Lecture 11: Radar Hardware
(Rinehart Ch2)
How does radar work?

- Active remote sensors emit electromagnetic (EW) waves that travel to an object and are reflected back toward the sensor. Example: X-Ray, Radar, Lidar

- Radar works by transmitting a pulse of EM waves. Objects (raindrops, ice, snow, birds, insects, terrain, and buildings) scatter that energy. Part of the backscattered energy is received back at the radar. Once the radar receives the reflected signal, computer programs and meteorologists interpret the signal to determine where it is precipitating.
Types of weather radar

• Monostatic vs. bistatic radar
  ◦ Monostatic: use a single antenna for both receiving & transmitting (most weather radars are monostatic)
  ◦ Bistatic: has two antennas (could be in different locations)

• Continuous wave vs. pulsed radar
  ◦ Pulsed Radar: Radar transmits (sends out) a short pulse of EM wave and then waits for an echo from target (weather radar are pulsed radar)
  ◦ Continuous wave radar: transmits and receives EM waves continuously (police radar)

• Doppler radar

• Polarization radar
Simplified block diagram of a pulsed weather radar

Figure 2.1 Block diagram of a simple radar

Rinehart (5th edition 2010)
Transmitter

Transmitter: the source of EM radiation emitted by a radar. It generates the high frequency signal which leaves the antenna and goes out into the atmosphere.

Types of transmitter:
- Magnetron: A self-exciting oscillator tube used to produce the microwave signal transmitted by some radars.
- Klystron:
  1) Easier waveform control
  2) More powerful
  3) Purer frequencies
- Solid state transmitter
  - Much lower power than magnetron & klystron
  - Can be used in phased-array antenna radar

Figure 2.2. Cross-section of magnetron showing the central cathode and surrounding anode. The magnetic field goes into the page. As electrons move from the cathode to the anode, the electric field causes them to spiral, creating a kind of “electronic whistle” which generates the microwave signal. That signal is picked up by the probe at left and radiated into the waveguide.
Modulator

- Switch the transmitter on and off and to provide the correct waveform for the transmitted pulse.
- Store up energy between transmitter pulses.
Master Clock/Computer

- Control Panel: for human to control the operation of the radar.
  - Select the range to display, elevation & azimuth angles to scan.
  - Signal processing (by computer)

Two main functions of master clock/computer:
1) Control how often the transmitter transmits:
   Pulse Repetition Frequency (PRF): 1 cycle/second = 1 Hz
2) Control how long the transmitter transmits:
   Pulse duration ($\tau$): 0.1 to 10 $\mu$s
   or Pulse length = $c \tau$
Figure 2.1 Block diagram of a simple radar

Rinehart (5th edition 2010)
Waveguide: efficient conductor to carry radar signals

Figure 2.3. Waveguide (top), feedhorn (lower right), and a waveguide joint (lower left). The joints are held together with screws and contain an “O” ring to seal them. They also have a 1/4 wavelength slot to prevent loss of signal.
Antenna

- Antenna is the device that sends the radar’s signal into the atmosphere.
- Isotropic antenna: An antenna that sends radiation equally in all directions.
- Weather radar’s antennas are directional, which makes it possible to locate targets in space.
Antenna

- Antenna system includes the combination of antenna and reflector
- The shape of the reflector determines the shape of the antenna beam pattern.
- Most weather radars use circular parabolic reflectors, which form conical and quite narrow beam pattern (typically 1° in width for the mainlobe).
- The bigger the reflector, the better it is able to direct the signal and the narrower the beam of the antenna.
Pencil Beam Antenna

1. Three-dimensional plot of the strength of the radiation from a pencil beam antenna.

Circular Parabolic Reflector

NCAR
S-POL
Cassegrain antenna: uses a sub-reflector in addition to a main reflector. Usually have better sidelobe patterns.

Offset Cassegrain antenna based on designs for New NSF CSU-CHILL antenna system.
**Feedhorn:** radiating element which transmits radar signal toward the reflector. Hence, it is the true antenna for many weather radar.

![Image of a Feedhorn antenna](image)

Figure 2.3 Principal $E$- and $H$-plane patterns for a pyramidal horn antenna.
Antenna Parameters

- **Wavelength:** the antenna must match the transmitter’s wavelength.
- **Size of the reflector:** for circular parabolic reflectors: 0.3 – 9 m in diameter.
Antenna Parameters: Gain

- **Gain:** the gain $g$ of an antenna is the ratio of the power that is received at a specific point (usually on the center of the beam axis where the maximum power exists) in space with the radar reflector in place to the power that would be received at the same point from an isotropic antenna. In the equation on the right, $P_1$ is the power on beam axis with the real antenna and $P_2$ is the power at the same point from an isotropic antenna.

- **Gain in Decibels:** logarithmic form of $g$. Typically $G = 20$ to $45$ dB.

$$G = 10 \log_{10} \left( \frac{P_1}{P_2} \right)$$
Antenna Parameters: Beamwidth

- **Beamwidth**: is the angular width of the antenna beam measured from the point where the power is exactly **half** what it is at the same range on the center of the beam axis. In the equation on the right, $\theta$ and $\phi$ are horizontal and vertical beamwidths of the antenna. $K$ is dependent on the kind of shape of antenna. For circular reflectors, $k=1$.

  \[ g = \frac{\pi^2 k^2}{\theta \phi} \]

- For circular reflectors, $\theta=\phi$, therefore:

  \[ g = \frac{\pi^2}{\theta^2} \]

- Gain is dependent on beamwidth, but independent of wavelength.
Idealized Antenna Pattern of Weather Radar with No Side Lobes (i.e., main lobe only).

Figure 2.6 (A) The relative one-way gain of an ideal antenna as a function of angle. The antenna beamwidth of this antenna is 1° (0.5° either side of the center). The solid line is the linear antenna gain (left ordinate) while the dashed curve is the logarithmic gain (right ordinate). The beamwidth is the angular width where the power is exactly half of the maximum power. On the linear scale, this is at a relative power of 0.5 of the maximum. On the logarithmic scale, the half-power point is 3 dB below the maximum. The dash-dot-dash curve represents a top-hat profile; this is physically unrealizable, but it is what we would like a radar antenna to have (left scale applies to the top-hat profile).

Figure 2.6 (B) 3-D view of parabolic beam for an antenna with a 1° beamwidth.

3-Dimensional View

Rinehart (2004)
Figure 2.7 Modeled two-way antenna beam pattern for the CF5-9 X-band antenna, showing the mainlobe and the first three sidelobes. This antenna has a mainlobe with a 1° beamwidth (from Donaldson, 1964). The top view (A) shows the beam pattern as a function of gain and angle. The view immediately above (B) shows the pattern in polar coordinates with the radar at the left; contours are 10 dB apart; tick marks are every 10° of azimuth. (C, next page) shows a 3-D view with gain vertically and relative azimuths and elevations on the lower two scales. Notice that the sidelobes are really quite close to the mainlobe in (B).

Figure 2.7C (continued).

Modeled Antenna Pattern of a typical weather Radar with main lobe and sidelobes.

- assumes symmetry of beam pattern in all directions.

Rinehart (2004)
FL2
S-band

Figure 2.8 Antenna beam pattern of the FL2 S-band radar. This pattern was taken using vertical polarization and is through the center of the beam axis at 0° elevation angle. (A) shows the pattern in terms of gain and angle while (B) shows the pattern in polar coordinates (10-dB circles; dots every 10° of azimuth).

Figure 2.9 Antenna beam pattern of the NCAR CP2 X-band Cassegrain-fed antenna. The elevation and azimuth angles extend about 5° either side of the mainlobe (0.1° per grid interval). Top image was done at National Bureau of Standards antenna range; bottom used radio tower to make the measurements. After Rinehart and Frush, 1983.

Measured Antenna Pattern of Weather Radar with main lobe and side lobes.
- note that sidelobes are not symmetric about azimuth or elevation angle.

Rinehart (2004)
More measured antenna patterns of real radars...

Fig. 7.28 Antenna pattern of the WSR-88D without radome. Sidelobes are specified to be below the dashed envelope.

Doviak and Zrnic (1993)

Skolnick (1990)
Duplexer (Transmit/Receive Switch)

- To protect the receiver from the high power of the transmitter.
  Transmitted power: up to $1 \text{ MW} = 10^6 \text{ Watts}$
  Received power: as small as $10^{-14} \text{ W}$ or less
Receiver

To detect and amplify the very weak signals received by the antenna.

Very sensitive, with wide range of reflectivities up to 8 to 10 orders of magnitude.

Modern Doppler radar receivers:

- Logarithmic receiver: produces an output proportional to the logarithm of the input power. They can have dynamic range of 80 dB or more.
- Digital receiver: able to dynamically measure and then adjust their gain such that they can measure very weak and very strong signals. Dynamic range of 90 dB or more.
Common Weather Radar Computer Displays/Indicators

Plan Position Indicator (PPI): displays the radar data in a map-like format, usually with the radar at the center. Distance is given by adding range marks (Range rings) around the radar. Compass coordinates: up- North; down-south; right-east, left-west.

Doppler radar viewing configuration (scanning 360 degree at a given elevation angle)

Figure 2.11 Schematic diagram of a PPI display showing nearby ground clutter and distant weather echoes. Echo intensity is indicated by shading, where the darker the shading, the stronger the echo.
Radar Display: PPI & RHI

RHI – Range Height Indicator

PPI – Plan Position Indicator

Range (km)

Height (km)
PPI: Ground Clutter

Doppler Velocity

Reflectivity
Bermuda Weather Service Radar image showing a band of rain associated with a cold front at 3:43pm local time December 31st 2013.
PPI and RHI: Squall Line

PPI Radar Reflectivity, West African Squall Line, 31 July 2006

RHI Radar Reflectivity, West African Squall Line, 31 July 2006

Earle Williams
Signal Processor

- Computer processors to process the received radar power returns (including remove the noise, calibration, etc) and translate them into final output parameters: reflectivity and radial velocity.
- Color displays
- Warning algorithms: automatic detection of hail, tornadoes, and microbursts.
Satellite-borne (downward looking) Radar Display Example

Hurricane Georges (1998)

Vertical Radar Cross Section
Outline

HW1: Everyone did it very well. Score range: 92-99.
HW2: Due Tue. Mar. 3 (after spring break)
Lec9: Rainbow explanation more slides
Lec10 QA: