LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Synthetic Aperture Radar (SAR)

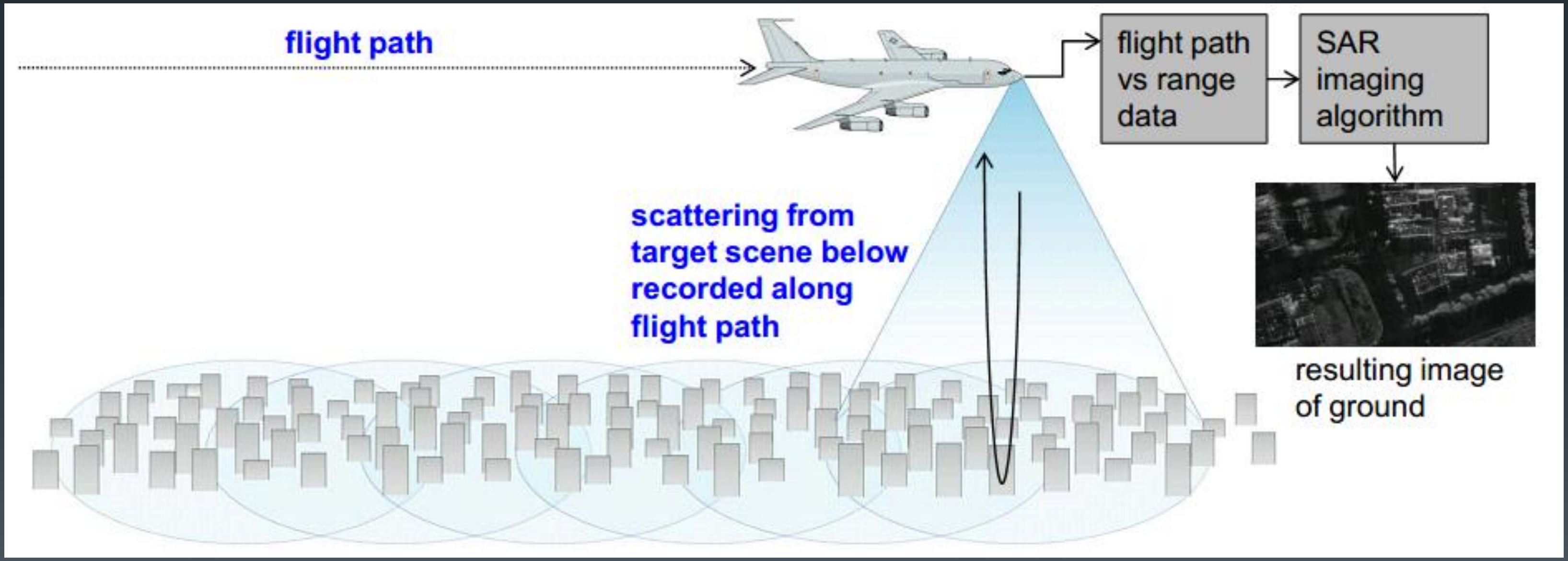
Team 5: Andy Myrick
Steve Hughey
Andrew Renton
Nur Syuhada Zakaria
Sponsor: MIT Lincoln Laboratory
Facilitator: Dr. H. Radha

Outline

- Introduction & Background
- How to do it?
  - Antenna Aperture
  - Phased Arrays
- How does it work?
  - Algorithm
  - Principle
- Applications & Alternatives
- Summary

Synthetic Aperture Radar

- Mostly airborne or space-borne, side-looking radar system
- Utilizes the path traversed by the platform [flight path]
- Simulate a large antenna or aperture electronically
- Generates high-resolution remote sensing imagery



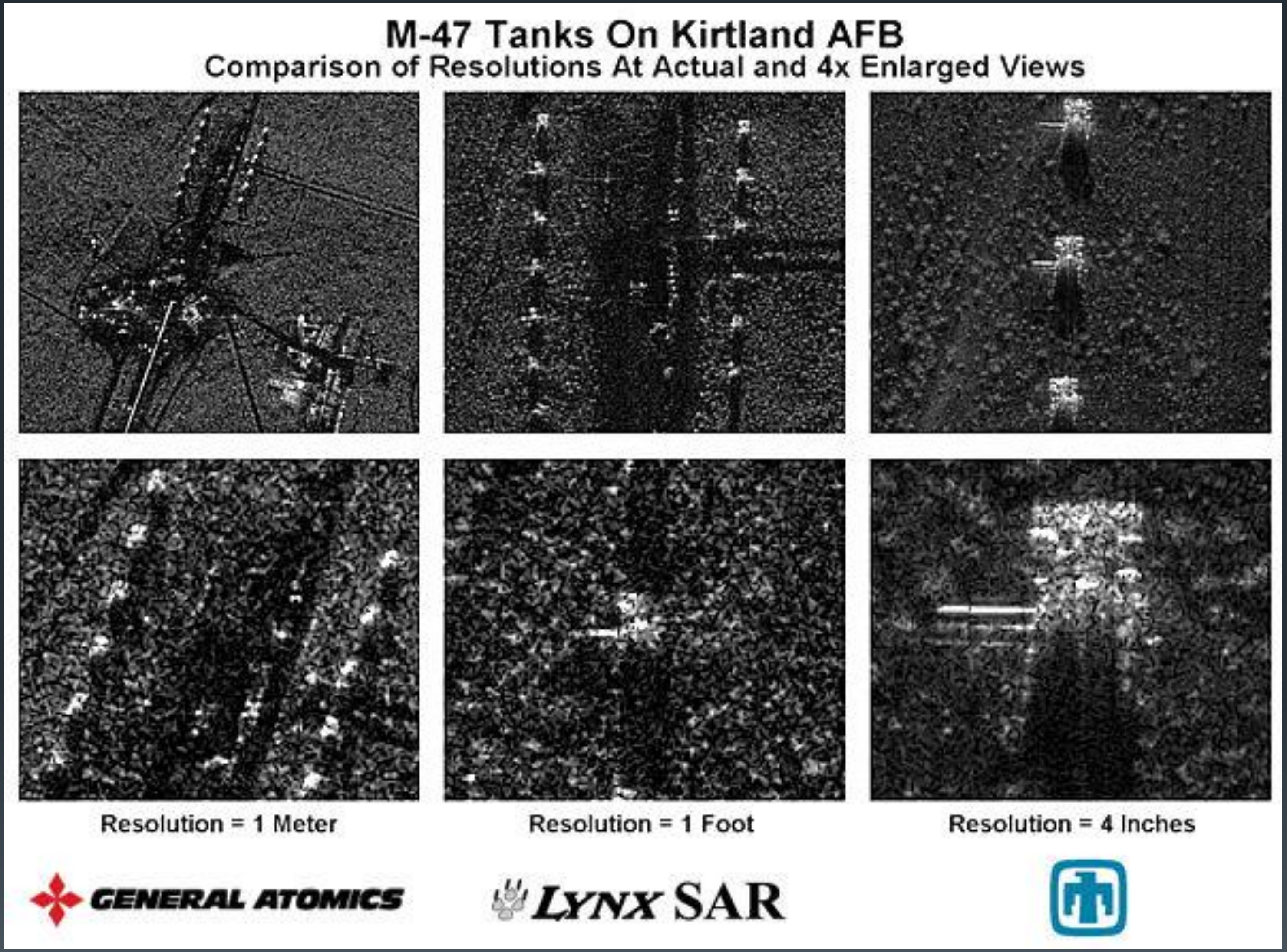
http://www.radartutorial.eu/20.airborne/ab07.en.html

Radar Handbook, Skolnik, M.I. 2008

History of SAR

- Carl A. Wiley, working at Goodyear Aircraft in 1951 invented SAR during research into ICBM guidance systems.
- A few months later, University of Illinois and University of Michigan (UM) researchers independently developed SAR.
- First SAR imagery produced by UM in 1957.
- SAR research nearly canceled that year because the quality and resolution of the images weren't very impressive.
- In 1957, 50 foot resolution was the goal. Today, sub-millimeter resolution is being shown in numerous laboratories.

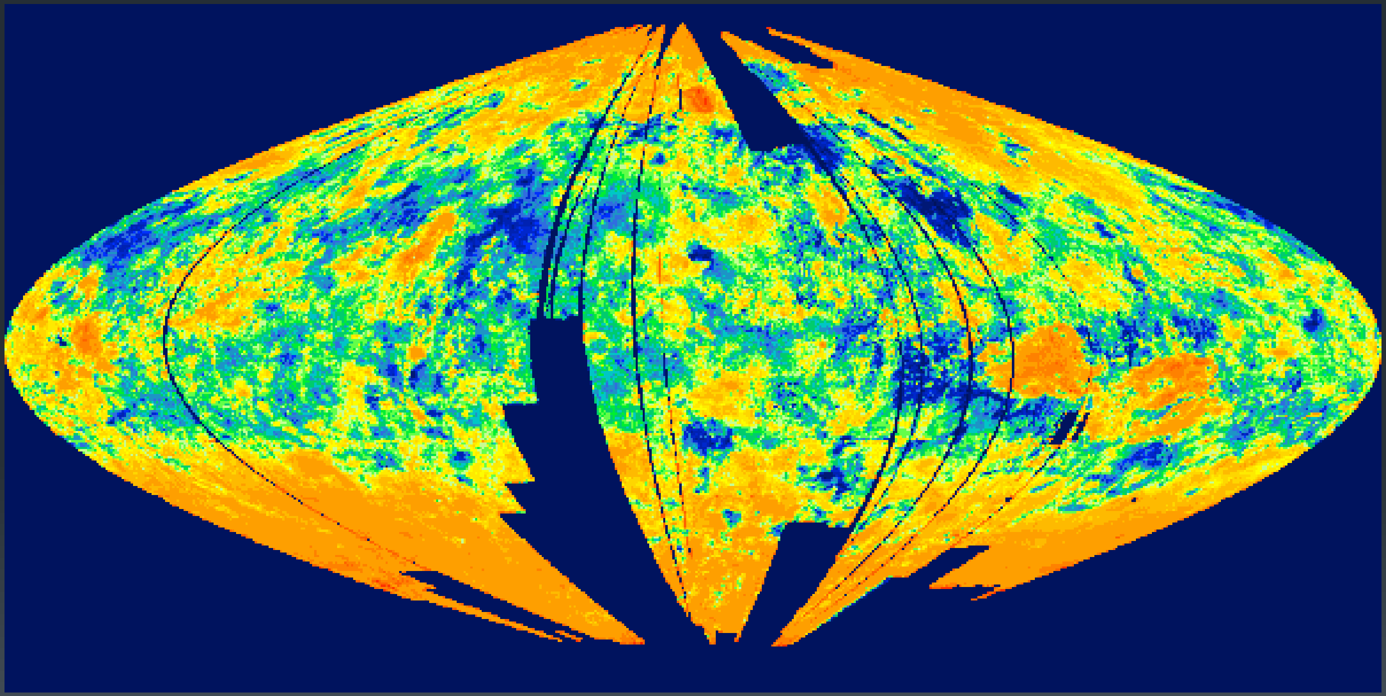
Image of Haiti after 2010 earthquake taken by ASTER satellite with 50-foot resolution.



Comparison between 3 foot, 1 foot and 4 inch SAR resolutions

Magellan Mission to Venus

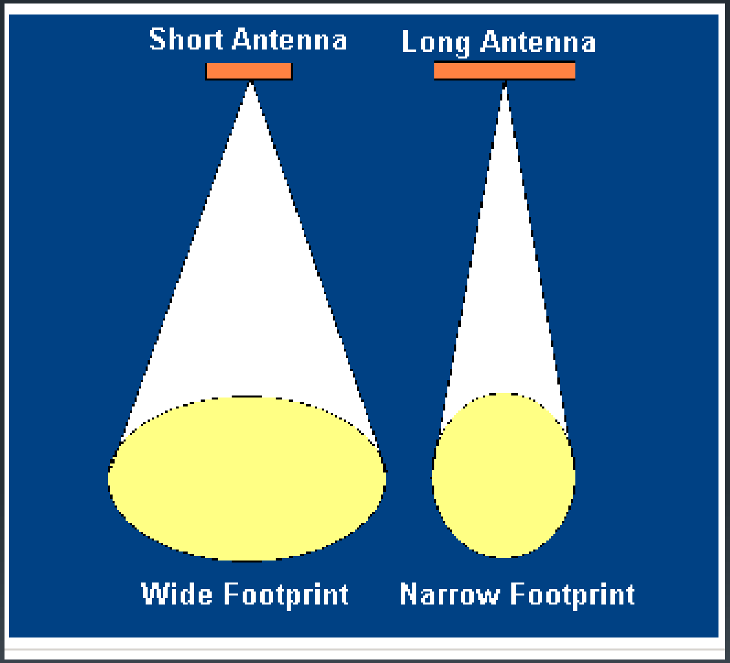
- Launched – May 4th 1989, Arrived – Aug 10th 1990
- To map the surface of Venus using SAR



http://nssdc.gsfc.nasa.gov/planetary/magellan.html
http://www.youtube.com/watch?v=79bX6aYe74I

Antenna's "Footprint"

- The beam sent out by the antenna illuminates an area on the targeted object
- Known as the antenna's "footprint"
- The recorded signal strength depends on the energy back scattered from the target inside this footprint



http://www.crisp.nus.edu.sg/~research/tutorial/mw.htm

Phased Arrays

- Consider a single antenna whose radiation pattern is given by the function $R(\theta, \varphi)$
- If we have N identical antennae in an array, positioned at points

  $$r_i = (x_i, y_i, z_i)$$

  then we can describe the total output Y of the array in terms of contributions from the individual antennae:

$$Y = R(\theta,\phi)\sum_{i=1}^{N} w_i e^{-j\mathbf{k}\cdot\mathbf{r}_i}$$

$$= R(\theta,\phi) AF$$

$$\boxed{AF = \sum_{i=1}^{N} w_i e^{-j\mathbf{k}\cdot\mathbf{r}_i}}$$

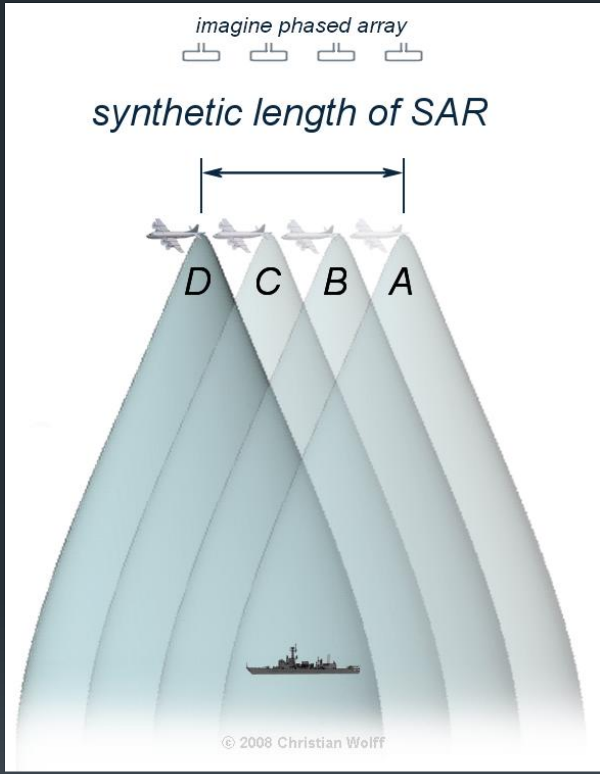
  - w_i is the complex weight of element *I*
  - **k** is the vector in the direction of wave propagation

- Phased arrays have many useful properties, but most importantly for our purposes they increase the overall gain of the transmitting/receiving system, and maximize the SNR

http://www.antenna-theory.com/arrays/arrayfactor.php

SAR analogy with phased arrays

- SAR data collection can be viewed as a virtual phased array in both space and time
- For a single antenna moving at constant velocity, position changes linearly with time
- If we assume the target to be stationary during the period of data collection, the time of collection is trivial and we wind up with a virtual phased array in space only

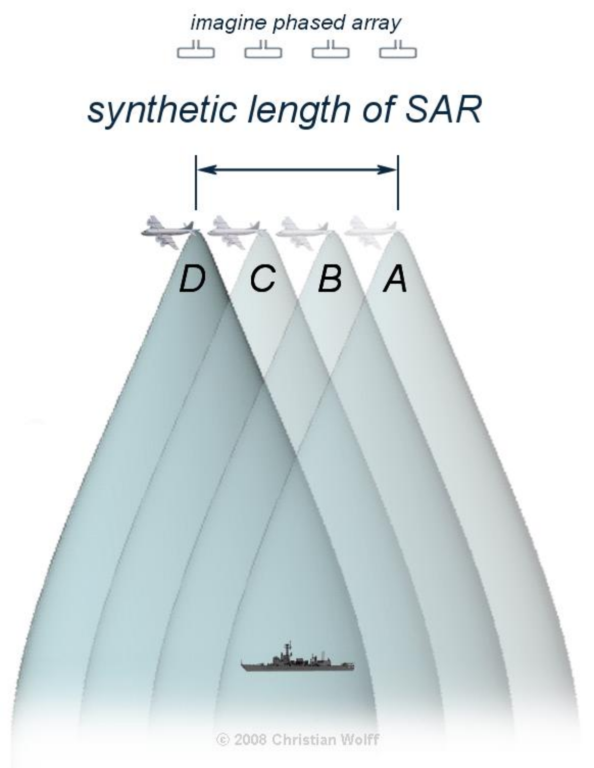


Virtual phased array > high SNR/large amount of coupled power > good target characterization!

Antenna Apertures & Arrays

Larger Aperture
Longer Array

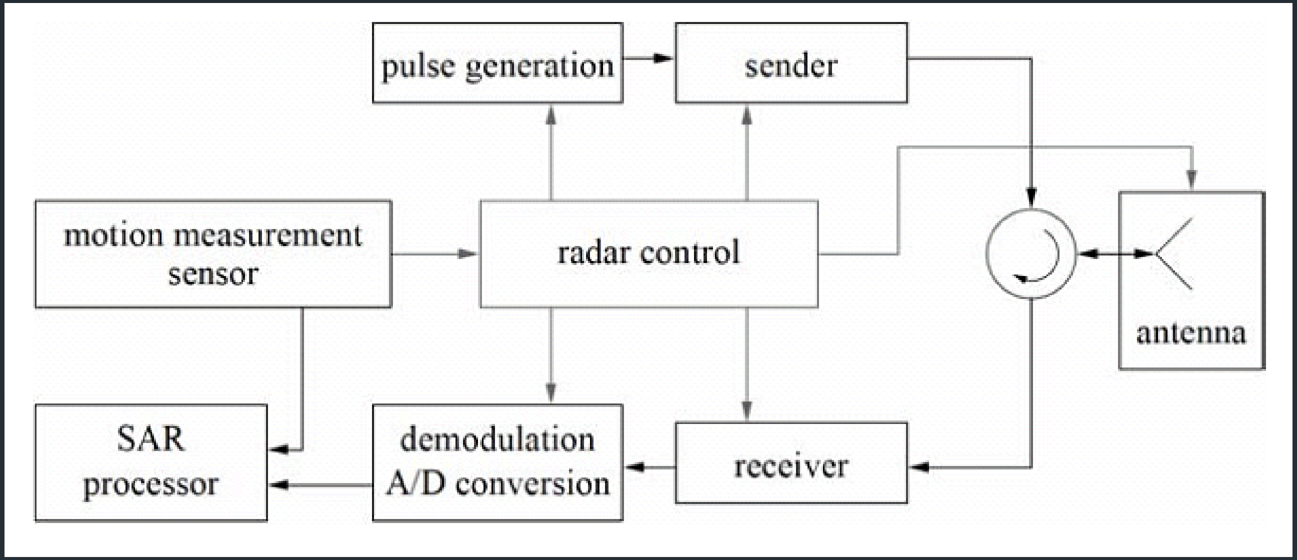
→More energy collected
→More gain compared to isotropic
→More SNR
→Narrower half-power beam width
→Greater angular resolution
→More elements



Uses one antenna in time-multiplex to operate similar to phased array

http://ocw.mit.edu/courses/

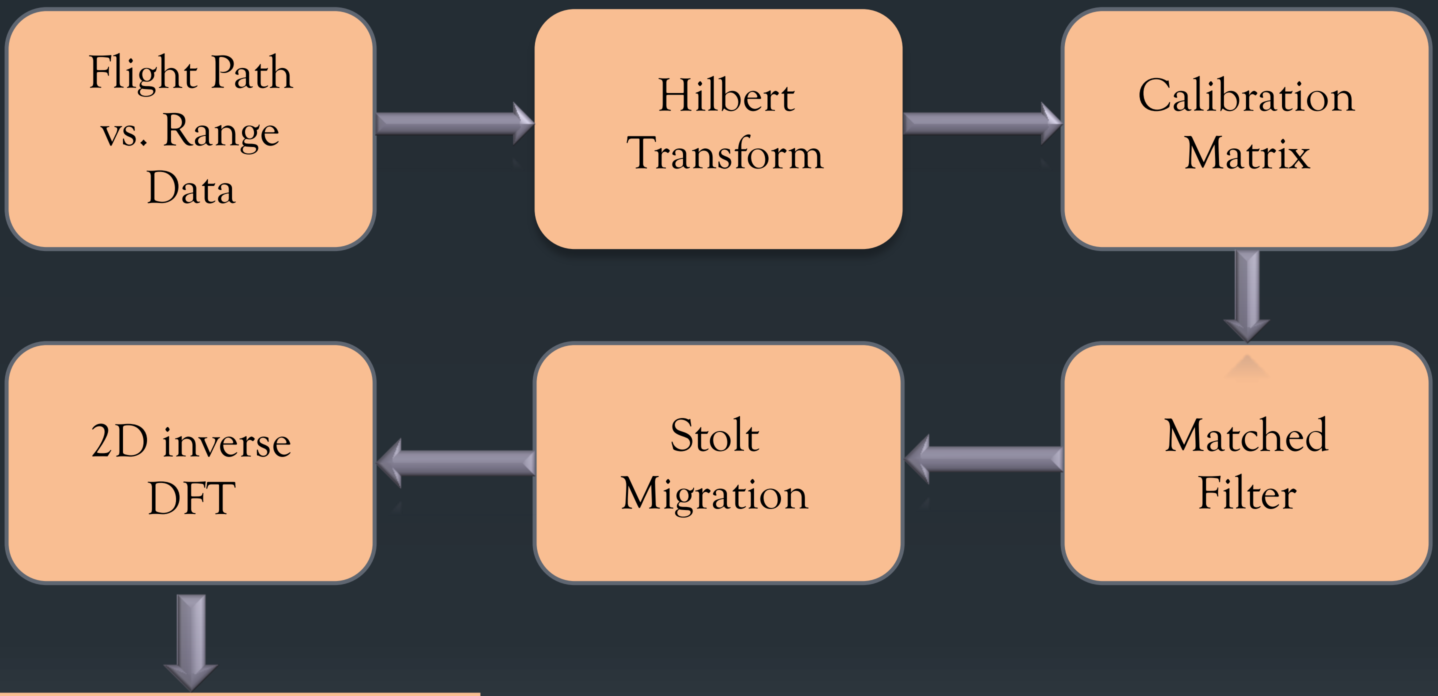
General SAR System



- Pulse generation creates pulses with a bandwidth according to the range resolution
- Sender amplifies the pulses and transfer it to the antenna via circulator
- Receivers amplifies the output signal of antenna and applies a band pass filter
- After the demodulation and A/D conversion, the SAR processor calculates the SAR image
- Radar control unit arranges the operation sequence particularly the time schedule

http://ftp.rta.nato.int/public//PubFullText/RTO/EN/RTO-EN-SET-086///EN-SET-086-03.pdf

SAR Imaging Algorithm



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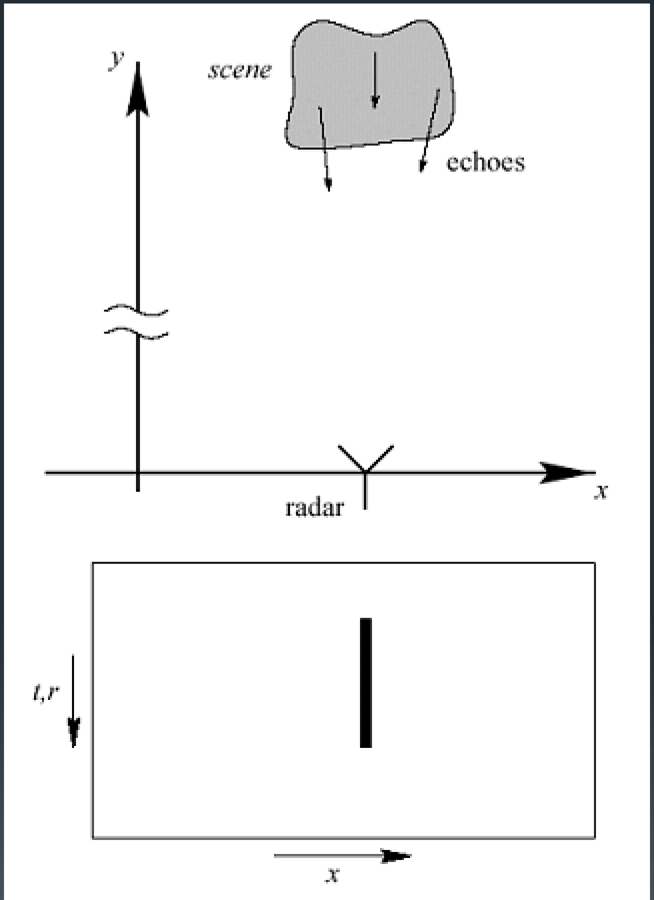
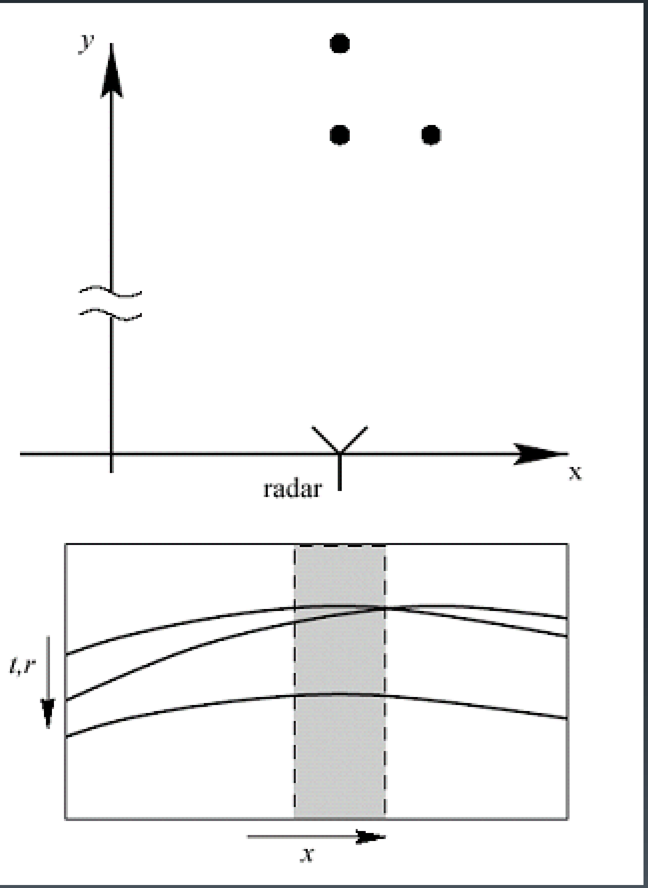
SAR Principle



- A radar sensor on the x-axis transmits a short pulse and receives the echoes
- SAR system stores the received signal in 2-dimensional array containing range, time, and radar position info
- Echoes superpose each other and result in the recorded data column, which contains a range profile

http://ftp.rta.nato.int/public//PubFullText/RTO/EN/RTO-EN-SET-086///EN-SET-086-03.pdf

SAR Principle



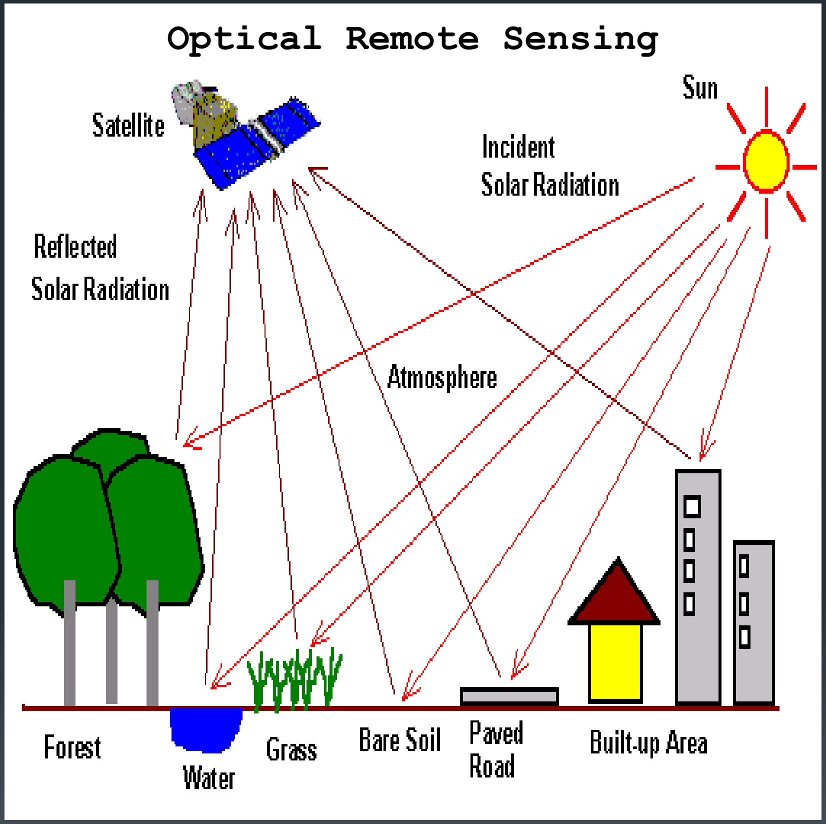
- 3 point targets are given at different positions
- The antenna moves in steps along the x-direction taking data samples
- A hyperbolic range history in the data results for each reflector, indicated by the curves
- Points will be generated in a second data array at the positions of the hyperbola vertex
- The signal intensity of the individual echoes, resulting from the reflectivity of the scene, controls the brightness of the points in the second data array, an image of the scene results

**point target – small object with reflectivity assumed to be at one discrete point*

http://ftp.rta.nato.int/public//PubFullText/RTO/EN/RTO-EN-SET-086///EN-SET-086-03.pdf

SAR vs. Optical Remote Sensing

- ✓ Independent of sun illumination
- ✓ Not affected atmospheric particles
- ✓ Accurate distance measurement
- ✓ Subsurface penetration
- ✓ Sensitivity to:
  - dielectric properties (water content, biomass, ice)
  - surface roughness (ocean, wind, speed)
  - man-made objects
  - target structure (structural details)

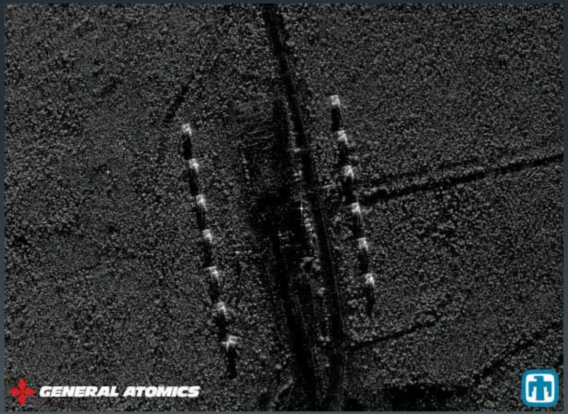


http://www.royalsoced.org.uk/cms/files/international/events/Cao_Zong-Jie.pdf
http://www.crisp.nus.edu.sg/~research/tutorial/optical.htm

Applications of SAR

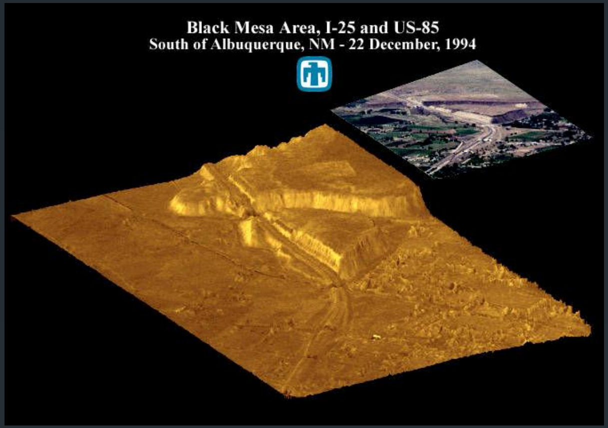
Military Surveillance and Targeting

Optical image of M-47 tanks



Aerial SAR image of M-47 tanks

3D Imaging

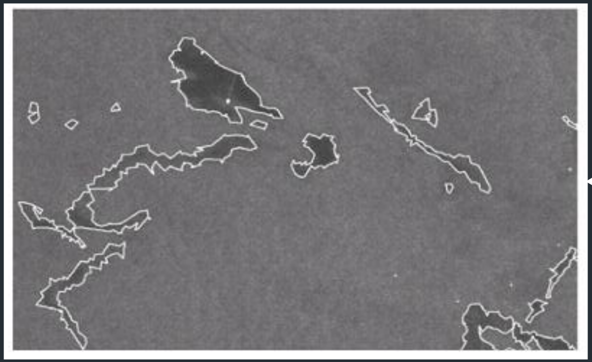


- Use 2 antennas on same air craft or make 2 passes offset in space
- Low-frequency (10 MHz – 1 GHz) SAR can penetrate the ground and optically opaque materials

http://www.sandia.gov/RADAR/sarapps.html
Radar Handbook, Skolnik, M.I. 2008

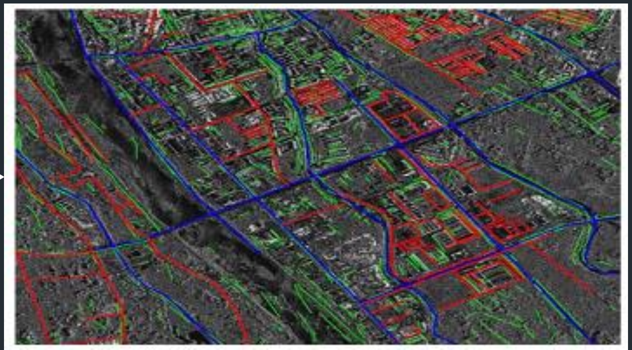
Other Applications

Environment Protection



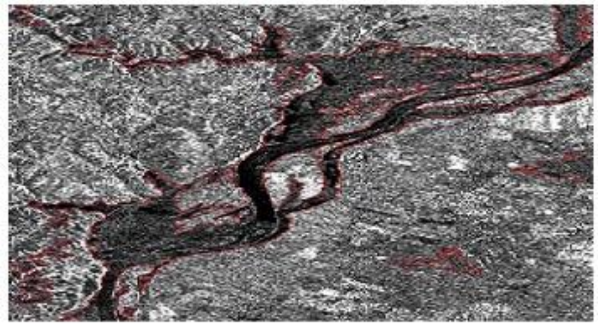
Oil spill segmentation result

Urban Construction



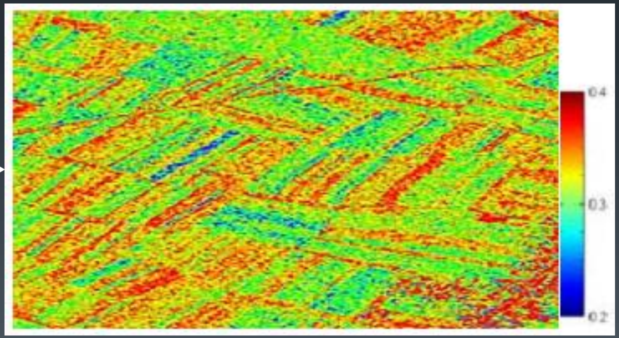
Road network extraction, Guan Xian, China

Natural Disaster Monitoring



Flood monitoring, Targus river, Portugal

Agricultural Survey

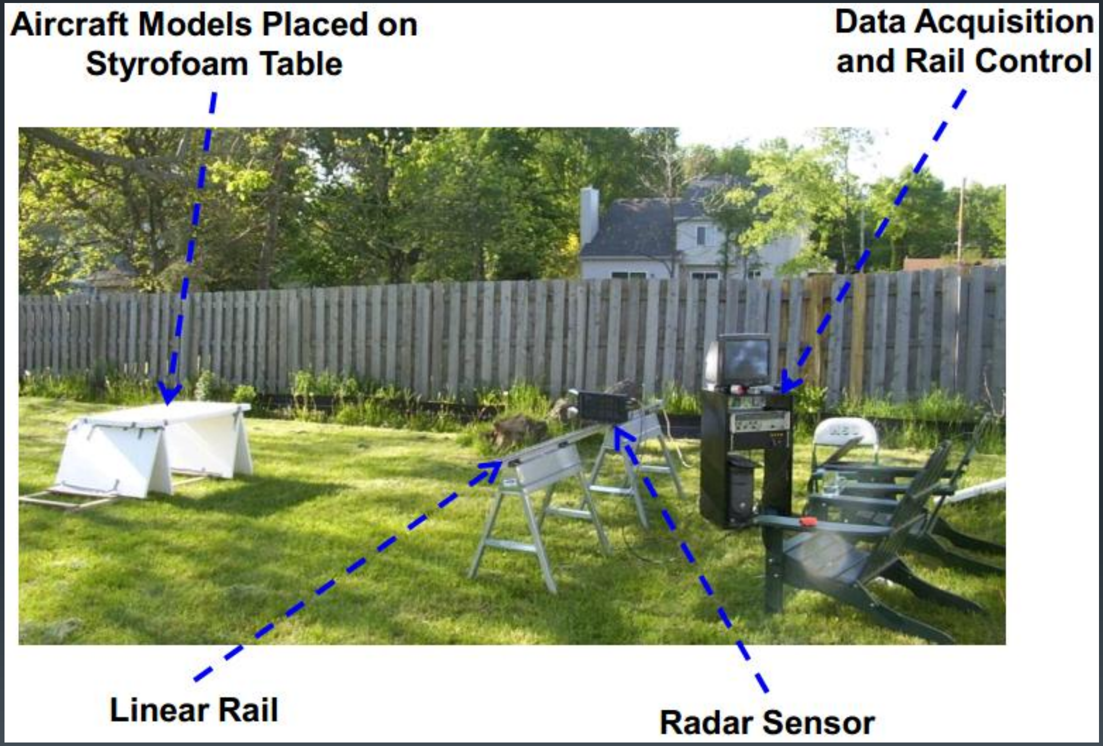


Soil moisture of an agricultural filed

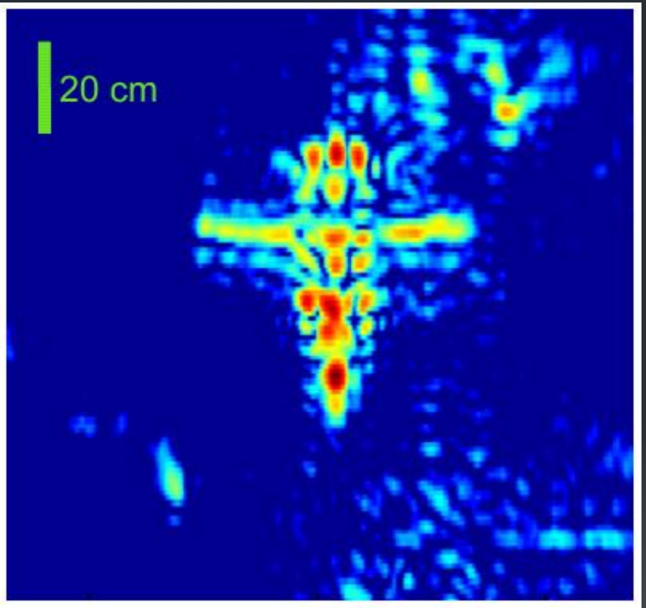
http://www.royalsoced.org.uk/cms/files/international/events/Cao_Zong-Jie.pdf

Backyard SAR by MITLL

Type : Rail



Aircraft Image on the Styrofoam Table



1:32 Scale F14

http://ocw.mit.edu/courses/

Summary

- SAR is mostly airborne or space borne
- Used to capture the image of earth's surface
- Works similar to phased antennas
- How it works?
  - Algorithm
  - Principle
- Applications & Alternatives

QUESTIONS?