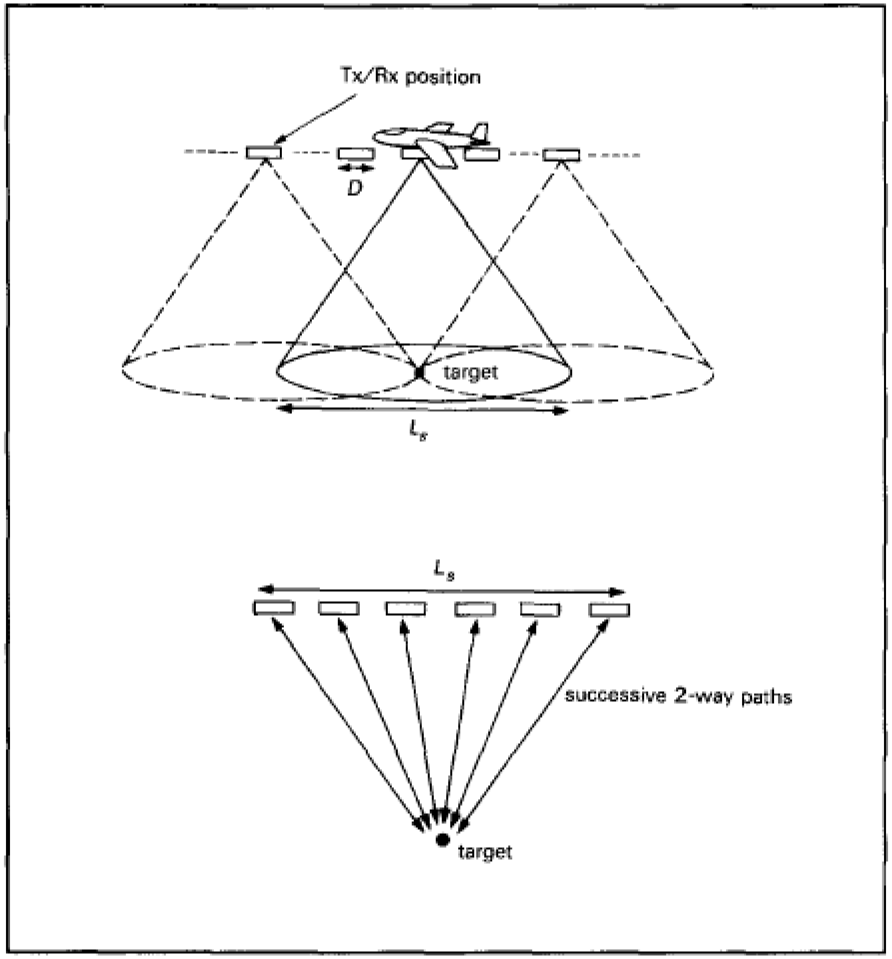
Synthetic Aperture Radar and Sonar – SAR and SAS

Sverre Holm

SAR Resolution

- Real aperture beamwidth: $\theta \approx \lambda/D$
- Size of footprint: $L_F \approx \theta \cdot R = R \cdot \lambda/D$
- Size of synthetic aperture = footprint: $L_s \approx L_F$
- Beamwidth of synthetic aperture: $\theta_s = (1/2) \cdot \lambda/L_s = (1/2) \cdot \lambda/(R\lambda/D) = D/(2R)$
- Ground resolution: $\Delta X_s = R\theta_s = D/2$



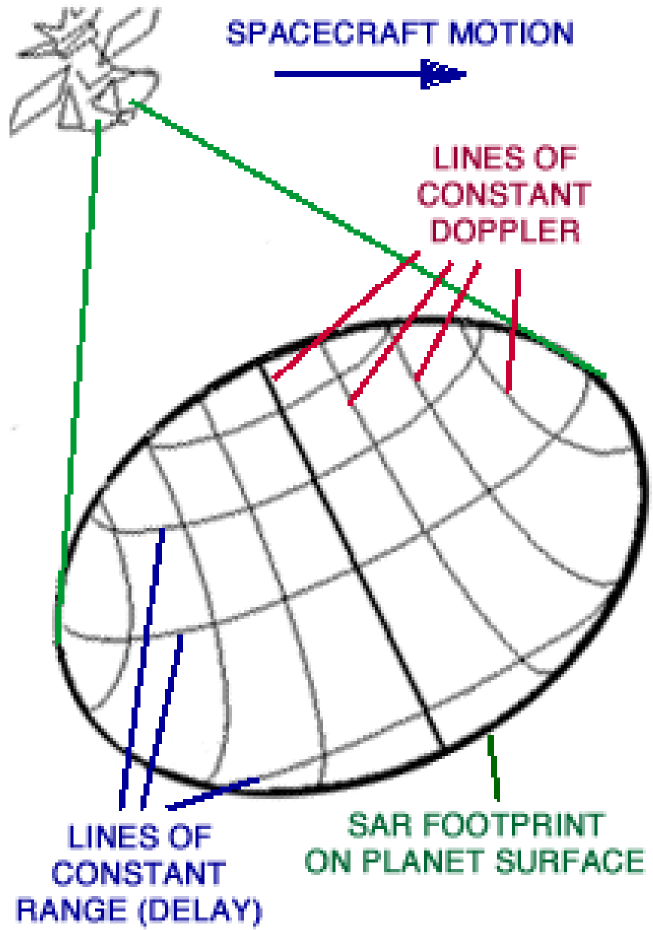
4 Aperture synthesis. The target is in the beam for a time $T_s = L_s/V$. After phase-correcting the signals, a synthetic antenna pattern is obtained which is equivalent to that of a conventional antenna of length $2L_s$

SAR Resolution

- Ground resolution: $\Delta X_s = R\theta_s = D/2$
- Note:
  - The smaller the real antenna, the better the resolution
  - Resolution is independent of range
  - Why? A small D causes the synthetic aperture to be larger
  - But, small D means energy is spread over larger area, so SNR suffers
- Range resolution: $\Delta X_r = cT/2 = c/2B$
  - as in any pulsed system

SAR – Doppler Interpretation

- Doppler equation: $f_D=2\cdot v/c\cdot f_0 \sin\theta$
- Max Dopplershift: $f_D=2\cdot v/c\cdot f_0 \sin\theta/2 \approx 2\cdot v/c\cdot f_0\,\theta/2 = v/c\cdot c/\lambda\cdot\lambda/D=v/D$
- Doppler bandwidth: $B_D=2\cdot f_D$
- Time resolution: $t_m=1/B_D=D/2v$
- Equivalent azimuth resolution: $X_a=v\cdot t_m=D/2$
- QED!
  Same result as found from aperture-resolution considerations



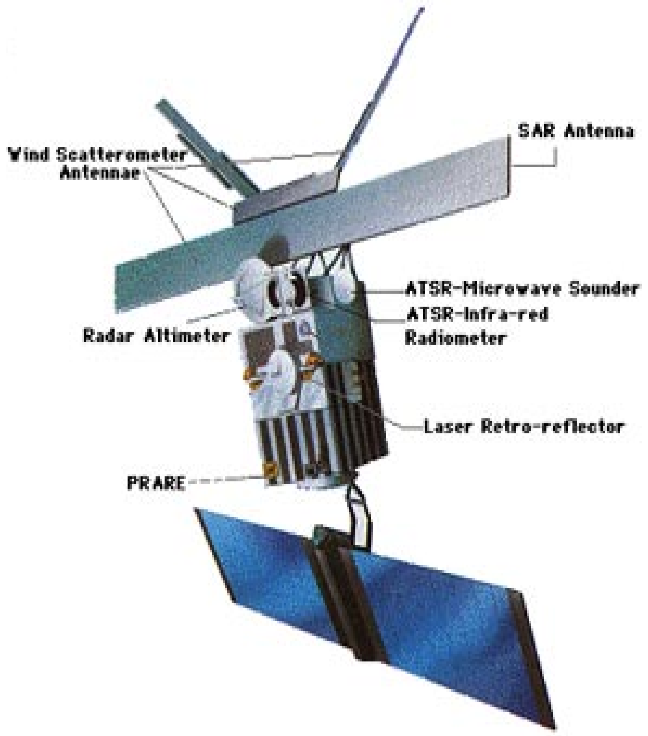
http://www2.jpl.nasa.gov/basics/bsf12-1.html

SAR – Doppler - Sampling

- Doppler shift is in the range +/- f_D
- Proper complex sampling with $PRF>2f_D=2v/D$
- Max movement of aperture per pulse:
  $x=v \cdot T=v/PRF=D/2$
  - Gough & Hawkins, IEEE JOE, Jan 1997 claim that there should be no more than D/4 between pulses
  - Element beamwidth/Doppler bandwidth is not easily defined:
    - D/4 ⇔ null-to-null sinc bw
    - D/2 ⇔ 3dB.
  - A question of acceptable level of azimuth ambiguity

Satellite SAR: ERS-1 (1991-2000)

- Satellite – the simplest SAR
- Real aperture: D=10 m
- Frequency: 5.3 GHz
- Wavelength: λ=5.66 cm
- Height: R=850 km
- Real aperture beamwidth: $\theta=\lambda/D=0.33^{o}$
- Real aperture azimuth resolution = synthetic aperture: $L_s=\lambda/D \cdot R=4850$ m
- SAR resolution: D/2=5 m
- B=19 MHz => Range res 8m
- Velocity: v=7 km/sec



<http://www.sso.admin.ch/Themes/02-Earth_observation/english/ e_03_ESA_missions_in_orbit.htm>

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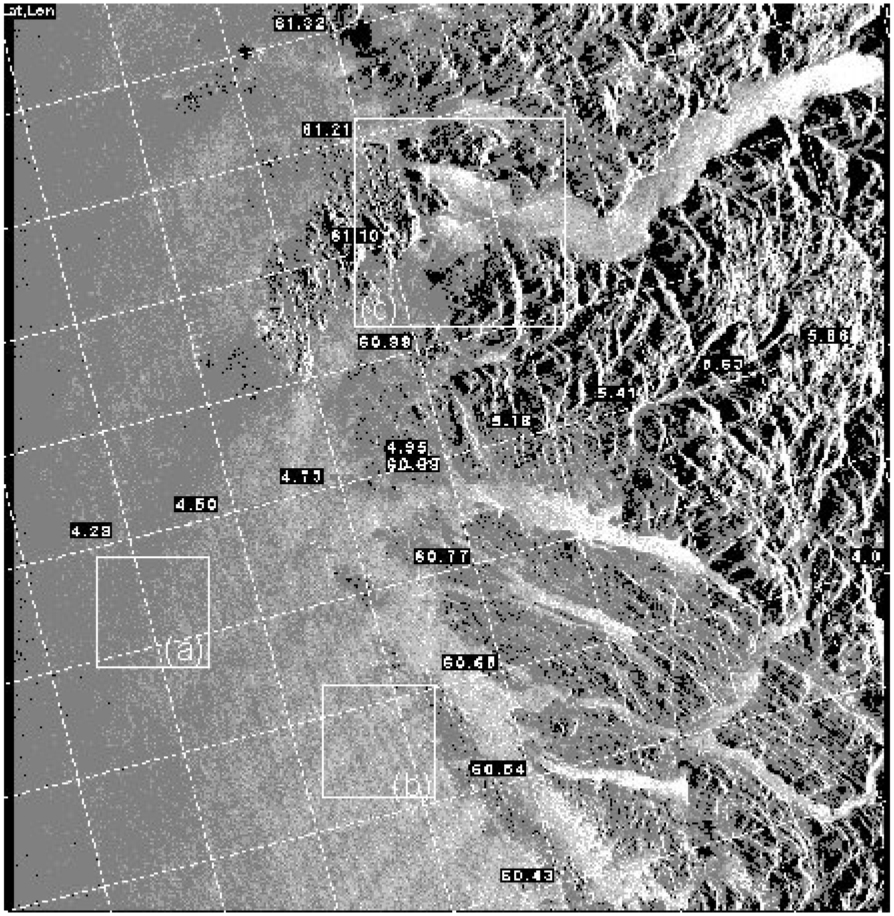
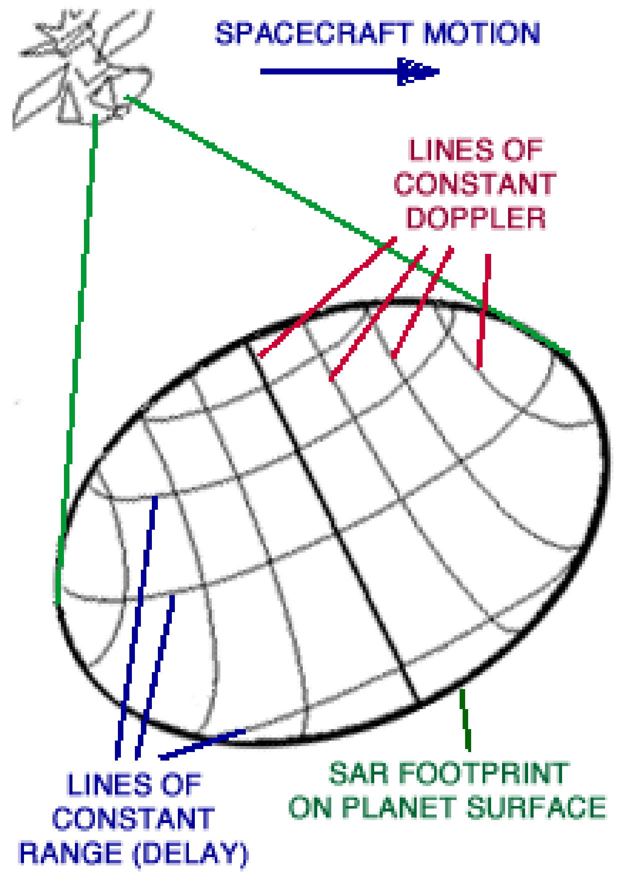
ERS-1 SAR image of west coast of Norway, 22 June 1996.



http://marsais.nersc.no/product_wind.html

Focused – unfocused SAR

- Small synthetic aperture => straight lines of constant delay => no focusing required
- Nearfield-farfield limit: $R_f=L_s^2/(4\cdot\lambda)$
- Largest unfocused synthetic aperture for $R=R_f$ => $L_s=2(R\lambda)^{0.5}$
- ERS-1: $L_s=439$ m < 4850 m
- Focusing is required in order to obtain full resolution



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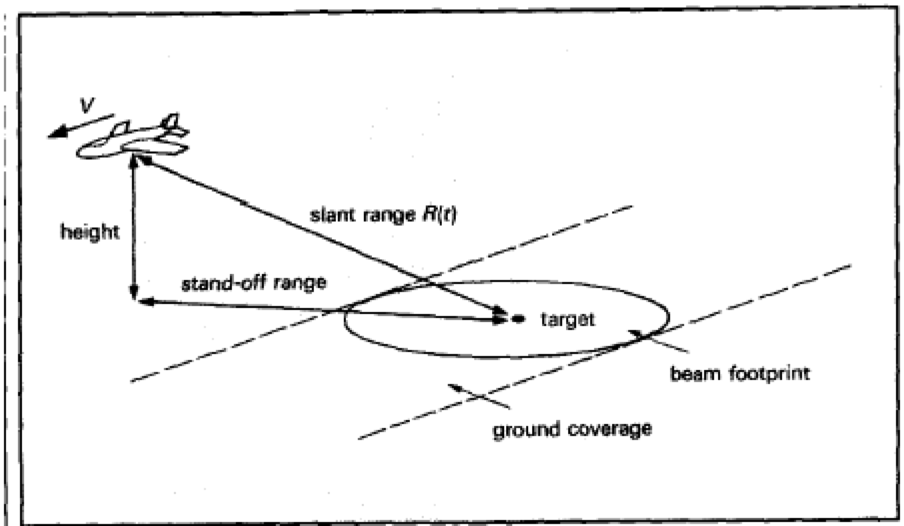
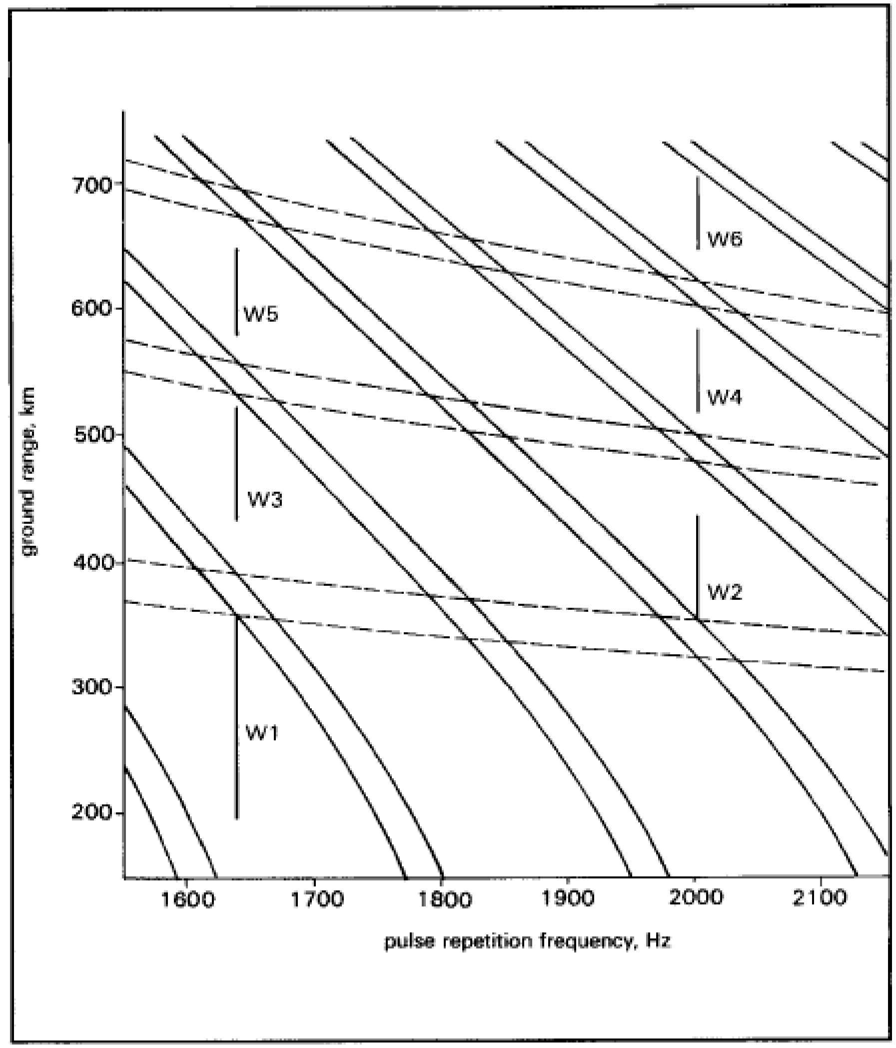
Sampling considerations

- Fast enough for Doppler ⇔ no grating lobes: PRF>2v/D
- Simple radar, only one pulse in medium at a time 1/PRF > 2R/c
  - i.e. 2v/D < PRF < c/2R
- Swath width < R such as in satellite SAR => Several pulses in medium at a time
- No sampling while tx
- No sampling during subsatellite echo



SAR coverage



9 Spaceborne SAR coverage diagram. The solid diagonal lines represent 'blind regions' which are invisible to the SAR owing to the fact that the radar cannot receive while transmitting. These regions form boundaries between mutually ambiguous swaths. The dotted lines represent regions which are saturated by strong subsatellite radar returns. The pulse repetition frequency of a system is usually set so that these regions coincide with the blind regions. Also shown on the diagram are the six swaths chosen for the VSAR system

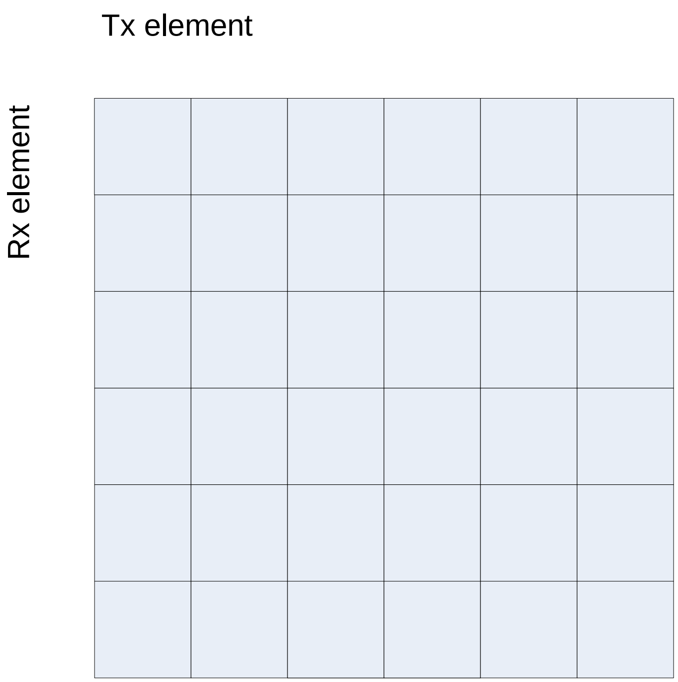
Aircraft SAR

- Real aperture: D=1 m
- Frequency: 5.3 GHz
- Wavelength: λ=5.7 cm
- Height: R=10 km
- Real aperture beamwidth: $\theta=\lambda/D=3.3^{\circ}$
- Real aperture azimuth resolution = Synthetic aperture: $L_s=\lambda/D \cdot R=570$ m
- SAR resolution: D/2=0.5 m
- v=720 km/hr = 200 m/s
- (Some guesses)

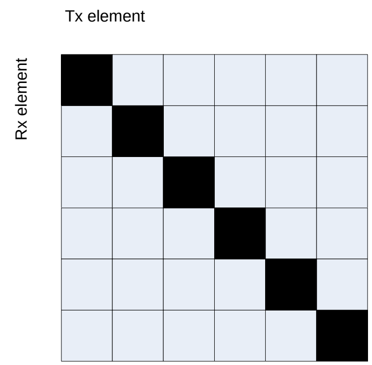
Synthetic aperture sonar: Hugin

Height: R = typ 20 m, speed: v = typ 2 m/s
FFI & Kongsberg Maritime

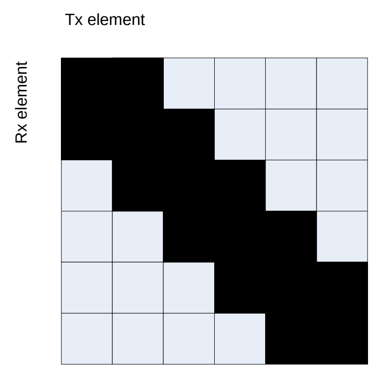
Real aperture – synthetic aperture



Real aperture – all rx/tx combinations



SAR



SAS – like seismics

Hugin

Edgetech:

- Rx: 6 x 20 cm (6 x 17λ)
- Tx: 1 rx element

- f = 125 kHz, λ= 1.2 cm
- Bandwidth B=15 kHz

- Synthetic aperture: $L_s=\lambda/D \cdot R=(0.012/0.2)\cdot 20 =1.2$m
- SAR resolution: 10 cm
- Range resolution: 5 cm

Sensotek:

- Rx: 1.5 m, 96 elements
- Tx: effectively 1.5λx1.5λ (larger defocused aperture to increase power)
- f=60-120, typ 90 kHz, λ= 1.67 cm
- Bandwidth, typ. B=30 kHz

- Synthetic aperture: $L_s=\lambda/D \cdot R=(1/1.5)\cdot 20 \approx 13$m
- SAR resolution: 1.25 cm
- Range resolution: 2.5 cm

SAR vs SAS

- Criterion for not creating increased sidelobe level:
  - position known to $\lambda/16$
- Satellite ERS-1, λ=5.7 cm
  - L_s = 4850 m, v = 7 km/s => 0.7 sec
  - Must know position within 3.5 mm over 0.7 sec
- Aircraft SAR, λ=5.7 cm
  - L_s = 570 m, v = 200 m/s => 2.85 sec
  - Must know position within 3.5 mm over 2.85 sec
- Sonar Hugin:

  Edgetech λ=1.2 cm, L_s = 1,2 m, v = 2 m/s => 0.6 sec
  - Must know position within 0.75 mm over 0.6 sec

  Sensotek λ=1.7 cm, L_s = 13 m, v = 2 m/s => 6.5 sec
  - Must know position within 1 mm over 6.5 sec!

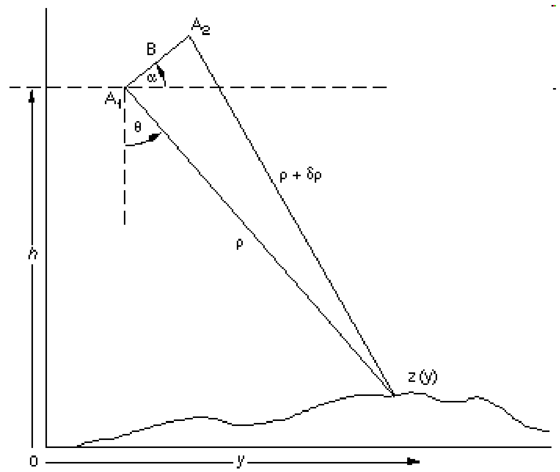
SAR vs SAS: $c=3\cdot10^8$ vs 1500 m/s

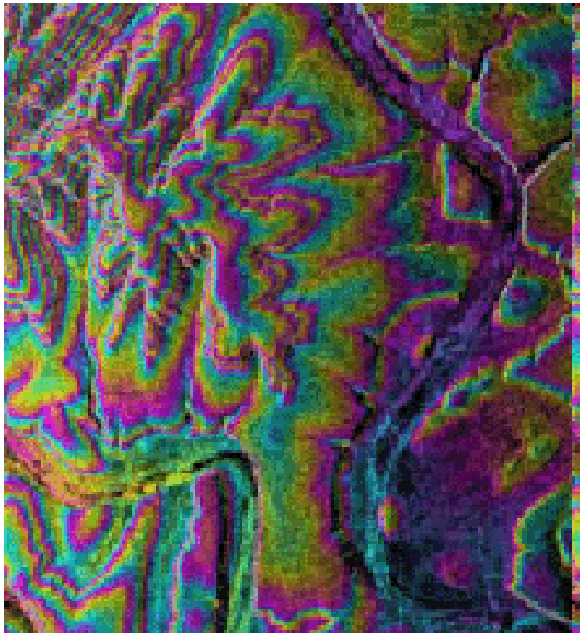
- **Motion compensation**: much more severe for sonar as it takes much longer to travel one synthetic aperture => accurate navigation and micronavigation (sub λ accuracy)
- More severe **range ambiguity** problem for sonar than radar. Harder to achieve good mapping rate => multielement rx arrays which also can be used for DPCA (displaced phase-center antenna) micronavigation
- **Noise:** SAR – thermal/electronic noise, SAS – noisy medium
- **Medium**: Sonar – multipath, refraction, instability, attenuation; Radar – much more stable, only spherical spreading loss
- Same **range resolution** for smaller bandwidth in SAS than SAR: $\Delta X_r=c/2B$

Interferometry

- Compare two images at slightly different aspects
- Requires image with amplitude and phase

- Dual-pass: Satellite SAR
- Single-pass, requires two imaging systems – Aircraft SAR, SAS

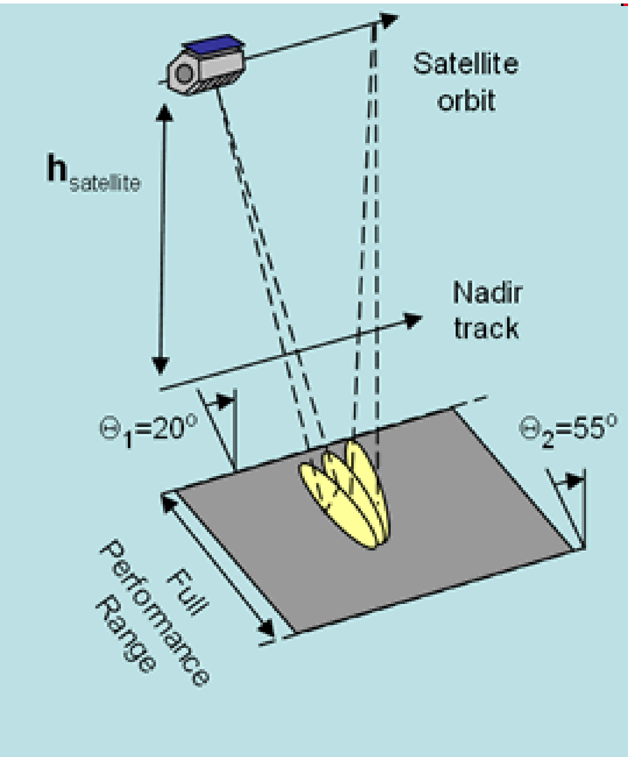




Ellery Creek floodplain,
http://www.csr.utexas.edu/rs/research/aussie/finke_flood.html

Imaging modes

- Strip-map (”standard mode”)
- Spotlight mode (figure)
- Squint mode



http://www.terrasar.de/en/prod/img_prod/hs/index.php

Literature

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- H D Griffiths: Synthetic aperture imaging with sonar and radar: A comparison, World Congress on Ultrasonics, Paris 2003.
- M.P. Hayes and P.T. Gough, Synthetic aperture sonar: A maturing discipline, Proc 7. Eur. Conf Underwater Acoustics, Netherlands, July, 2004