GEOS 657 – MICROWAVE REMOTE SENSING

GRADUATE-LEVEL COURSE AT THE UNIVERSITY OF ALASKA FAIRBANKS

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Lecture 7: Principles of Radar & Active Microwave Systems

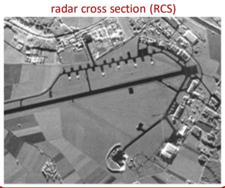
UAF Course GEOS 657

SOME BASICS AND THREE TYPES OF RADAR SYSTEMS

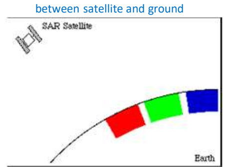
Active Microwave Systems are called RADARs

- **Radars actively transmit microwave signals (usually a radar *pulse*)**
- Radar antenna provides directivity for transmitted signal
- **A radar sensor records three different parameters**: **Amplitude**, **Phase** and polarization of the reflected microwave signals (here we focus on amplitude and phase)

Detected amplitude measures surface radar cross section (RCS)

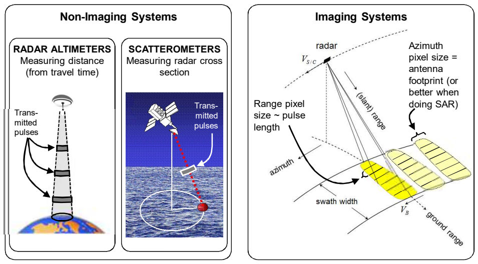


Timing of transmitted signal (radar pulse) provides information about distance between satellite and ground

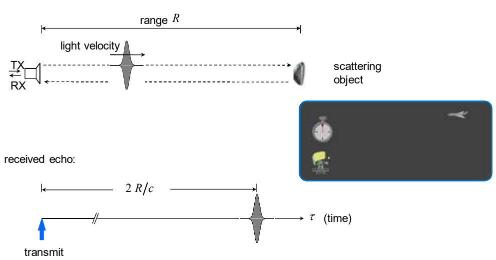


Three Different Types of Radar Systems

- Based on measurement type**, three** different radar systems can be discriminated:



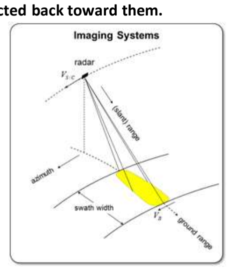
Radar Principle



Think – Pair – Share

So Earth observation radars send signals to the Earth surface and record the amplitude, phase, and polarization of the part of the signal that is reflected back toward them.

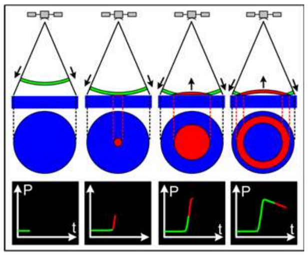
- **Q1:** A lot of energy is lost as the signal travels from the transmitter to the ground and back. **Which of the following contributes most of the loss in signal power?**
  - **A:** Limited Transmit antenna efficiency (ability of the antenna to transmit)
  - **B:** Losses along the path from sensor to the ground and back
  - **C:** Losses during surface scattering (radar cross section)
  - **D:** Limited Receiver gain (ability of the antenna to collect returned energy)
- **Q2: What percentage of a the transmitted signal power do you think arrives at the receiver?**
  - **A:** 1%
  - **B:** 0.001%
  - **C:** $1\text{x}10^{-10}$%
  - **D:** $1\text{x}10^{-22}$%



A Short Word on Radar Altimeters

- Radar altimeter emits pulses towards the Earth's surface (nadir direction)
- Signal travel time (transmission to reception) is proportional to satellite altitude.
- **Measuring Signal travel time not easy** as echo signal has funny shape

Idealized altimeter echo from flat surface (e.g., smooth ocean surface



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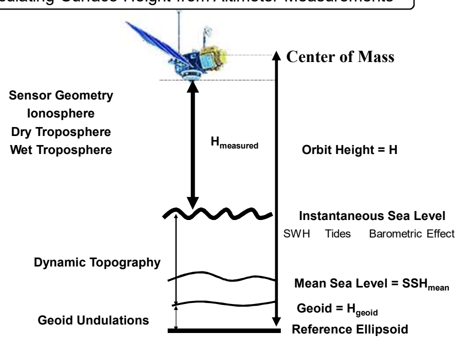
Calculating Surface Height from Altimeter Measurements



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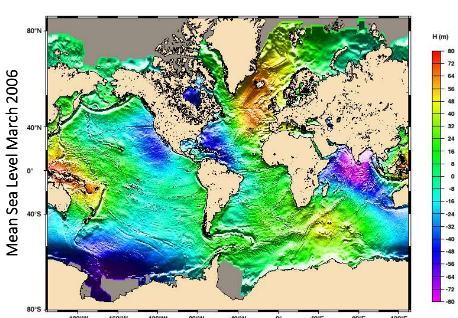
Mean Sea Level Height from Altimetry



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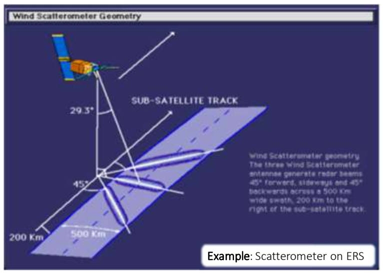
Microwave Scatterometers

- **Goal**: measurement of wind speed and direction over oceans



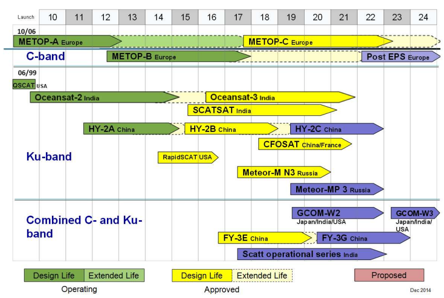
Example: Scatterometer on ERS

wind
⇩
ocean surface roughness
⇩
radar backscatter

Recently-Launched Scatterometer Instruments

- Widespread usage of scatterometers started in the 1990s.
- Today, scatterometer data is operationally used especially for data assimilation and for marine nowcasting.
- Figure shows an overview of the current and proposed satellite missions carrying scatterometers.

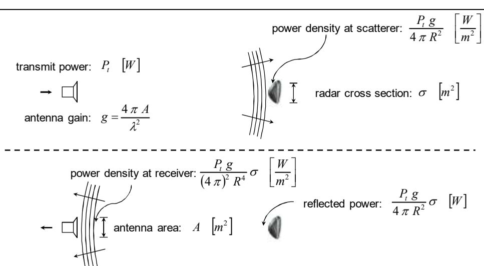
source



QuikSCAT Windfield

Imaging Radar Concepts

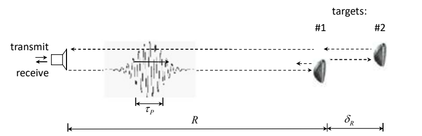
The Radar Equation – A Reminder



received power: $P_r = A\frac{P_t\, g}{(4\,\pi)^2\, R^4}\sigma = \frac{g\,\lambda^2}{4\pi}\frac{P_t\, g}{(4\,\pi)^2\, R^4}\sigma = P_t\frac{g^2\,\lambda^2}{(4\,\pi)^3\, R^4}\sigma$ $[W]$

Insert Boardwork here: Radar Equation

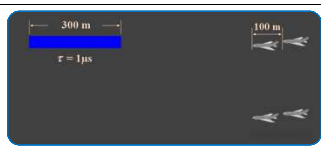
Pulse Waveform and Range Resolution



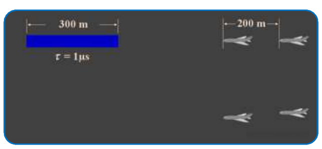
targets #1 and #2 easily separable, if $\delta_R \geq \rho_R = \tau_P c/2$ (range resolution)

Range Resolution Example

- Insufficient Target Separation



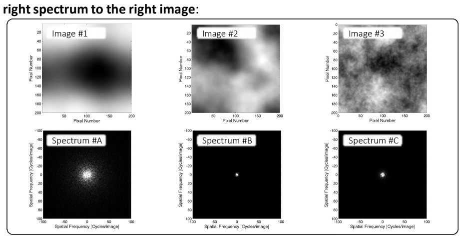
- Sufficient Target Separation



AN A BIT MORE ESOTERIC THINK – PAIR – SHARE

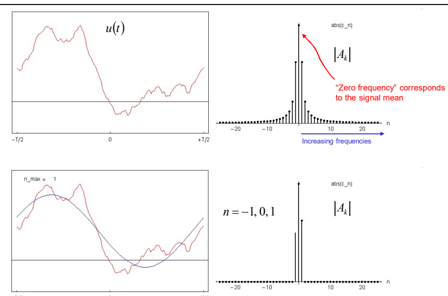
Think – Pair – Share
What does the Spectrum of an Image Tell Us?

1. **Explain what the "Spectrum (Fourier Representation)" of an Image represents**
2. **Assign the right spectrum to the right image**:

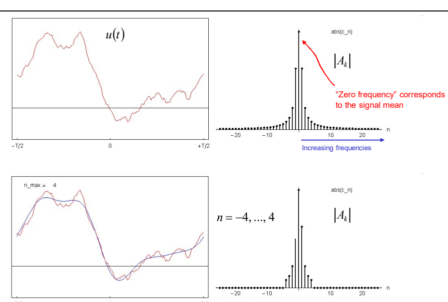


3. Based on these image relationships above, **which image parameter dictates how "wide" the spectrum of the image is?**

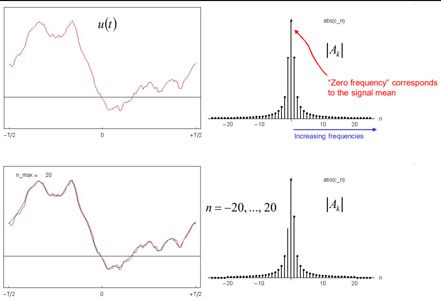
Approximation of a Signal by Finite Fourier Series



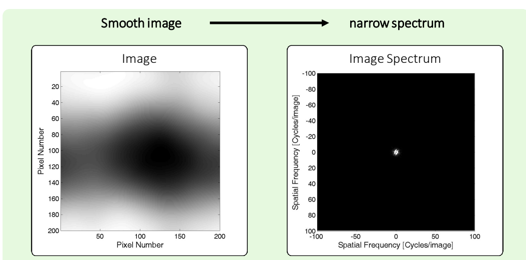
Approximation of a Signal by Finite Fourier Series



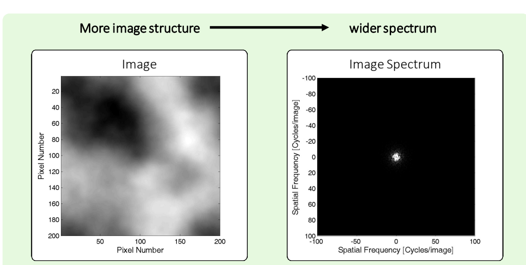
Approximation of a Signal by Finite Fourier Series



Shape of Image Spectrum depends on Image Structure

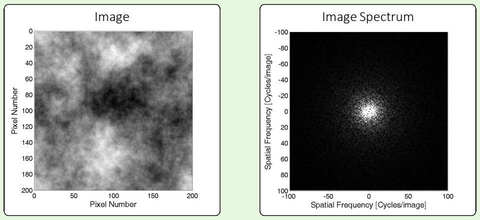


Shape of Image Spectrum depends on Image Structure



Shape of Image Spectrum depends on Image Structure

Even more image structure → even wider spectrum



IMAGING RADAR – HOW IT'S REALLY DONE

Some Problems with the Radar Imaging Concept

- **Power P_r of returned signal reduces rapidly the distance R to the target**

$$P_r \propto \frac{1}{R^4} P_t \quad with\ P_t = transmit\ power$$

- **For satellite applications:** $P_r \approx \frac{1}{40000000000000000000000000} \cdot P_t$!!!!!!!

→ **For Satellite applications:**
Difficult to transmit a pulse that (1) has enough power to be able to detect backscattered response AND (2) is short enough to yield sufficient range resolution

Most Radars Replace Pulse with Linear Frequency Modulated (Chirped) Signal

- **Reason:** Sending sufficient power in a single short pulse is near impossible
- Radars that send chirped signal are called "**Pulse Compression Systems**"

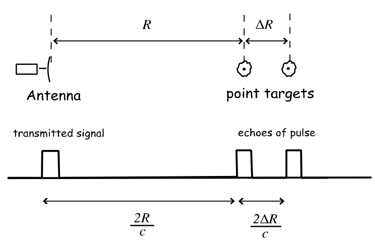
- **Procedure:**
  1. Transmit frequency coded signal of length τ_P
  2. Receive frequency coded echo
  3. Compress frequency coded signal using a decoding operation called matched filtering

- **What is the resolution of the compressed pulse?**
  - Ability to compress the pulse depends on the bandwidth W_P of transmitted chirp signal
  - The higher the bandwidth, the narrower the compressed pulse

$$\rightarrow \tau_P = \frac{1}{W_P}$$

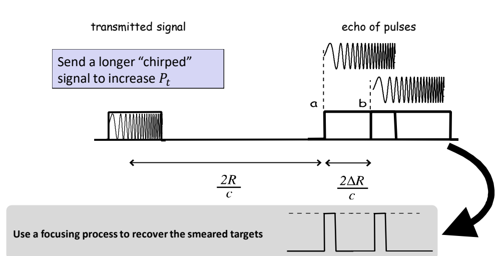
Achieving Good Range Resolution

The Airborne Case



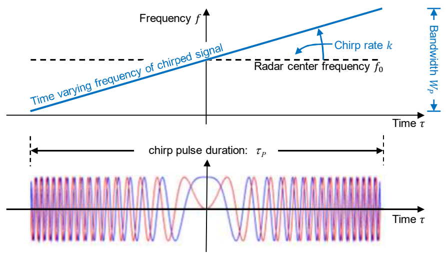
Achieving Good Range Resolution

The Spaceborne Case



Properties of the Frequency Coded (Chirped) Signal

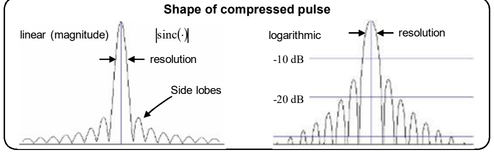
- **Chirp signal:** $u(\tau) = exp(j\pi k\tau^2) = cos(\pi k\tau^2) + j \cdot sin(\pi k\tau^2)$



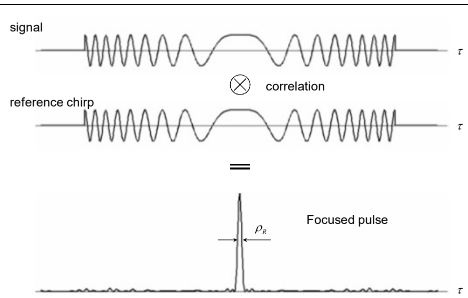
Range Compression by Matched Filtering (I)

1. **Data Acquisition:**
   1. Transmit chirp instead of short pulse
   2. Every point target will return chirp echo
2. **Range Compression:** **Correlate** received signal with replica of transmitted chirp
3. **Final range resolution after Range Compression:** $\rho_R \cong \frac{c}{2W_P}$

Shape of compressed pulse

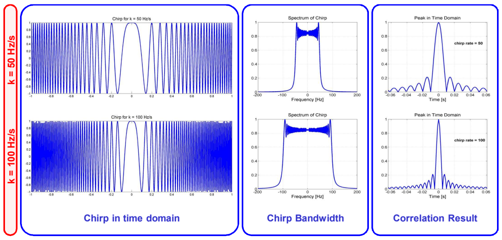


Range Compression by Matched Filtering (II)

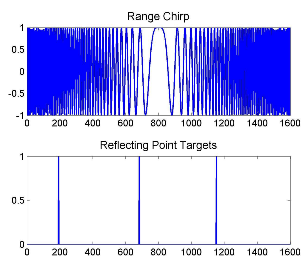


Range Compression: Resolution-Bandwidth Duality

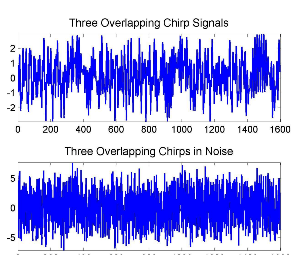
- You see two different chirps of identical duration but different chirp rates ($k = 50$ & $k = 100$ Hz/s)
- Higher chirp rate → twice the bandwidth → two times better resolution after correlation



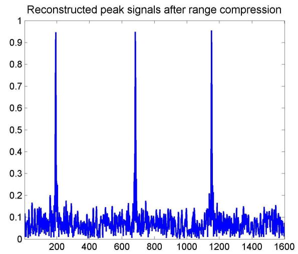
Range Compression: Matlab Example (I)



Range Compression: Matlab Example (II)



Range Compression: Matlab Example (III)

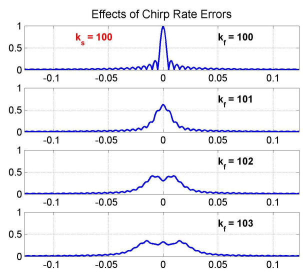


Chirp-Rate Error Effects – Matlab Example

k_s: Chirp rate of transmitted signal

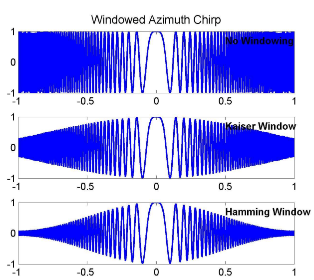
k_f: Chirp rate used for focusing

Chirp rate errors → insufficient focusing of scattered energy



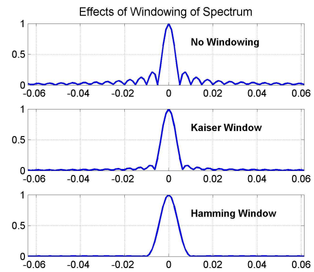
Where Do Side-Lobes Come From?

Effect of Windowing – Matlab Example (I)



Where Do Side-Lobes Come From?

Effect of Windowing – Matlab Example (II)

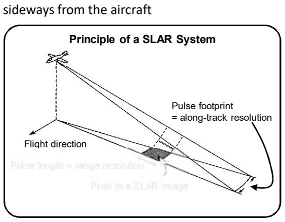


Examples of Imaging Radar Data

Side-Looking Radars Use Pulse Compression to Increase Range Resolution

Side-Looking Airborne Radars (SLARs)

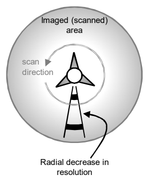
- Developed in 1950s driven by military
- Key element: Long antenna transmitting narrow fan-beams sideways from the aircraft
- Resolution defined by pulse length & length of antenna
- *Resolution generally fair*



Imaging the Surface with SLARs

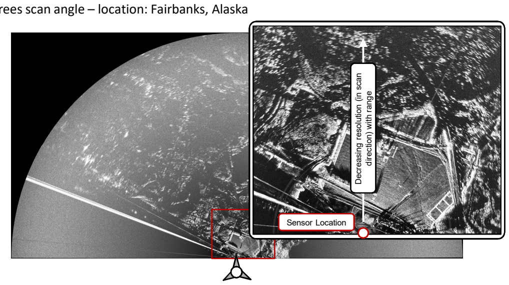
Scanning Ground-based Radar System as a SLAR Example

- Resolution defined by pulse length & length of antenna



Example of Scanning Ground-Based Radar Acquisition

- 180 degrees scan angle – location: Fairbanks, Alaska



What's Next?

- We will have an outdoor lab on Thursday to look at a simple ground-based real aperture radar system
- After improving resolution in range we also want to enhance the azimuth resolution of imaging radars
- Hence, next lecture (next Tuesday) we will chat about something called "**Aperture Synthesis**" (the basis of Synthetic Aperture Radar)

- **In preparation for next Tuesday please read in Woodhouse (2006)**:
  - Pages 271 – 280
  - Specifically think about the two different interpretations of the aperture synthesis process (we will discuss those in class)