Lecture 20

Principles of active remote sensing: Radar.

Radar sensing of clouds and precipitation.

Objectives:

1. Radar basics. Main types of radars.

2. Basic antenna parameters.

Required reading:

S: 8.1, p.401-402

Additional/advanced reading:

Tutorials on ground-based weather radars:

http://www.srh.noaa.gov/srh/jetstream/doppler/doppler_intro.htm

http://www.weathertap.com/guides/radar/weather-radar-tutorial.html

Tropical Rainfall Measuring Mission (TRMM) web site:

http://trmm.gsfc.nasa.gov/

http://www.eorc.jaxa.jp/en/hatoyama/satellite/satdata/trmm_e.html

Liu, Zhong, Dana Ostrenga, William Teng, Steven Kempler, 2012: Tropical Rainfall Measuring Mission (TRMM) Precipitation Data and Services for Research and Applications. Bull. Amer. Meteor. Soc., 93, 1317–1325.

CloudSat web site: http://cloudsat.atmos.colostate.edu/

CloudSat Data Center: http://www.cloudsat.cira.colostate.edu/

1. Radar basics. Main types of radars.

- Radar is an active remote sensing system operating at the microwave wavelength.
- Radar is a ranging instrument: (RAdio Detection And Ranging)

Basic principles:

The sensor transmits a microwave (radio) signal towards a target and detects the backscattered radiation. The strength of the backscattered signal is measured to discriminate between different targets and the time delay between the transmitted and reflected signals determines the distance (or **range**) to the target.

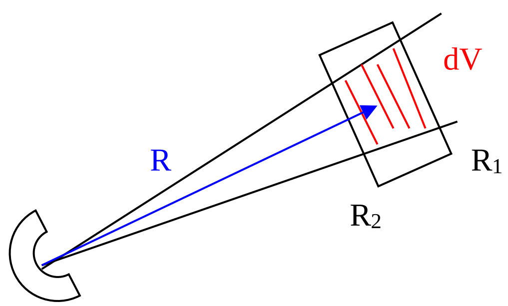
✓ Two primary advantages of radars: **all-weather and day /night imaging**

Radar modes of operation:

- Constant wave (CW) mode: continuous beam of electromagnetic radiation is transmitted and received => provides information about the path integrated backscattering radiation
- Pulsed mode: transmits short pulses (typically 10^{-6}-10^{-8} s) and measures backscattering radiation (also called echoes) as a function of range.

Radar range resolution:

Consider a radar with pulse duration $\mathbf{t_p}$



$t-t_p/2 \Rightarrow R_2 = c\,(t-t_p/2)/2$

$t \Rightarrow R = ct/2$

$t+t_p/2 \Rightarrow R_1 = c\,(t+t_p/2)/2$

Thus **radar range resolution is**

$$R_1-R_2 = \mathbf{ct_p/2 = h/2} \qquad [20.1]$$

where c is the speed of light.

Problem: A police pulsed speed-measuring radar must be able to resolve the returns from two cars separated by ~10 m. Find the maximum pulse duration that can be used to prevent overlapping of the returns from the two vehicles. Ignore the Doppler effect.

Solution:

R_1-R_2 = 10 m thus $\mathbf{t_p} =$ 2*10m/3*10^8 m/s = 6.67*10^{-8} s

Polarizing Radar has four possible combinations of both transmit and receive polarizations as follows:

- HH - for horizontal transmit and horizontal receive,
- VV - for vertical transmit and vertical receive,
- HV - for horizontal transmit and vertical receive, and
- VH - for vertical transmit and horizontal receive.

Microwave bands commonly used in radar remote sensing:*(see also Table 2.3, Lecture 2)*

- Ka, K, and Ku bands: very short wavelengths used in early airborne radar systems but uncommon today.
- X-band: used extensively on airborne systems for military terrain mapping.
- C-band: common on many airborne research systems (CCRS Convair-580 and NASA AirSAR) and spaceborne systems (including ERS-1 and 2 and RADARSAT).
- S-band: used on board the Russian ALMAZ satellite.
- L-band: used onboard American SEASAT and Japanese JERS-1 satellites and NASA airborne system.
- P-band: longest radar wavelengths, used on NASA experimental airborne research system.

Types of radars:

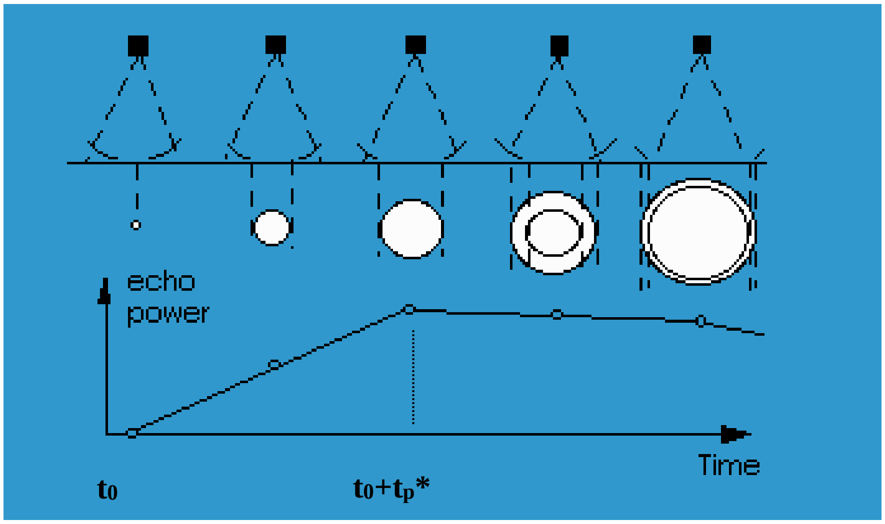
- ➢ **Non-imaging: (altimeters and scatterometers):**

- ***Altimeters*** (often nadir-looking)

Operation principles: transmit short microwave pulses and measure the round trip time delay to targets to determine their distance from the sensor;

Applications: used on aircraft for altitude determination and on aircraft and satellites for topographic mapping, sea surface height measurements from which wind speed can be estimated

Example: ERS altimeter



t_0=2H/c t_p*> t_p t_p is the duration of the pulse

Figure 20.1 Reflection of an altimeter pulse from a flat surface. As the pulse advances, the illuminated area grows rapidly from a point to a disk, as does the returned power. Eventually, an annulus is formed and the geometry is such that the annulus area remains constant as the diameter increases. The returned signal strength, which depends on the reflecting area, grows rapidly until the annulus is formed, remains constant until the growing annulus reaches the edge of the radar beam, where it starts to diminish.

- **Scatterometers**

Operation principles: transmit microwave signal and measures the strength of the backscattering radiation (reflection);

Applications: measurements of wind speed and wind direction over the oceans. Ground-based scatterometers are used extensively to accurately measure the backscatter from various targets in order to characterize different materials and surface types.

Example: NASA Quick Scatterometer (QuikSCAT):

- Radar: 13.4 gigahertz; 110-watt pulse at 189-hertz pulse repetition frequency (PRF)

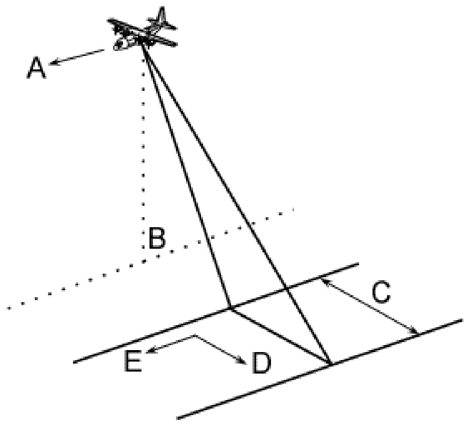
- Antenna: 1-meter-diameter rotating dish that produces two spot beams, sweeping in a circular pattern

QuikSCAT measurement capability:

- 1,800-kilometer swath during each orbit provides approximately 90-percent coverage of Earth's oceans every day.
- Wind-speed measurements of 3 to 20 m/s, with an accuracy of 2 m/s; direction, with an accuracy of 20 degrees. Wind vector resolution of 25 km.

➢ **Imaging radars**:

The two-dimensional representation of imaging sensors:



Side-looking viewing geometry of imaging radar systems:

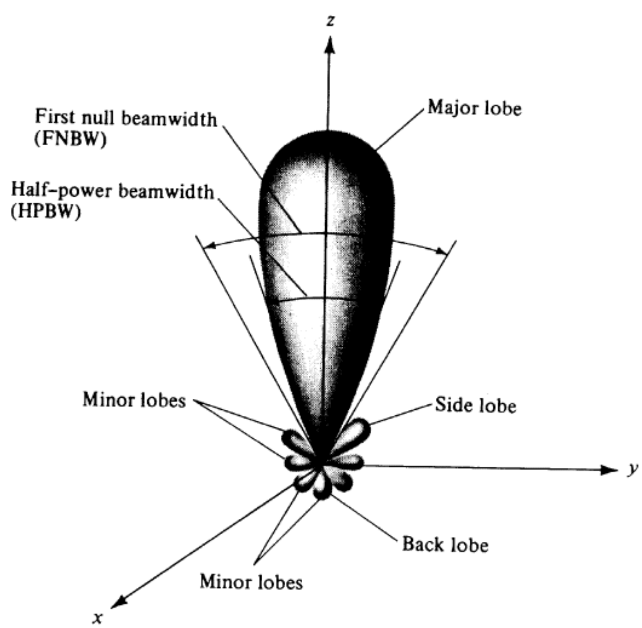
The platform travels forward in the **flight direction** (A) with the **nadir** (B) directly beneath the platform. The microwave beam is transmitted obliquely at right angles to the direction of flight illuminating a **swath** (C). **Range** (D) refers to the across-track dimension perpendicular to the flight direction, while **azimuth** (E) refers to the along-track dimension parallel to the flight direction.

2. Basic antenna parameters.

Antenna is a structure which serves as a transition between wave propagating in free space and the fluctuating voltages in the circuit to which it is connected.

Basic antenna parameters (in free space):

1) Field pattern: 3-D quantities involving the variation of EM field or EM power as a function of the spherical coordinates θ and φ: power pattern $\boldsymbol{P}(\theta, \varphi)$ (in W sr^{-1}) and normalized power pattern: $\boldsymbol{P_n}(\theta, \varphi) = \boldsymbol{P}(\theta, \varphi) / \boldsymbol{P_{max}}(\theta, \varphi)$



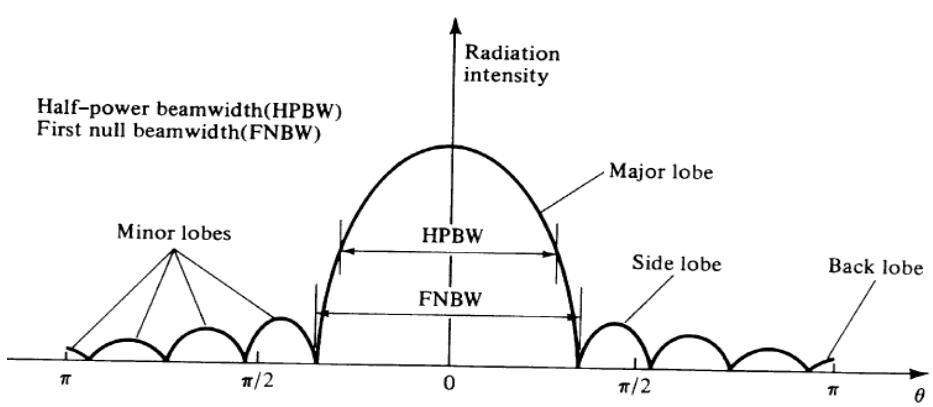


Figure 20.2 Antenna power pattern in polar coordinates and in rectangular coordinates.

NOTE: "same name": Major lobe=Main lobe = Main beam

Since the difference between the power transmitted by an antenna, $\boldsymbol{P_t}$ (in W), and the power received from backscattering is typically several orders of magnitude, the received signal is expressed in **Decibels (dB):**

$$P(in\ dB) = 10\log\frac{P}{P_t} \qquad [20.2]$$

2) **Antenna gain** is defined as the ratio of the intensity at the peak of the transmission pattern, $\boldsymbol{I_p}$, to an isotropic intensity that is derived assuming that the total power, $\boldsymbol{P_t}$ (in W), is distributed equally in all direction

$$G = \frac{I_p}{P_t / 4\pi R^2} \qquad [20.3]$$

R is the range.

3) **Beam area (or** beam solid angle) (in sr) is defined as

$$\Omega_A = \int_{4\pi} P_n(\theta,\varphi)d\Omega \qquad [20.4]$$

The beam area is a solid angle through which all of the power radiated by the antenna would stream if ***P***(θ, φ) maintained its maximum value over Ω_A and was zero elsewhere => **Power radiated** (in W) = $\boldsymbol{P_{max}}(\theta, \varphi)\ \Omega_A$

The beam area can be approximated by the product of the half-power beamwidths (HPBW, see Fig.20.2) in two principal planes

$$\Omega_A \approx \theta_{HP}\varphi_{HP} \qquad [20.5]$$

where θ_{HP} is Δθ of the HPBW and φ_{HP} is the Δφ of the HPBW.

4) **Effective aperture**, A_e, (in m^2) is defined as

$$\lambda^2 = A_e\Omega_A \qquad [20.6]$$

where λ is the wavelength (in m)

5) **Directivity**, D, (≥ 1, dimensionless) is defined as the ratio of the maximum power to its average value: $\boldsymbol{D} = \boldsymbol{P_{max}}(\theta, \varphi) \,/\, \boldsymbol{P_{av}}(\theta, \varphi)$

Other expressions for the **directivity**

$$D = \frac{4\pi}{\Omega_A}$$ directivity from pattern [20.7]

$$D = 4\pi \frac{A_e}{\lambda^2}$$ directivity from aperture [20.8]

- **<u>Friis transmission formula</u>**

Consider a transmitting antenna of effective aperture A_{et} and receiving antenna with effective aperture A_{er}. The distance between the antennas is R.

If transmitted power P_t is radiated by an isotropic source, the power received per unit area at the receiving antenna if

$$F = \frac{P_t}{4\pi R^2} \qquad [20.9]$$

and the power available to the receiver is

$$P_r = FA_{er} \qquad [20.10]$$

But the transmitting antenna has an effective aperture A_{et} and hence a directivity D (from Eq.[20.8]):

$$D = 4\pi \frac{A_{et}}{\lambda^2}$$

Thus the power available to the receiver is D times greater

$$P_r = FA_{er}D = FA_{er}\frac{4\pi A_{et}}{\lambda^2} \qquad [20.11]$$

Substituting Eq.[20.9] into Eq.[20.11] gives

$$P_r = \frac{P_t A_{er}}{4\pi R^2}\frac{4\pi A_{et}}{\lambda^2} \qquad [20.12]$$

or

$$\boxed{\frac{P_r}{P_t} = \frac{A_{er}}{R^2}\frac{A_{et}}{\lambda^2}} \qquad [20.13]$$