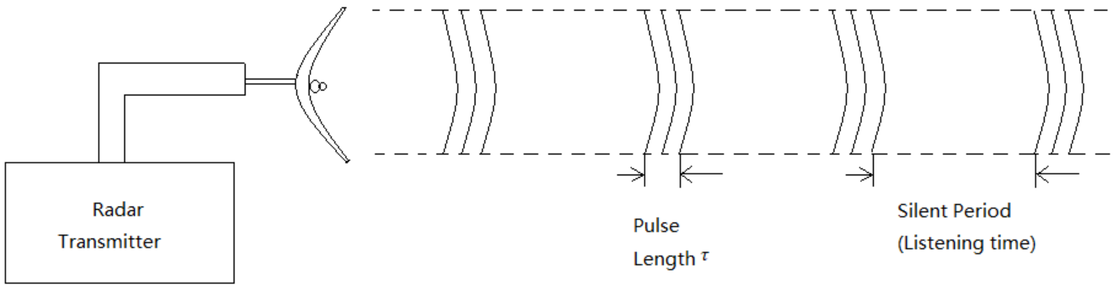
Lecture 13 Radar Pulse Characteristics and Radar Eq for Distributed Targets

Radar Pulse Characteristics



1) How to calculate the distance of a target?

$$dis = \frac{tc}{2}$$

(c is speed of light, t is time)

2) Pulse Length (or duration):
τ in μs (microseconds), or $h = c\tau$ in meters.
For $\tau = 0.1\ \mu s$, $h = 30\ m$; $\tau = 10\ \mu s$, $h = 3000\ m = 3\ km$

Trade off about choosing pulse length: longer pulse emitted from a radar return more power, thus increased target information and data reliability. However, longer pulses mean poorer range resolution.

3) Minimum Range (R_{min}): $R_{min} = \frac{h}{2}$
Minimum Range is defined as one-half of the pulse length. Targets more than one-half the pulse length from the antenna can be correctly processed. Less than R_{min}, the targets can't be detected by the radar because the pulse's leading edge will strike the target & return before the radar can switch into its receive mode.

For 88-D radar, $\tau = 1.57\ \mu s$, $h = 470\ m$, $R_{min} = 235\ m = 0.235\ km$.

4) Range Resolution ($= \frac{h}{2}$):
   - Range Resolution is a radar's ability to display multiple targets clearly and separately.
   - Longer pulse have poorer range resolution
   - Targets must be more than one-half pulse length apart, or they will occupy the pulse simultaneously and appear as a single target.

5) Pulse Repetition Frequency (PRF)
   - PRF is the rate at which pulses are transmitted (per second).

- PRF controls the duration of listening time, therefore controls the maximum effective range by a radar.

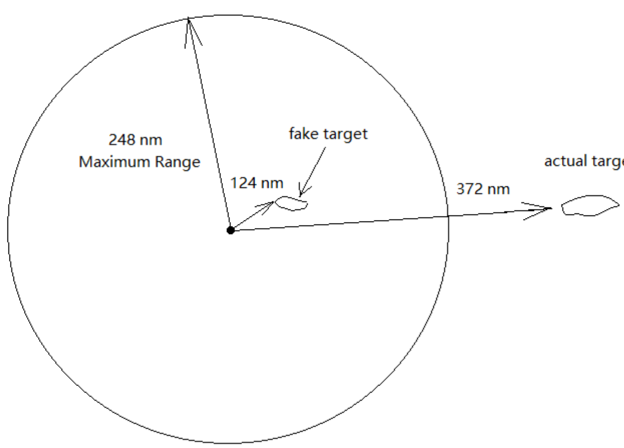
6) Listening time (t_0):
   - The period when the radar switches to receive mode awaiting its returns.
   - Listening time determines a radar's maximum effective range
   - Relationship between Pulse Repetition Frequency (PRF) and Listening time (t_0): RPF=1/ t_0

7) Maximum Unambiguous Range (R_{max})
   - R_{max} is the longest distance to which a transmitted pulse can travel and return to the radar before the next pulse is transmitted. R_{max} is the maximum distance radar energy can travel round trip between pulses.

     $R_{max} = \frac{c}{2\times PRF}$ (*c* is a constant)

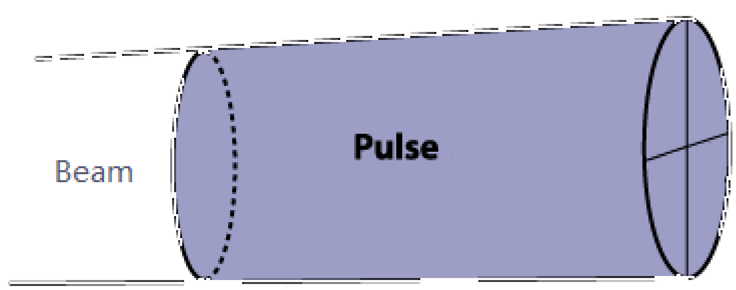
8) Range Ambiguity and Range Folding:

   If a pulse strikes a target outside R_{max}, the echo may return after the transmitter has emitted another pulse. i.e., during the next pulse's listening time. This produces a complex problem known as range ambiguity or range folding.



   For example, a target at 372 nm away can be displayed at 124 nm range by a radar with $R_{max} = 248\ nm$.

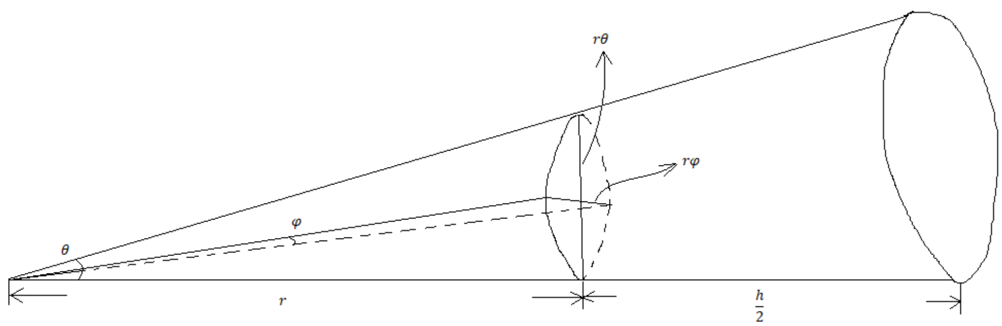
9) Sample Volume *V* (Pulse Volume):



- Sample Volume is the space the pulse occupies along the beam at any point in time.
- It shapes like a cone with its point cut off.
- Sample volume increases with distance from the antenna as the pulse expands in all directions.
- Sample volume *V*:

$$V = \pi \frac{r\theta}{2}\frac{r\varphi}{2}\frac{h}{2} = \frac{\pi r^2 \theta\varphi h}{8}$$

If energy is concentrated within beam width θ, φ.



Radar Equation for Distributed Targets:

1) Distributed targets: many raindrops or cloud particles fill in the sample volume at the same time.
2) Total backscattering cross-sectional area

$$\sigma_t = \sum_{\lambda=1}^{n} \sigma_i = V \sum_{vol} \sigma_i$$

($\sum_{vol} \sigma_i$ is backscattering cross section areas in a unit volume)

3) Sample volume for real antenna beam.

$$V = \frac{\pi r^2 \theta\varphi h}{16\ln(2)}$$

by assuming a Gaussian shaper for beam pattern.

4) Radar equation for distributed targets.
Recall radar Eq for point targets:

$$P_r = \frac{P_t g^2 \lambda^2 \sigma}{64\pi^3 r^4}$$

replacing σ with $\sigma_t = V \sum_{vol} \sigma_i = \frac{\pi r^2 \theta\varphi h \sum_{vol} \sigma_i}{16ln2}$

Then,

$$P_r = \frac{P_t g^2 \lambda^2 \theta\varphi h \sum_{vol} \sigma_i}{1024 ln(2) \pi^2 r^2}$$

5) Radar reflectivity η (for distributed targets only)

$$\eta = \sum_{Unit\ Vol} \sigma_i$$

$$unit = \frac{area}{volume} = cm^{-1}$$

— an old definition, is not used any more.

6) When Rayleigh approximation applies:

$$\sigma_i = \frac{\pi^5 |k|^2 D_i^2}{\lambda^4}$$

Where D_i is diameter of i^{th} sphere, $k = \frac{m^2-1}{m^2+2}$

$$m = \frac{N_2}{N_1} \approx N_2$$

N_2 is the complex refractive index of the sphere.

$$m \approx N_2 \approx n_r + n_i i$$

$|k|^2$ for water is 0.93.
$|k|^2$ for ice is 0.197.

7) Radar equation in terms of D^6 and radar reflectivity factor z:
Substitute σ_i, we get:

$$P_r = \frac{\pi^3 P_t g^2 \theta \varphi h |k|^2 \sum_{Unit\ Vol} D_i^6}{1024 ln(2) \lambda^2 r^2}$$

Define the radar reflectivity factor *z* as:

$$z = \sum_{Unit\ Vol} D_i^6$$

Unit: mm^6/m^3

Then we get the general radar equation:

$$P_r = \frac{\pi^3 P_t g^2 \theta \varphi h |k|^2 z}{1024 ln(2) \lambda^2 r^2}$$

8) **Radar reflectivity** and radar constant:
Combine all parameters associated with a specific radar and constants.
We have $P_r = \frac{C_1 |k|^2 z}{r^2} = \frac{C_2 z}{r^2}$ (Note the inverse square law).
$\Longrightarrow z = c_3 P_r r^2$ —c_3 is called radar constant.

Define **radar reflectivity** *Z* as the logarithmic reflectivity factor in dBZ (note this is the radar reflectivity we refer to everyday):

$Z = 10 log_{10}(z)$, where z must be in Unit: mm^6/m^3

An example: For 100,000 droplets with diameter=0.1 mm, z=10^5 x $(0.1)^5$=1, then:

Z (in DBZ)= 10 $\log_{10}$ z =10$\log_{10}$1=10 dBZ

Then: $Z = C_3 + P_r + 20log(r)$

Where Z is in dBz, P_r is in dBm and $C_3 = 10 \cdot log_{10}(c_3)$

9) Effective radar reflectivity factor z_e:
Because raindrops and cloud particles are usually not spherical, we should call the measured reflectivity factor as equivalent or effective radar reflectivity factor z_e.

10) radar reflectivity factor z and dropsize spectra:

$$z = \sum_{i=1}^{n} N_i D_I^6$$

Dropsize distribution model: we quantize the measurements into small diameter intervals, for example: A dropsize distribution for rain could be like this:
$N = 100$ for $D = 0.2\ mm$ to $0.5\ mm$
$N = 250$ for $D = 0.5\ mm$ to $0.6\ mm$