University of Massachusetts Amherst

Lecture 7–Radar

ECE 197SA – Systems Appreciation

Air Traffic Control

- Radar has broad application in daily life
  - Sensing of object locations
  - Sensing of object speed
  - Sensing of object properties
- Today's lecture:
  - Air traffic control
    - Very large application of ECE technologies
  - Radar
    - Basics of radar systems
    - System design for air traffic control
  - Radar for speed measurement

Air Traffic

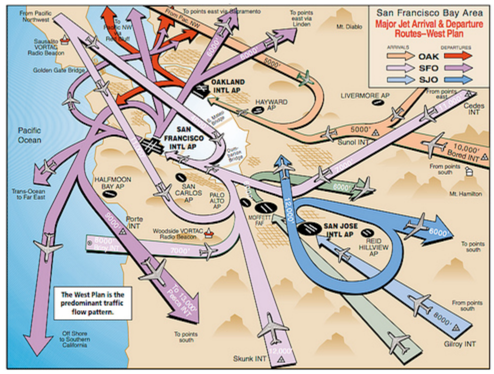
- Air travel important mode of transportation
  - 13 million commercial flights per year
  - 3 billion passengers between 2002 and 2006
  - Fatal accident rate only 0.023 per 100,000 flights

Daily Flight Activity

- Over 87,000 flights per day
  - Commercial flights: 28,537
  - General aviation flights: 27,178
  - Air taxi flights: 24,548
  - Military flights: 5,260
  - Air cargo flights: 2,148
  - On average: 5,000 planes in the skies
  - From: http://sos.noaa.gov/Datasets/dataset.php?id=44# http://www.natca.org/

Air Traffic Control

- Coordination of air space critical
  - Planes are very restricted in their movements
  - Small problems can lead to large accidents
- Traffic control requires complete picture of all planes
  - Central coordination by ATC
  - Instructions radioed to pilots
- Necessary information:
  - Location
  - Altitude
  - Heading
  - Speed
  - Other
    - » Destination
    - » Type of aircraft
    - » …



Flight Tracking

- All commercial flights in the U.S. can be tracked
  - Example (flights to/from Newark (EWR)):

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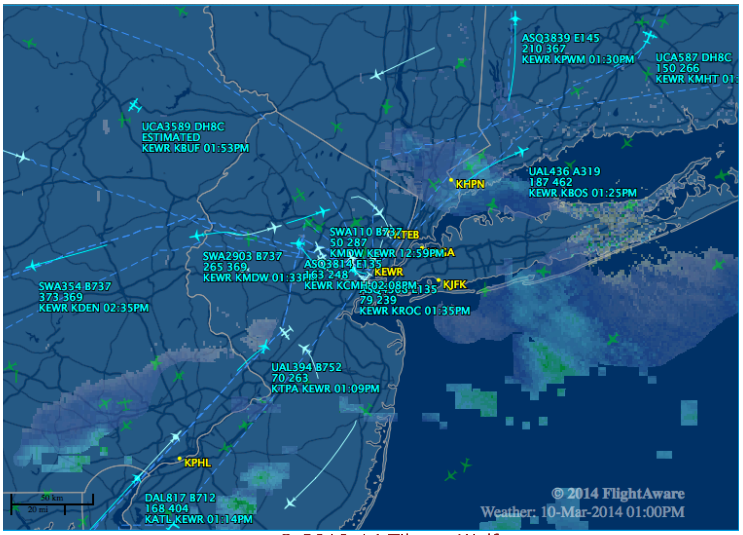


Location Problem

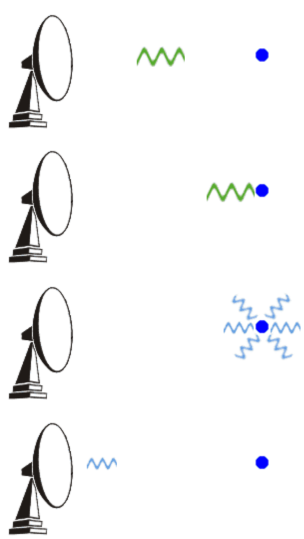
- How to determine where something is located?
  - General systems problem with many uses
- Example scenarios:
  - Air traffic control
  - Warfare (e.g., missiles)
  - Weather (e.g., severe weather)
  - Automotive traffic (e.g., adaptive cruise control)

Location Problem

- How would you design system to locate object?
  - Locate in 3 dimensions
  - Use any technology you like
  - What accuracy can you achieve?

Principles of Radar

- RAdio Detection And Ranging (RADAR)
  - Radar transmits short pulse of radio signal
    - » Typically 1–60GHz
  - Signal reflects/scatters off object
  - Reflected signal travels back to radar
  - Round-trip time proportional to distance of object
    - » Pulse propagates at speed of light
- Radar needs to switch from sending to receiving
  - No simultaneous send and receive
- Tradeoff
  - Longer pulses easier to detect
  - Shorter pulses lower minimum range



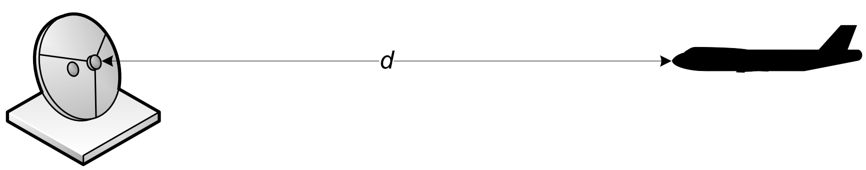
Radar Frequency Bands

Band name	Frequency range	Wavelength range	Notes
HF	3–30 MHz	10–100 m	coastal radar systems, over-the-horizon radar (OTH) radars; 'high frequency'
P	< 300 MHz	1 m+	'P' for 'previous', applied retrospectively to early radar systems
VHF	30–330 MHz	0.9–6 m	Very long range, ground penetrating; 'very high frequency'
UHF	300–1000 MHz	0.3–1 m	Very long range (e.g. ballistic missile early warning), ground penetrating, foliage penetrating; 'ultra high frequency'
L	1–2 GHz	15–30 cm	Long range air traffic control and surveillance; 'L' for 'long'
S	2–4 GHz	7.5–15 cm	Terminal air traffic control, long-range weather, marine radar; 'S' for 'short'
C	4–8 GHz	3.75–7.5 cm	Satellite transponders; a compromise (hence 'C') between X and S bands; weather
X	8–12 GHz	2.5–3.75 cm	Missile guidance, marine radar, weather, medium-resolution mapping and ground surveillance; in the USA the narrow range 10.525 GHz ±25 MHz is used for airport radar. Named X band because the frequency was a secret during WW2.
K_u	12–18 GHz	1.67–2.5 cm	high-resolution
K	18–24 GHz	1.11–1.67 cm	from German *kurz*, meaning 'short'; limited use due to absorption by water vapour, so K_u and K_a were used instead for surveillance. K-band is used for detecting clouds by meteorologists, and by police for detecting speeding motorists. K-band radar guns operate at 24.150 ± 0.100 GHz.
K_a	24–40 GHz	0.75–1.11 cm	mapping, short range, airport surveillance; frequency just above K band (hence 'a') Photo radar, used to trigger cameras which take pictures of license plates of cars running red lights, operates at 34.300 ± 0.100 GHz.
mm	40–300 GHz	7.5 mm – 1 mm	millimetre band, subdivided as below. The frequency ranges depend on waveguide size. Multiple letters are assigned to these bands by different groups. These are from Baytron, a now defunct company that made test equipment.
Q	40–60 GHz	7.5 mm – 5 mm	Used for Military communication.
V	50–75 GHz	6.0–4 mm	Very strongly absorbed by atmospheric oxygen, which resonates at 60 GHz.
E	60–90 GHz	6.0–3.33 mm	
W	75–110 GHz	2.7 – 4.0 mm	used as a visual sensor for experimental autonomous vehicles, high-resolution meteorological observation, and imaging.
UWB	1.6–10.5 GHz	18.75 cm – 2.8 cm	used for through-the-wall radar and imaging systems.

From wikipedia.com

Ranging with Radar

- How can the radar calculate distance *d*?



Ranging with Radar

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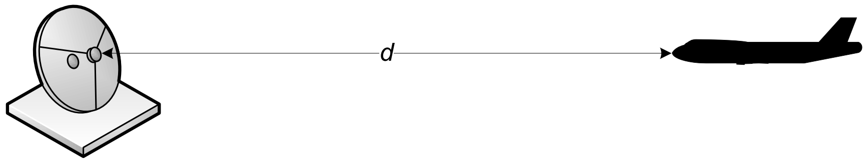


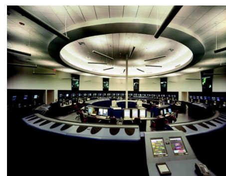
- Observations:
  - Radar pulse travels twice the distance *d* during one round-trip time *t*
  - Propagation speed of pulse is c≈300,000km/s
- Distance $d = \frac{c \cdot t}{2}$
- Example: pulse returns after *t*=25μs
  - Distance d = $3 \cdot 10^8$m/s · 2.5 ·10^{-5}s / 2 = 3.75 km
- How to determine bearing?

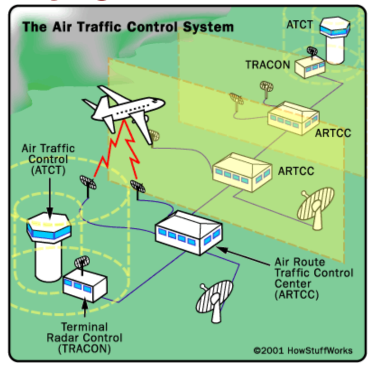
Air Traffic Control Radar

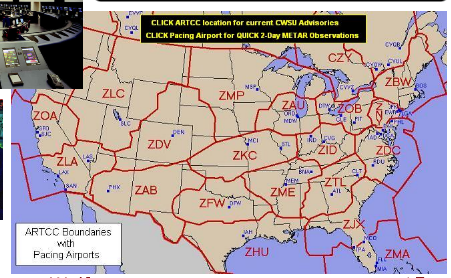
- Primary Surveillance Radar (PSR)
  - Determines distance of planes from reflection echo
  - Determines bearing from its rotation at time of transmission
  - Cannot determine altitude of plane
- Secondary Surveillance Radar (SSR)
  - Triggers airplane transponder
  - Receives messages from airplane transponder with altitude information
- SSR similar to IFF
  - "Identification friend or foe"
  - Used by military to authenticate airplanes

Air Traffic Control

- Hierarchy of controlling entities
- Air traffic control tower (ATCT)
  - Local control, departures, ground control
- Terminal Radar Approach Control (TRACON)
  - Near airport(s)
- Air Route Traffic Control Center (ARTCC)
  - Regional control







Global Positioning System

- Technical details next lecture
- Planes can determine their own location
  - Planes can share information if they choose
- Recent legislation
  - Update air traffic control system with GPS

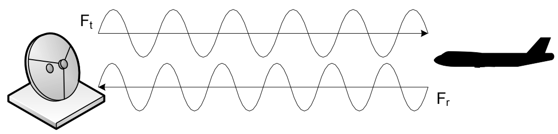
Avoiding Radar

Avoiding Radar

- Mechanical countermeasures
  - Chaff: metal-coated glass fibers
- Electronic countermeasures
  - Generation of fake/noisy/etc radar responses

Speed Measurement with Radar

- … and now for something completely different
  - Determining speed with radar ("radar gun")
- Doppler effect can be used to determine speed
  - Reflection of approaching object increases frequency of pulse
  - Frequency increase proportional to relative speed

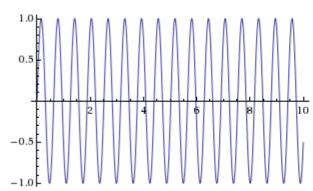


  - Superposition of F_t and F_r leads to "beat frequency" F_d
- Speed v of object:

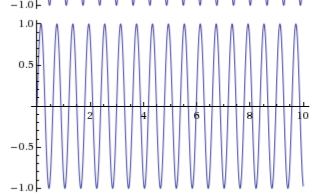
$$F_d \approx 2v\frac{F_t}{c} \quad \text{or} \quad v \approx c\frac{F_d}{2F_t}$$

Superposition of Sine Waves

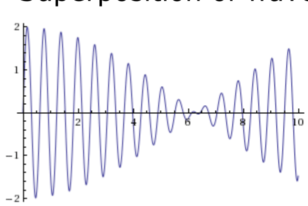
- Example:
  - Original wave: sin(10x)

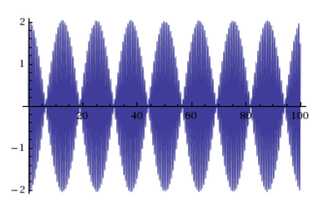


  - Reflected wave: sin(10.5x)



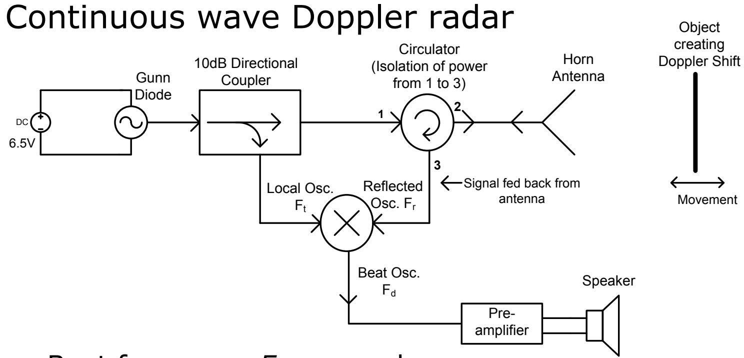
  - Superposition of waves: sin(10x)+sin(10.5x)





Experiment

- Continuous wave Doppler radar



  - Beat frequency F_d on speaker
- Beat frequency in audible range
  - Approximately 9 GHz radar signal
  - Assume 2m/s of object movement:

$$F_d \approx 2v\frac{F_t}{c} = 2 \cdot 2m/s \cdot \frac{9 \cdot 10^9\,Hz}{3 \cdot 10^8\,m/s} = 120Hz$$

Courses in ECE Curriculum

- ECE 333 – Fields and Waves
- ECE 584 – Microwave Engineering I
- ECE 585 – Microwave Engineering II
- ECE 606 – Electro-Magnetic Field Theory
- ECE 686 – Intro Radar Systems
- ECE 687 – Antenna Theory & Design

Upcoming…

- Global Positioning System
- Moodle quiz

Interesting Links

- Air traffic control maps
  - http://flightaware.com/live/
  - http://travel.flightexplorer.com/
- Live air traffic control audio
  - http://www.liveatc.net/

