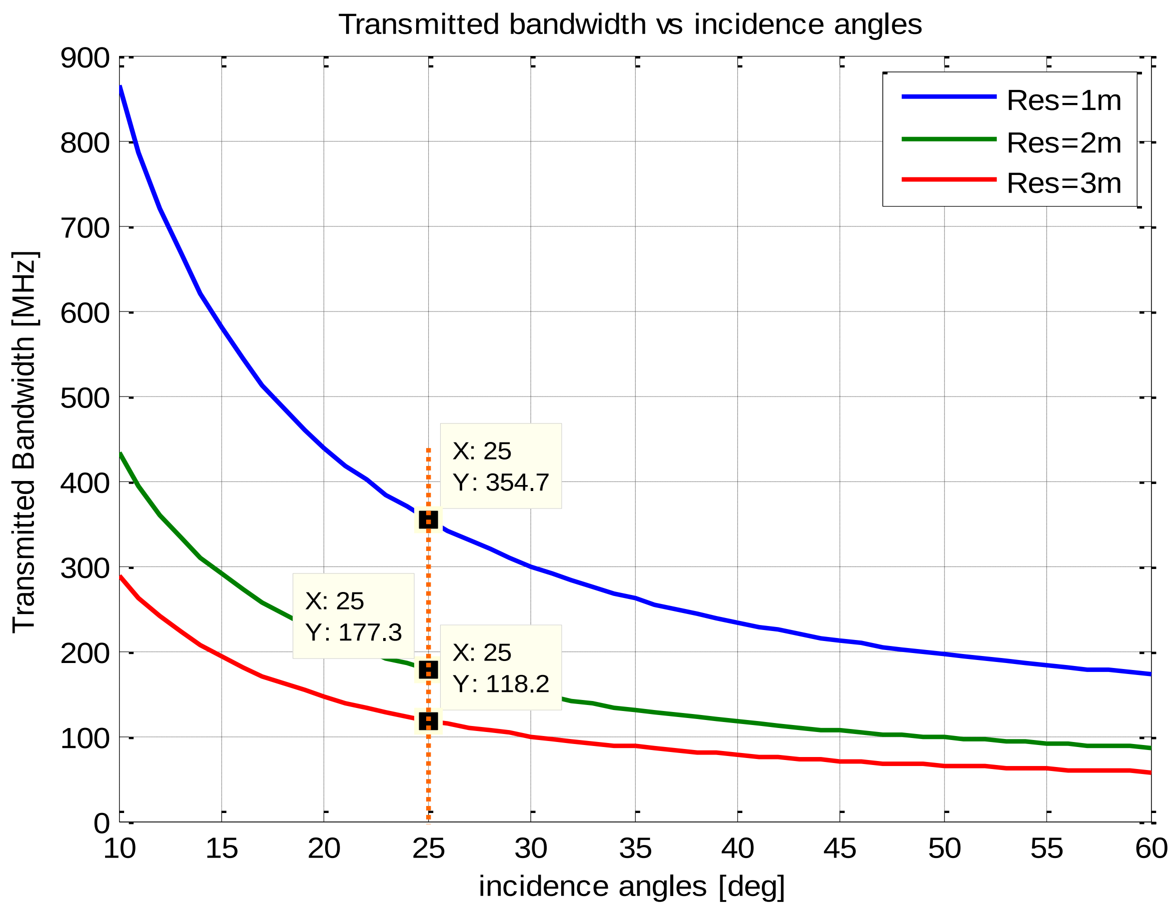
- SPOTLIGHT: high resolution over a limited imaged area.



Quality Parameters: Range resolution

Range resolution

- The Range resolution has a direct impact on the transmitted pulse characteristics and depends on the incidence angle.



$$R_{rg}(\vartheta) = \frac{c}{2 \cdot B \sin(inc)}$$

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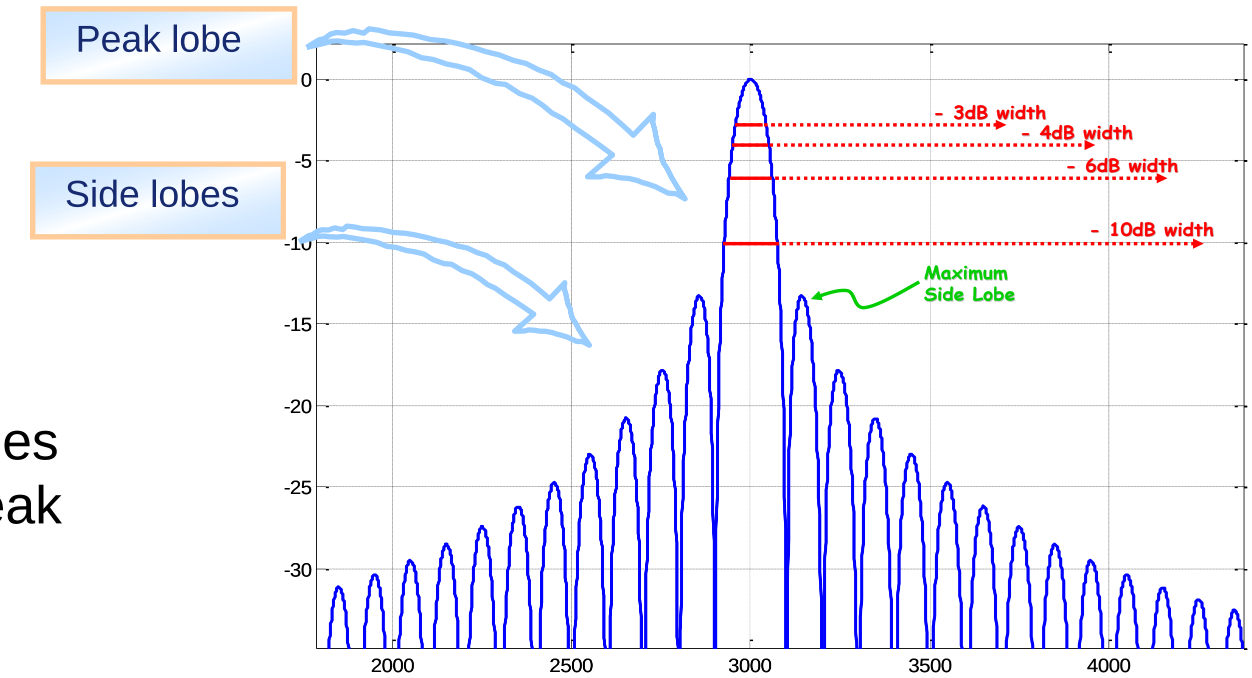
Quality Parameters: PSLR

- The Peak Side Lobe Ratio (PSLR) defines the capability to detect two close targets with different intensities.
- The point target would be seen:
  - In an ideal system, as a single bright point
  - In a real system as a bright point rounded by smaller points with decreasing intensity (side lobes).

- The evaluation of the PSLR is performed on the Impulse Response Function, both in azimuth and range direction.
- A very bright target has side lobes whose intensity may mask a weak target in the surrounding.



Quality Parameters: PSLR

- Example of PSLR of -13dB (left) and -20 dB (right), on a ship target.
- The side lobe reduction is achieved by non-linear filtering, the loss in resolution is reduced by 25% with respect to standard processing.