Synthetic Aperture Radar (SAR) Imaging using the MIT IAP 2011 Laptop Based Radar*

Presented at the 2011 MIT Independent Activities Period (IAP)

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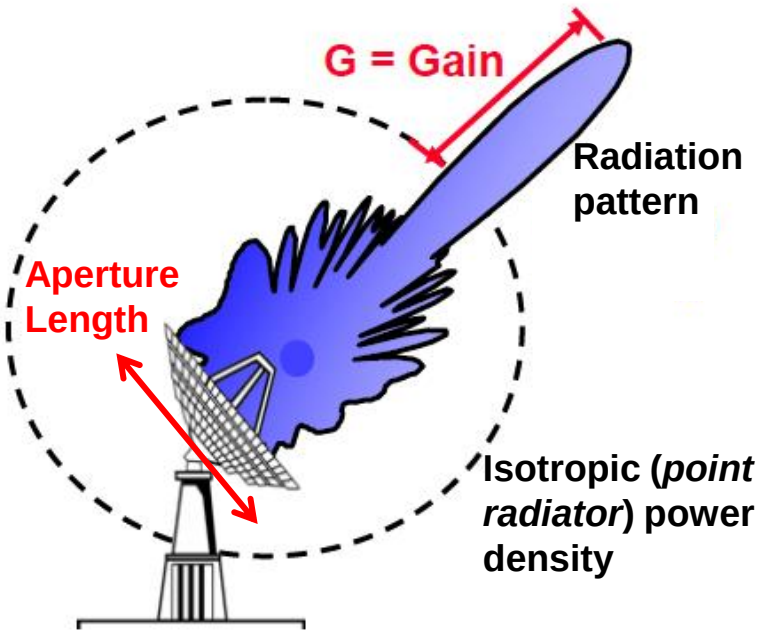
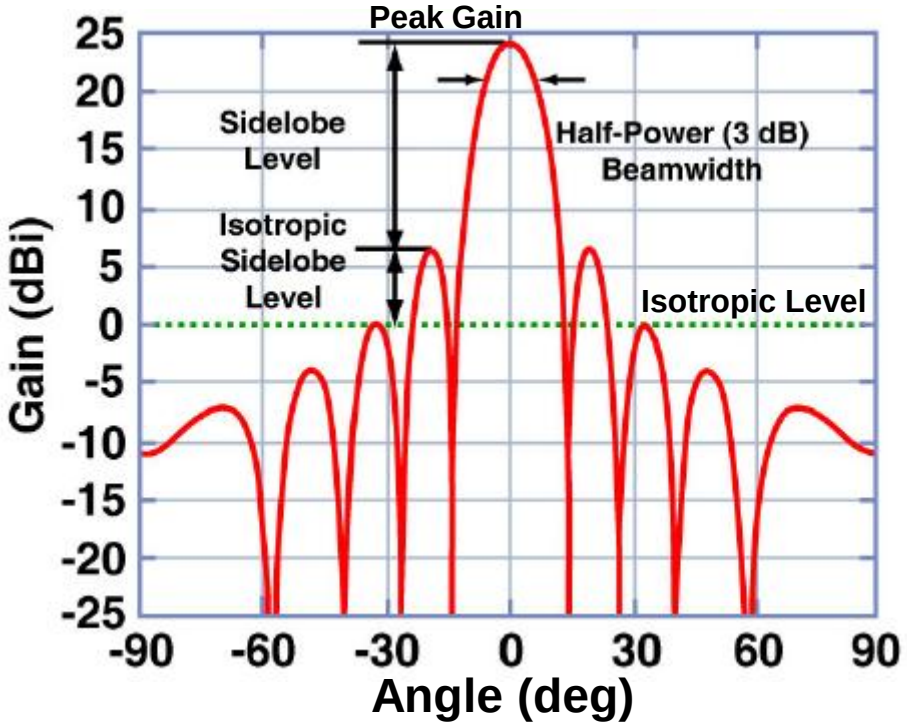
Outline

- Aperture, Antennas, and Arrays
- Synthetic Aperture Radar (SAR)
- Airborne SAR
- Rail SAR
- SAR using the MIT IAP Radar
- Homework

Antenna Aperture

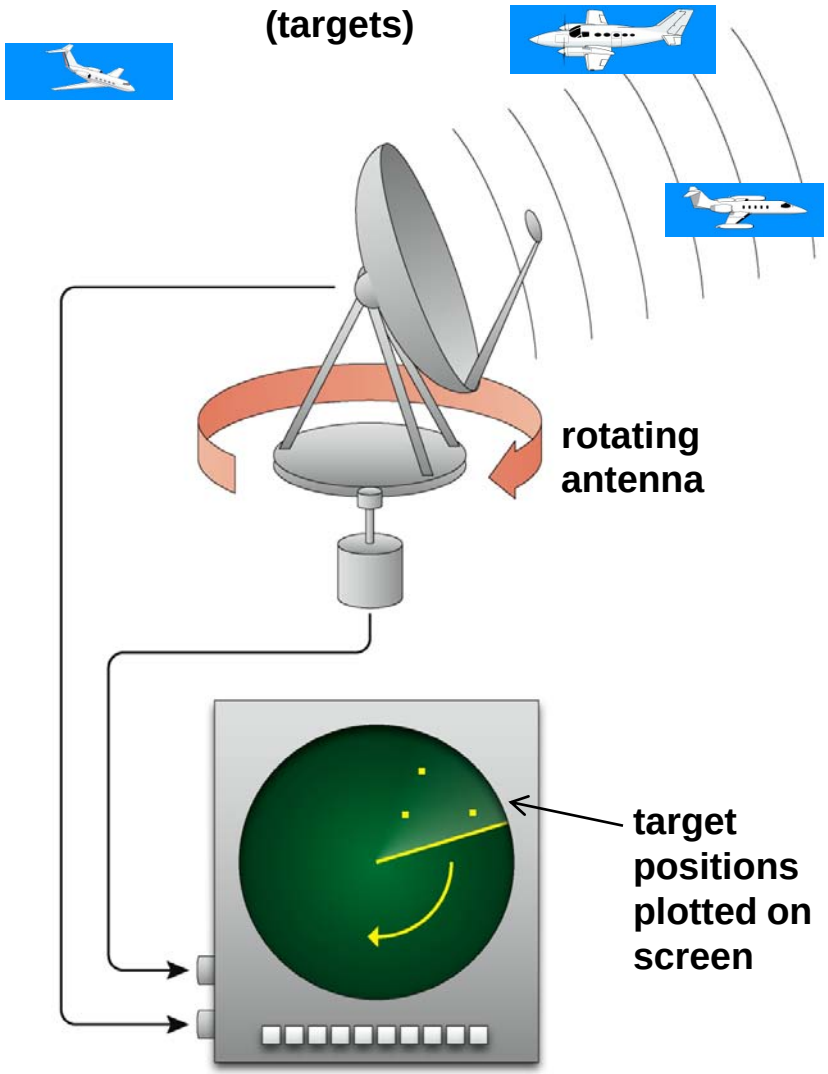




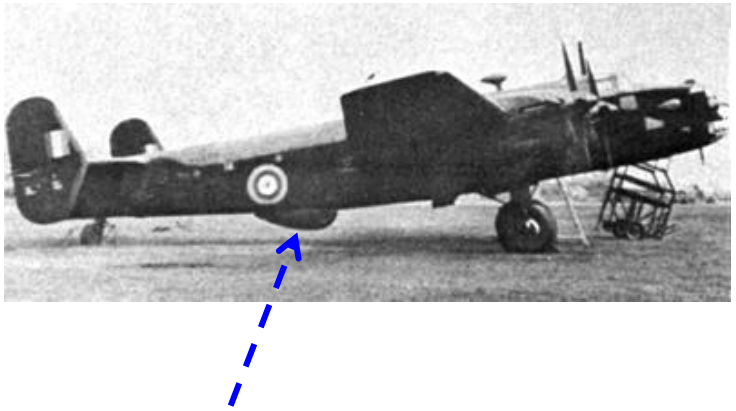
- Similar to a camera, larger the aperture the more energy collected
- For a parabolic antenna, the 'dish' is the aperture
- Larger the 'dish' the greater the gain compared to isotropic *(ideal point radiator*) providing increased signal-to-noise (SNR).
- Larger the dish the narrower the half-power beamwidth providing greater angular resolution.

Plan Position Indicator (PPI)

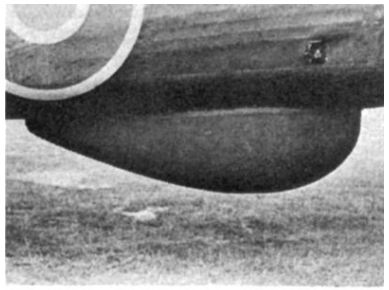
- Contemporary radar system
- Rotate a large aperture for a PPI (angle vs. range) image
  - angular resolution depends on aperture size
  - gain depends on aperture size

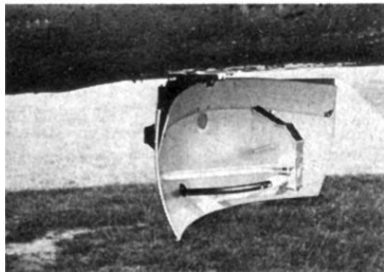


PPI Radar for Ground Mapping: H2S

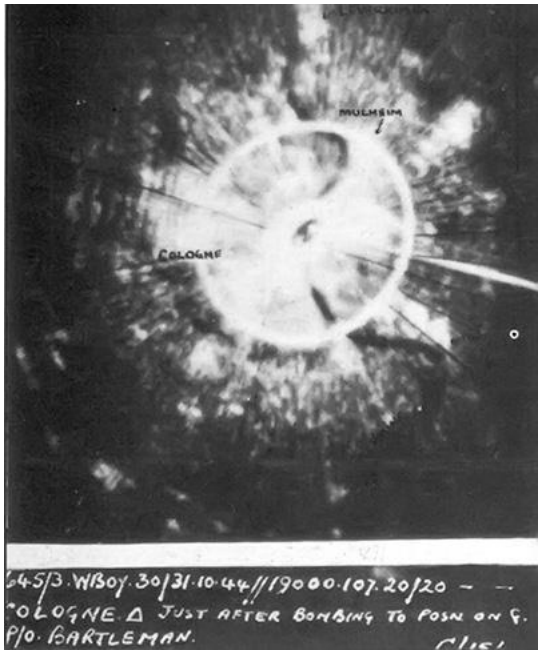


Radome mounted on bottom of a Halifax





Radome & Antenna

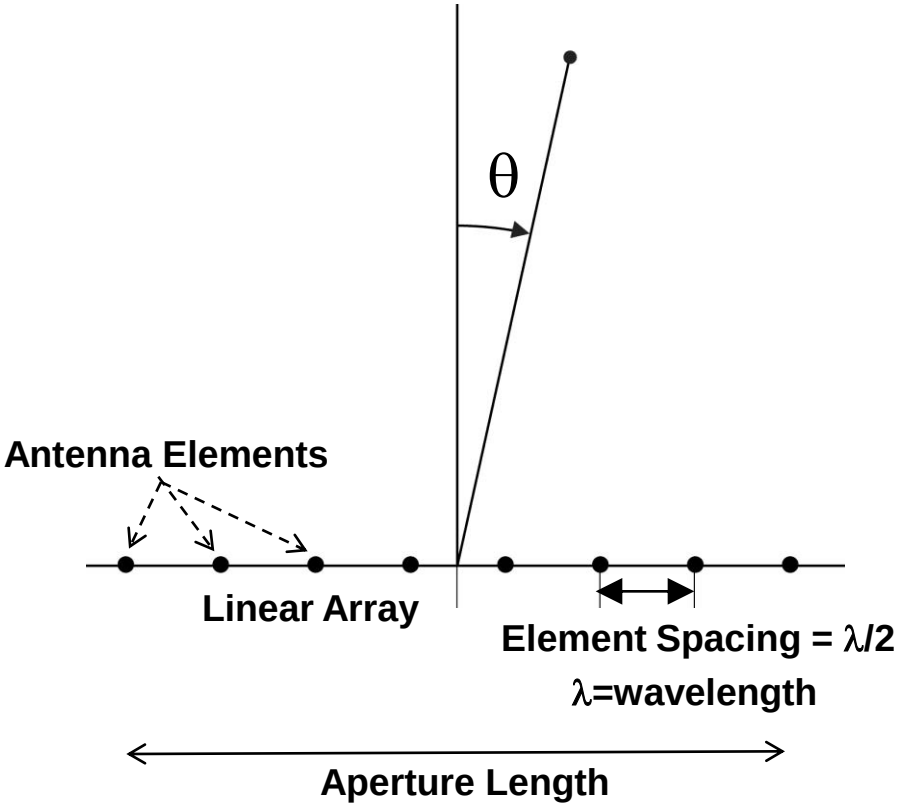


Radar image of Cologne

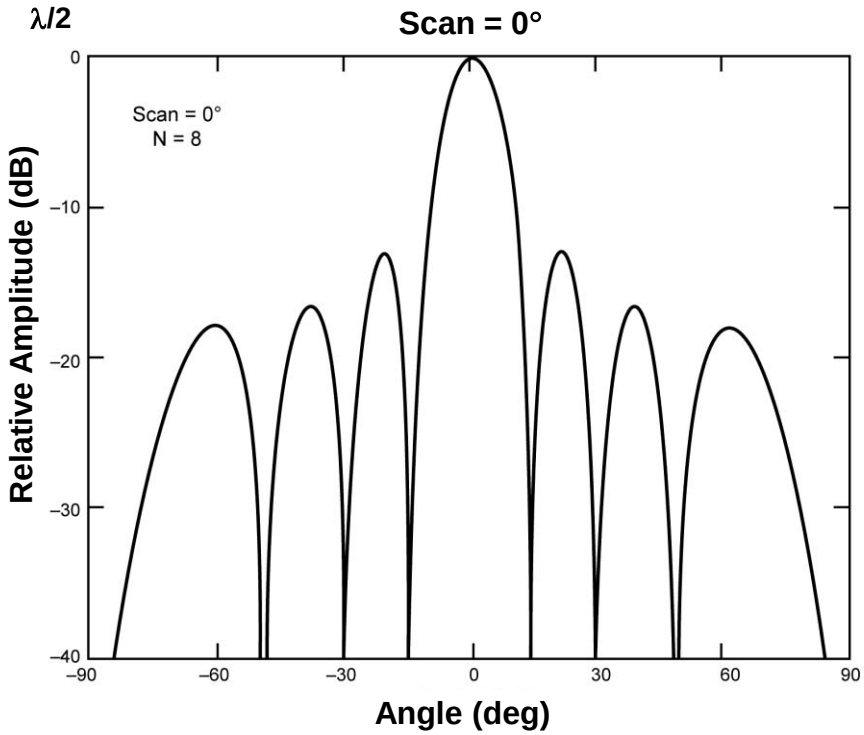
Public domain photos.
See http://en.wikipedia.org/wiki/H2S_radar

- Cloudy skies above western Europe
- RAF bombing at night complicating navigation
- H2S ground mapping radar solved problem [1]
  - navigation and bomb laying
  - could map out where cities were located
  - later versions could map out cities

Antenna Aperture and Arrays



Array Factor: $\mathrm{AF}(\theta) = \sum_{n=1}^{N} A_n e^{j\beta x_n(\sin\theta - \sin\theta_s)}$



- Longer the array the more elements
- More elements provides more gain providing greater SNR
- More elements reduces 3 dB beamwidth providing higher resolution

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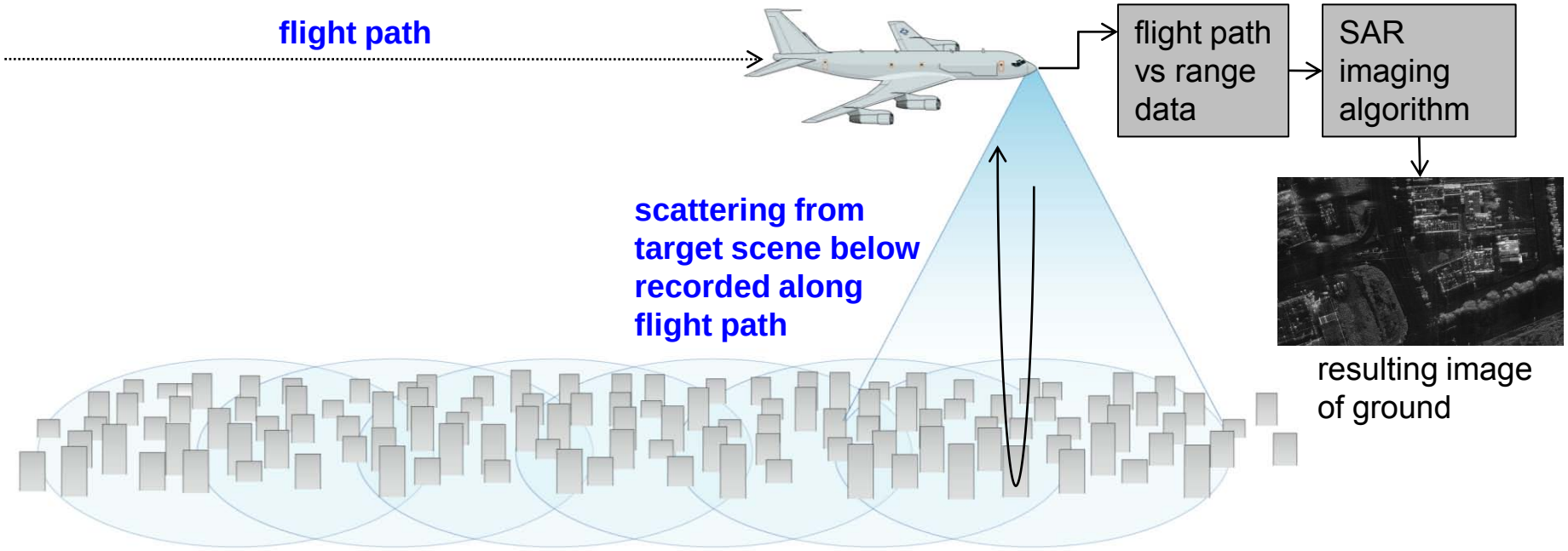
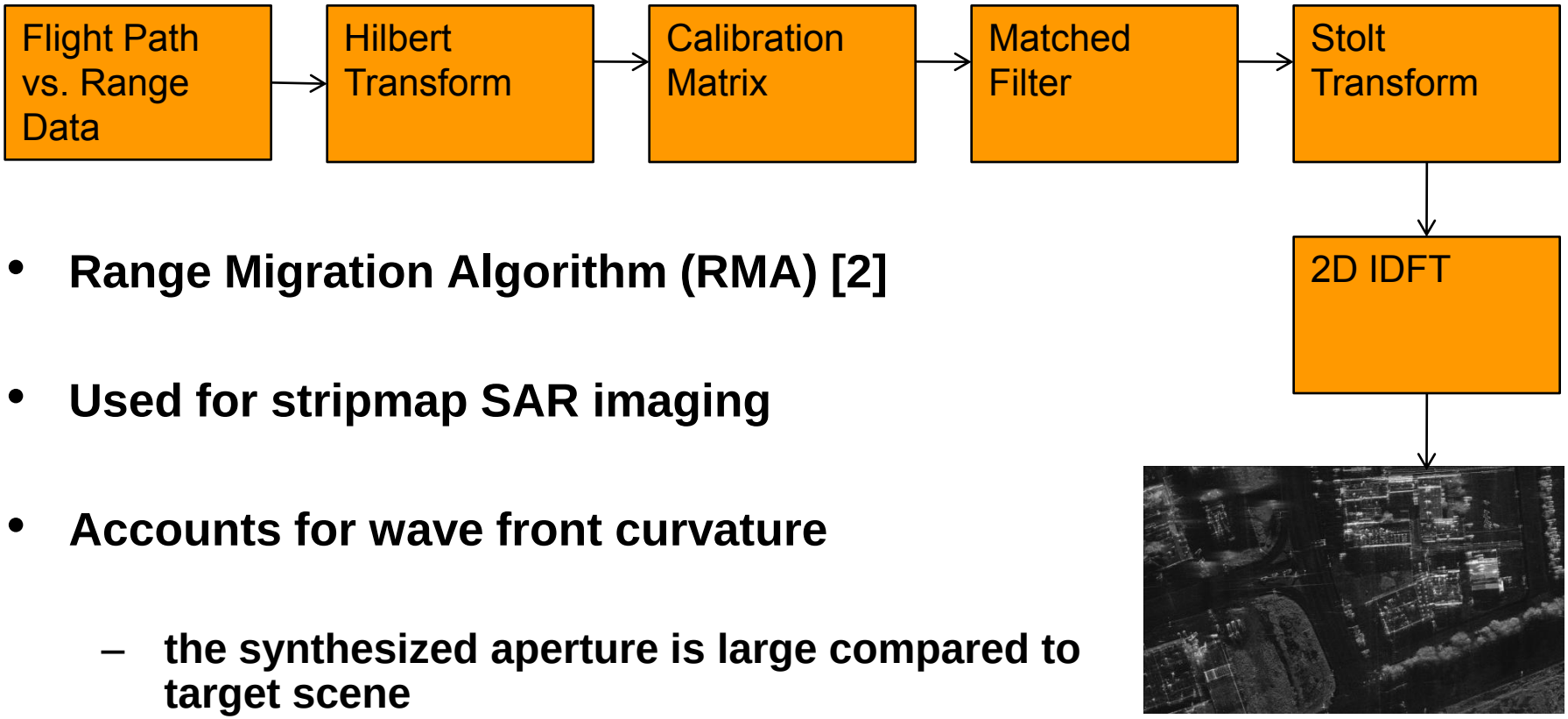
Synthetic Aperture Radar (SAR)



- **Small antenna on aircraft illuminates large swaths of ground**
- **Range profiles recorded along flight path**
- **SAR algorithm processes data into image of ground [2]**
  - ***thereby synthesizing an aperture the length of the aircraft flight path***
  - ***narrow beamwidth, high resolution and gain***

Real-Time Imaging SAR Algorithm



- **Range Migration Algorithm (RMA) [2]**
- **Used for stripmap SAR imaging**
- **Accounts for wave front curvature**
  - **the synthesized aperture is large compared to target scene**

resulting image

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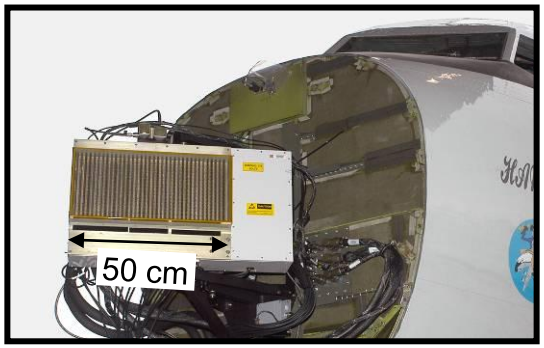
LiMIT Ultra-Wideband X-Band SAR
2.5 in × 2.5 in Resolution (3.0 GHz)

Sierra Vista, AZ, August 18, 2005

160 m Range cutout (400 m swath)

Lincoln Multi-mission ISR Testbed (LiMIT)

Phased-Array Antenna



260 m Cross Range cutout (2 km swath)

G. R. Benitz, 'Synthetic Aperture Radar (SAR),' MIT Lincoln Laboratory, 2007.

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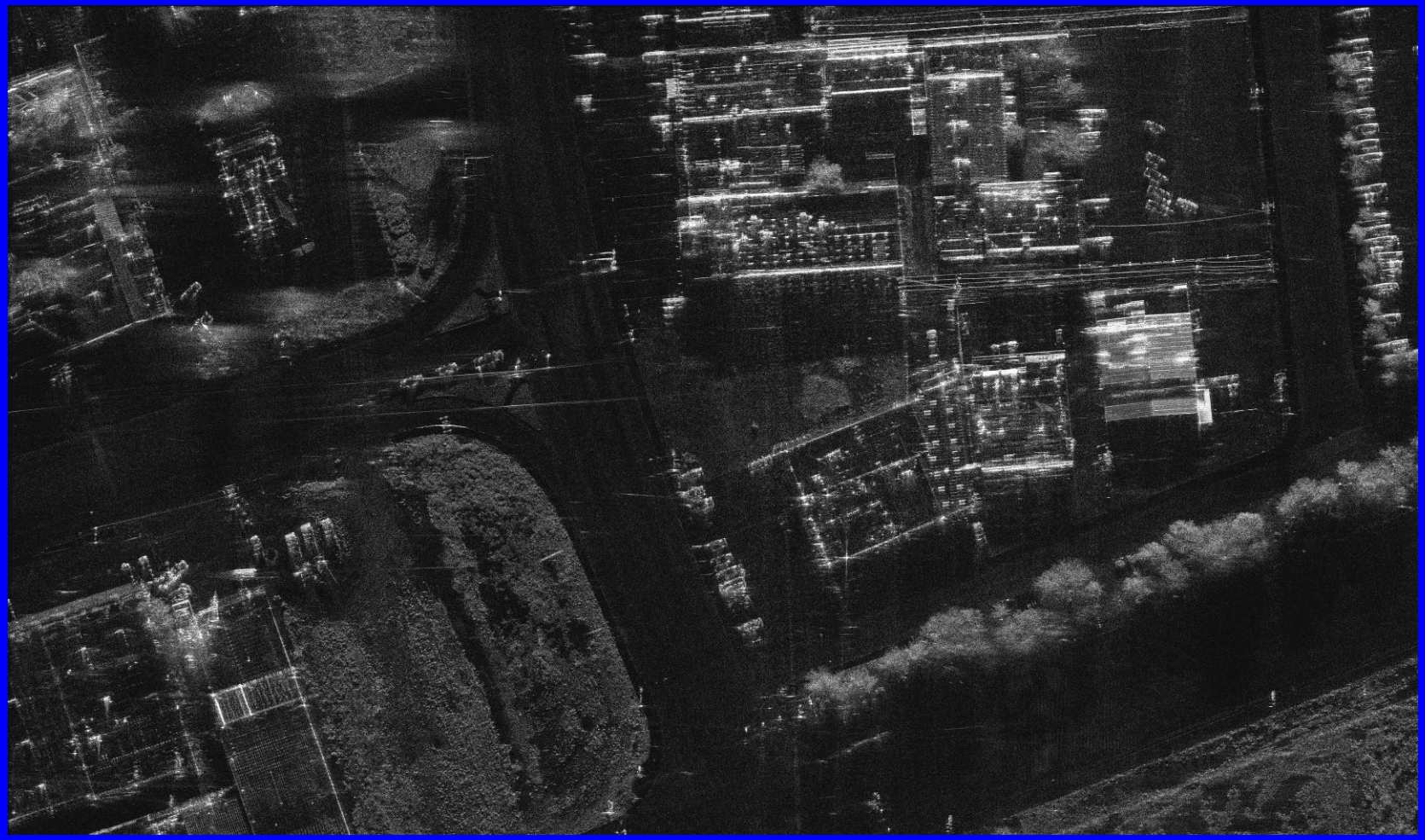

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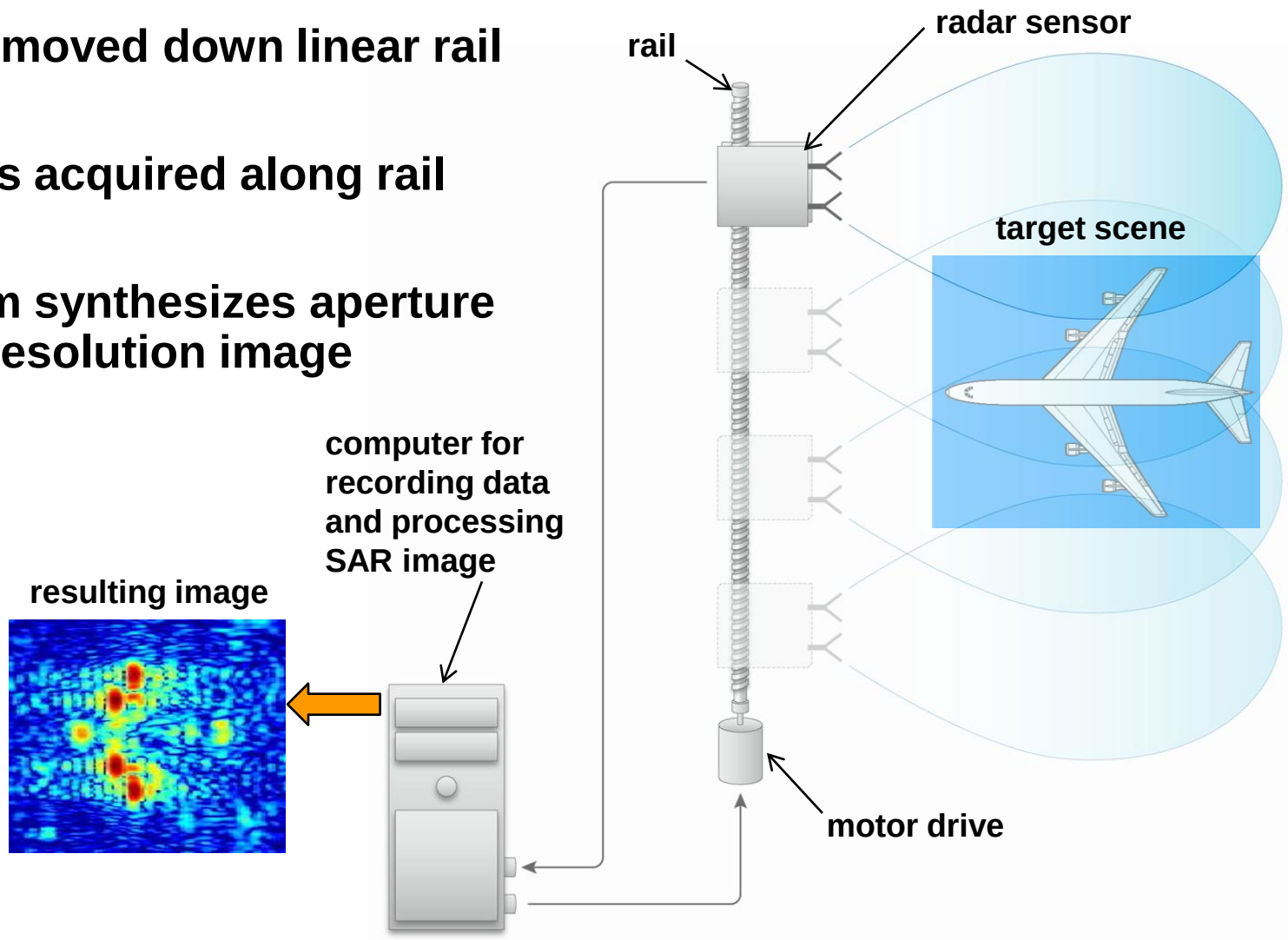
Linear Rail SAR

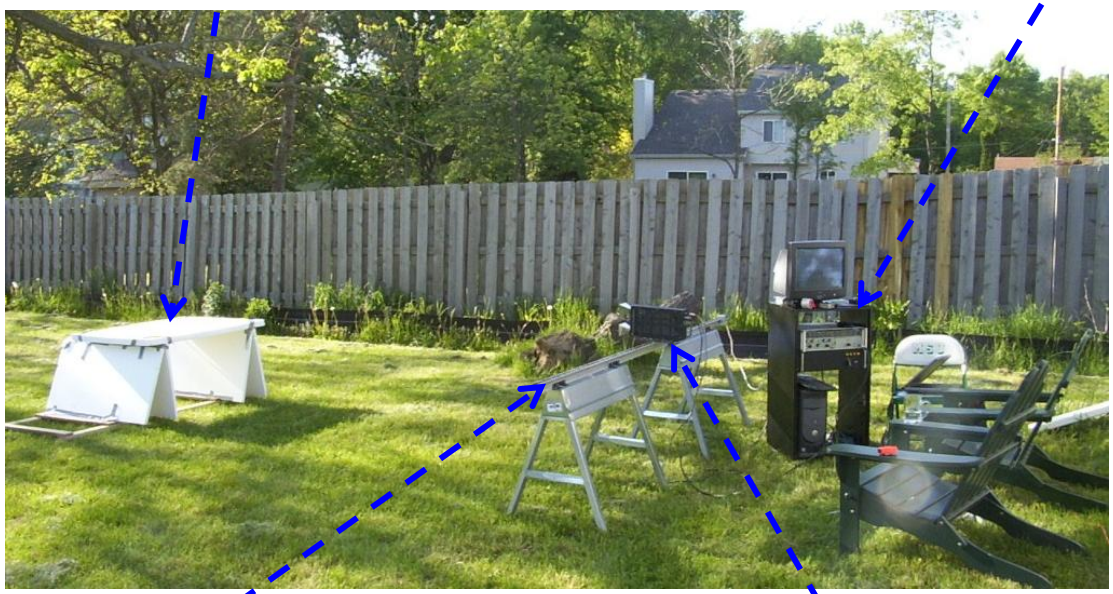
- FMCW Radar moved down linear rail
- Range profiles acquired along rail
- SAR algorithm synthesizes aperture to form high resolution image



Rail SAR example: Backyard SAR

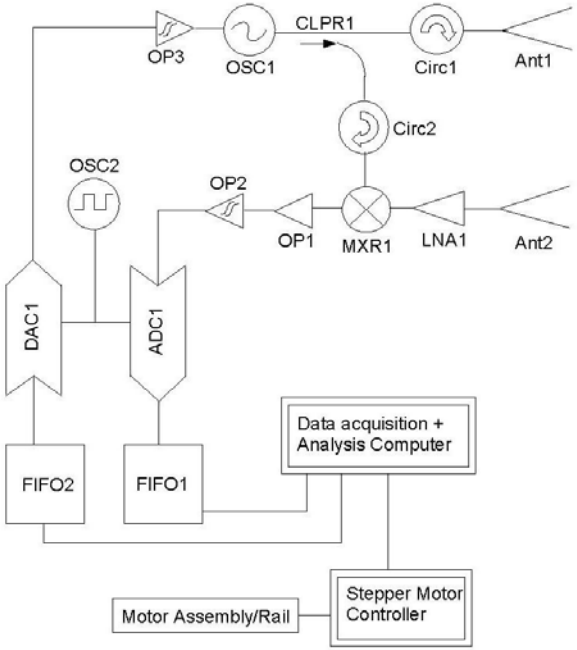
Aircraft Models Placed on Styrofoam Table

Data Acquisition and Rail Control



Linear Rail

Radar Sensor



Block Diagram

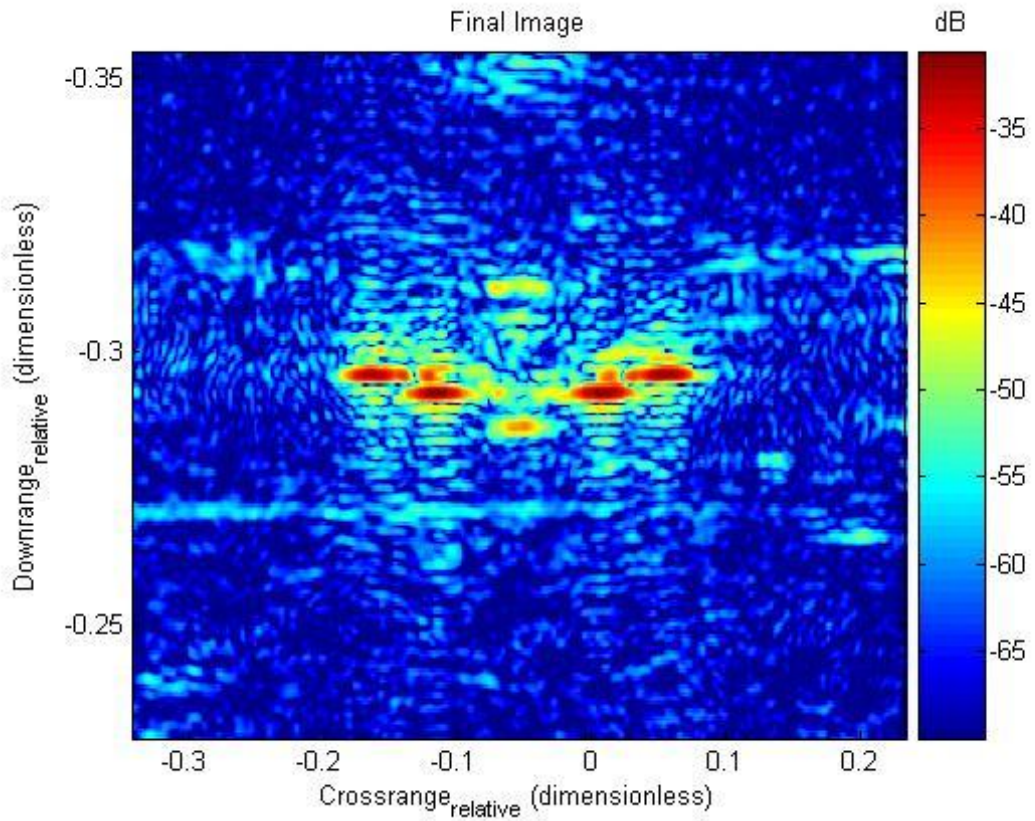
http://blog.makezine.com/archive/2010/06/how-to_build_a_synthetic_aperture_r.html
http://hackaday.com/2010/06/17/x-band-linear-rail-sar-imaging/
http://hardware.slashdot.org/story/10/06/18/1350259/DIY-Synthetic-Aperture-Radar
http://www.popsci.com/diy/article/2010-06/diy-synthetic-aperture-radar-system-250

G. L. Charvat. "Low-Cost, High Resolution X-Band Laboratory Radar System for Synthetic Aperture Radar Applications." Austin Texas: Antenna Measurement Techniques Association conference, October 2006.

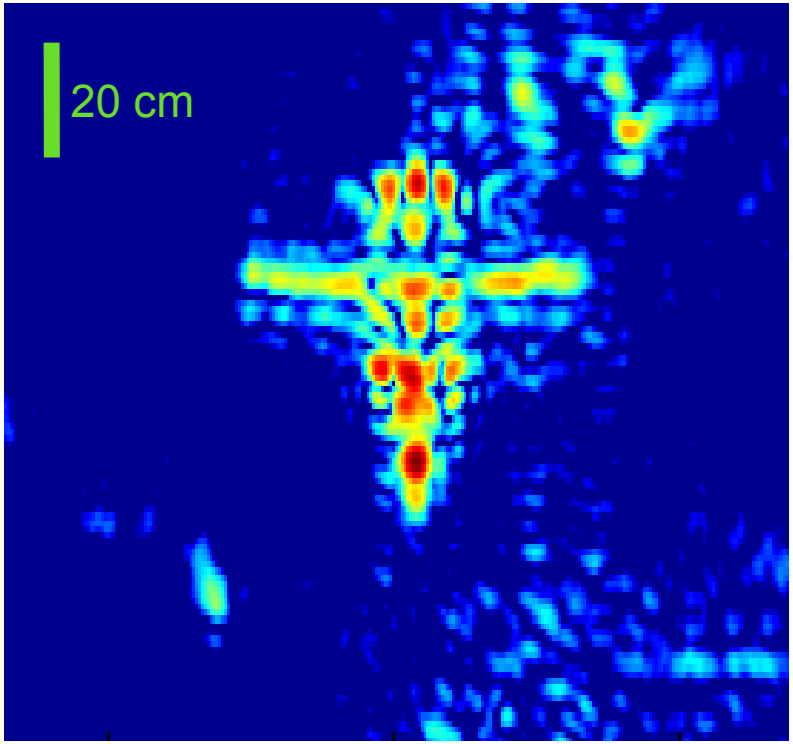
G. L. Charvat, L. C. Kempel. “Low-Cost, High Resolution X-Band Laboratory Radar System for Synthetic Aperture Radar Applications.” East Lansing, MI: IEEE Electro/Information Technology Conference, May 2006.

Backyard SAR Imagery

Imagery of aircraft placed on Styrofoam table

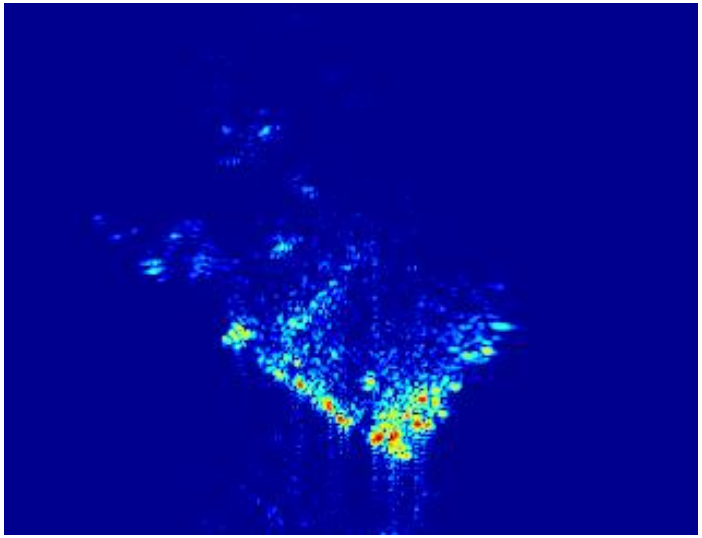


1:48 Scale B52

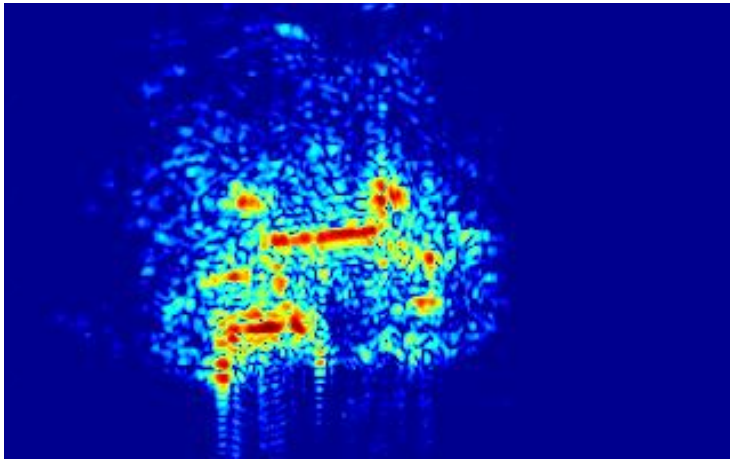


1:32 Scale F14

Backyard SAR Imagery



5.0 Mustang on radar



Cannondale M300

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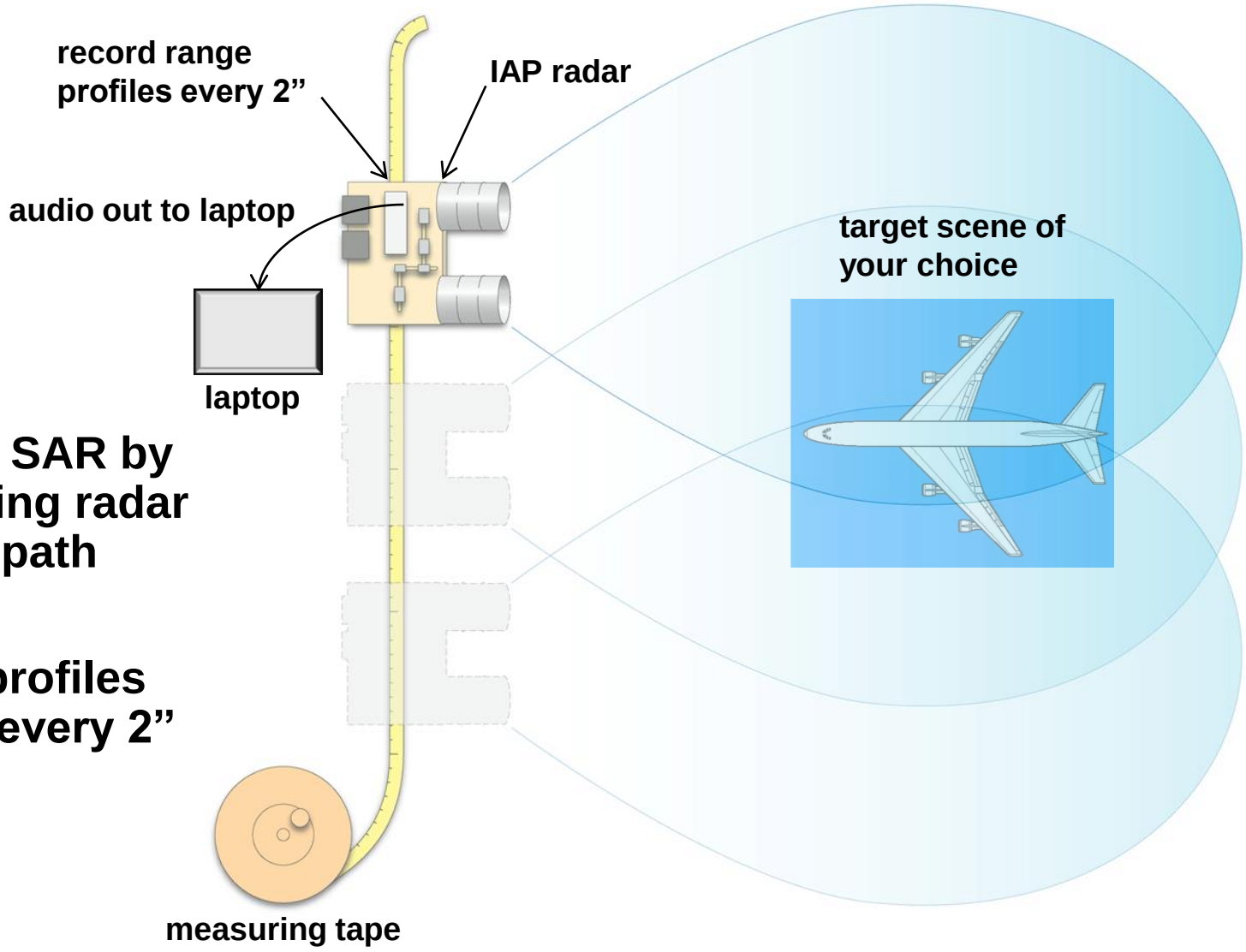
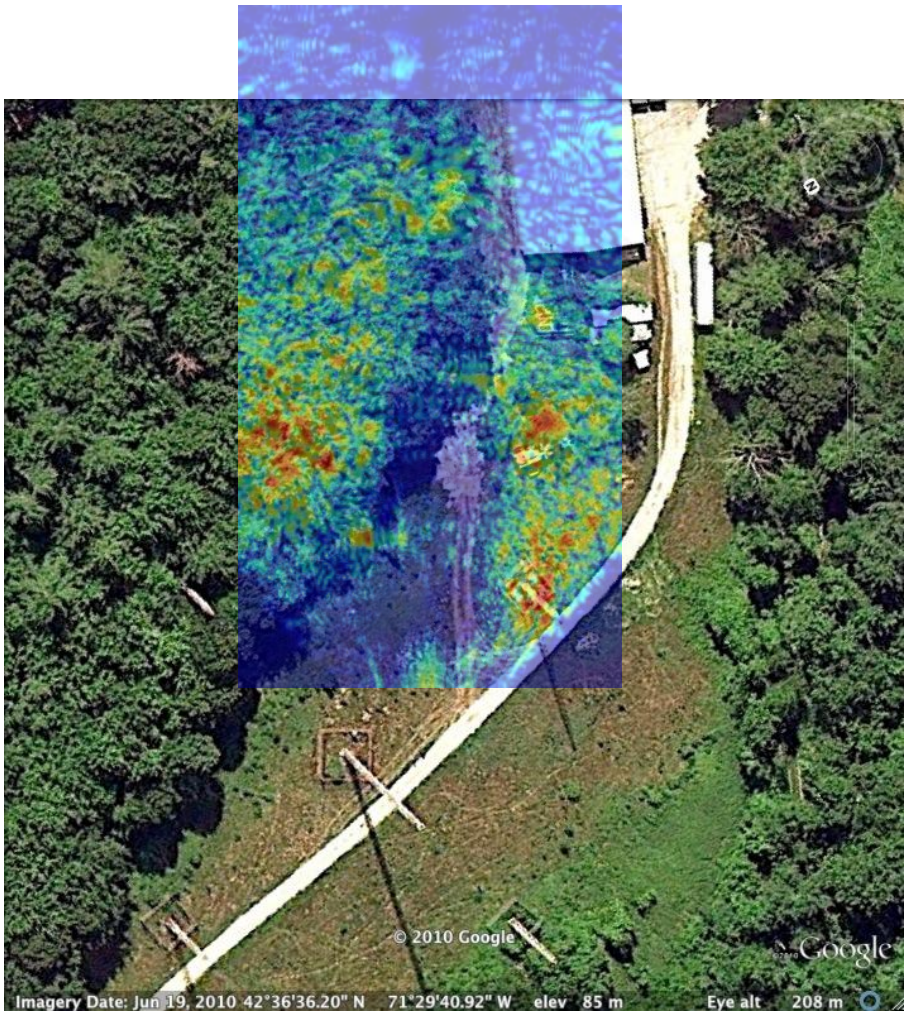
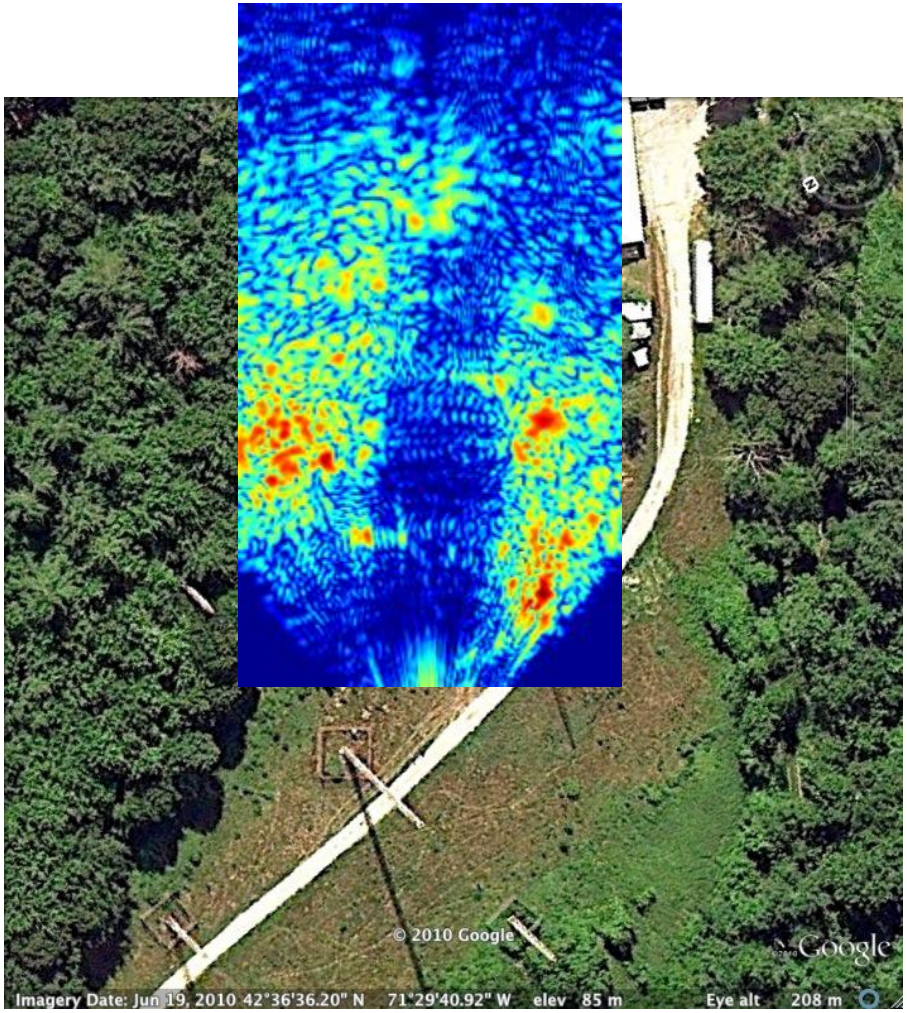
IAP SAR Geometry and Processing



- implement rail SAR by manually moving radar down straight path
- record range profiles incrementally every 2”
- process with SAR_image.m

Example: SAR image of Back of Warehouse using IAP '11 Radar





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Homework

- **Use the MIT IAP radar to make SAR imagery of one or more interesting target scenes of your choice**

- **Discussion of your imagery during final class on 1/28/11**

References

[1] B. Lovell, Echoes of War: The Story of H2S Radar, Taylor & Francis Group, New York, NY, 1991.

[2] W.G. Carrara, R.S. Goodman, and R.M. Majewski, Spotlight Synthetic Aperture Radar Signal Processing Algorithms, Artech House, Boston, MA, 1995.

[3] G. L. Charvat, "A Low-Power Radar Imaging System," Ph.D. dissertation, Deptartment of Electrical and Computer Engineering, MichiganState University, East Lansing, MI, 2007.

Resource: Build a Small Radar System Capable of Sensing Range, Doppler, and Synthetic Aperture Radar Imaging
Dr. Gregory L. Charvat, Mr. Jonathan H. Williams, Dr. Alan J. Fenn, Dr. Steve Kogon, Dr. Jeffrey S. Herd