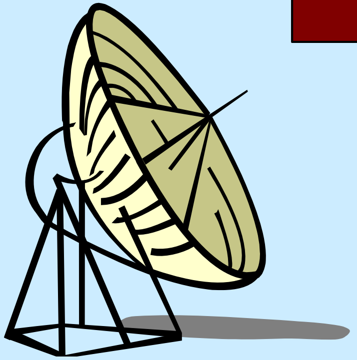
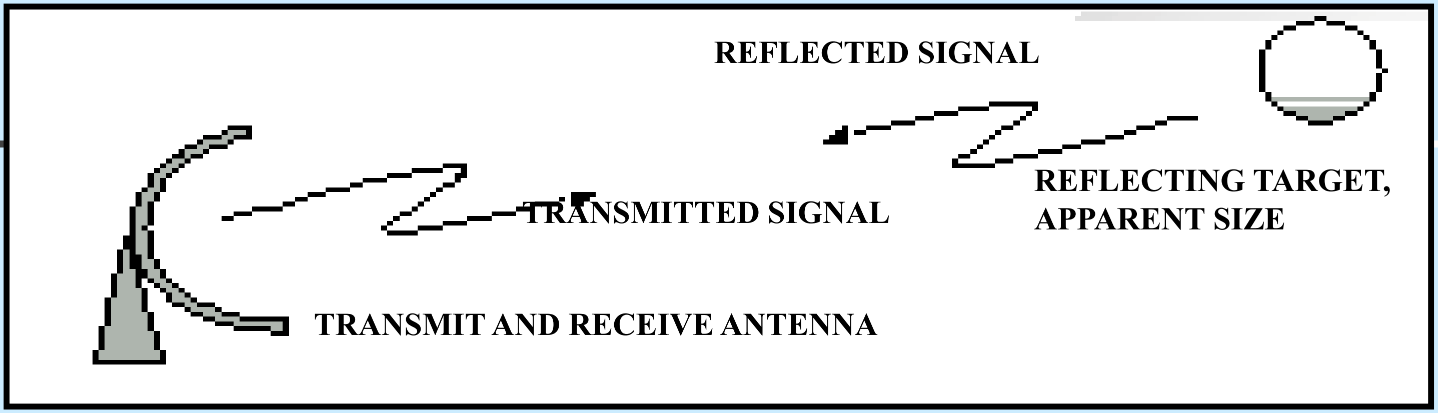
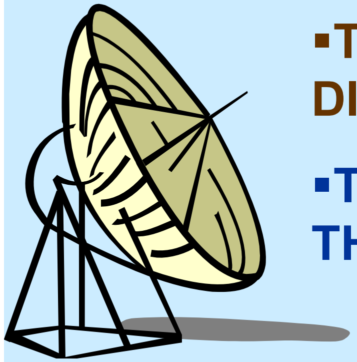
RADAR
EQUATION



TYPICAL RADAR GEOMETRY

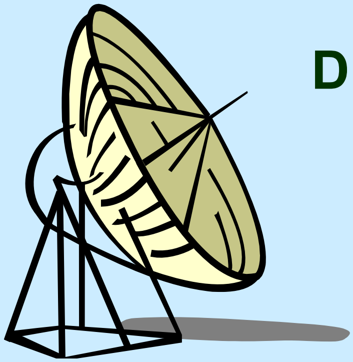


- A TYPICAL RADAR SYSTEM CONSISTS OF A CO- LOCATED PULSED TRANSMITTER AND A RECEIVER,USUALLY SHARING AN ANTENNA.
- A PULSE IS TRANSMITTED AND THEN THE RECEIVER LISTENS FOR THE RETURN.
- THE STRENGTH OF THE RETURN SIGNAL DEPENDS UPON THE DISTANCE TO THE TARGET AND ITS (ELECTRICAL) SIZE.
- THE RADAR DETERMINES THE DISTANCE TO THE TARGET FROM THE TIME DELAY BEFORE RECEIVING THE REFLECTED PULSE.



RADAR

- ACRONYM FOR RADIO DETECTION AND RANGING
- RADAR CAN BE THOUGHT OF AS A PAIR OF ONE – WAY COMMUNICATION LINKS, WITH THE RETURN LINK BEING THE RADAR REFLECTION.
- CONSIDER THE RADAR PROBLEM,WHERE IN GENERAL THE TRANSMITTER AND RECEIVER ARE CO-LOCATED AND THE RECEIVED SIGNAL IS A REFLECTION.
- THE EXPRESSION FOR POWER DENSITY AT A DISTANCE d IS: $W = P_T \cdot G_R / 4\pi d^2$ watts / m^2



RADAR EQUATION

Free Space Propagation

- The power density at a distance, *d*, is

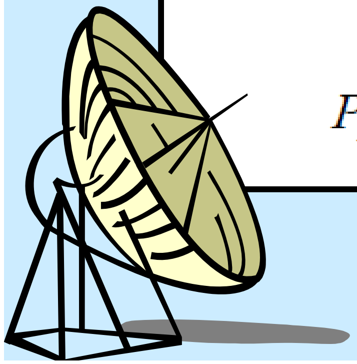
$$W = \frac{EIRP}{4\pi\, d^2} \ \text{watts/m}^2$$

- The power available at the output of a receive antenna would be the product of the power density at that point times the antenna's effective area

$$P_R = \frac{P_T \cdot G_T}{4\pi\, d^2} \cdot A_e$$

- Substituting the expression for antenna gain yields the Friis free space loss equation

$$P_R = \frac{P_T \cdot G_T \cdot G_R \cdot \lambda^2}{(4\pi)^2\, d^2} \ \text{watts} \quad \text{or} \qquad L = \frac{P_R}{P_T} = \frac{G_T \cdot G_R \cdot \lambda^2}{(4\pi\, d)^2}$$



RADAR EQUATION

The Radar Equation

- So, the reflected signal can be determined from the power density at the target times the RCS

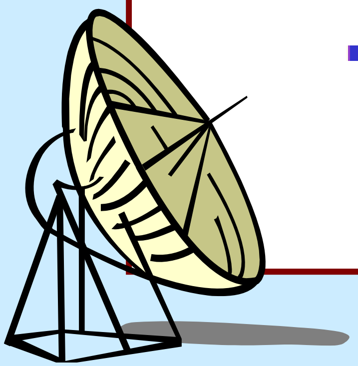
$$P_{refl} = \frac{P_T \cdot G_T}{4\pi\, d^2} \cdot \sigma_t$$

- The power density at the receiver from the reflected signal is

$$W_R = \frac{P_T \cdot G_T \cdot \sigma_t}{4\pi\, d^2} \cdot \frac{1}{4\pi\, d^2}$$

- When multiplied by the effective area of the radar antenna, this becomes

$$\boxed{P_R = \frac{P_T \cdot G_T \cdot \sigma_t \cdot A_e}{(4\pi)^2\, d^4} = \frac{P_T \cdot G_T \cdot G_R \cdot \sigma_t \cdot \lambda^2}{(4\pi)^3\, d^4}}$$



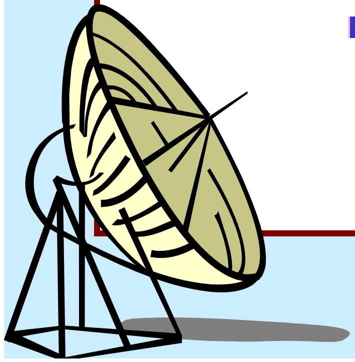
RADAR EQUATION

The Radar Range Equation

- For a required received signal level, we can solve the radar equation for *d* and find the maximum distance at which detection is possible

$$d_{\max} = \sqrt[4]{\frac{P_T \cdot G_T \cdot G_R \cdot \sigma_t \cdot \lambda^2}{P_{R\min} (4\pi)^3}}$$

- In radar, it is customary to use *R* for range instead of *d* for distance



RADAR EQUATION

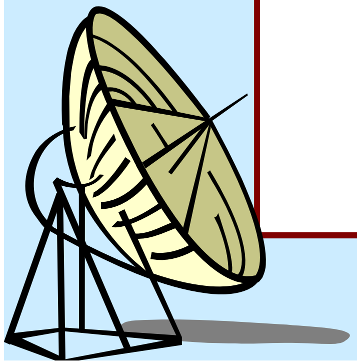
Radar Example

- Consider a radar system with the following parameters:

$f = 2$ GHz
$P_T = 1$ w $= 0$ dBw
$R = 2$ km
$F = 5$ dB

$\sigma_t = 1\ \text{m}^2$
$G_T = G_R = 18$ dB
$B = 50$ kHz
$\lambda = 0.15$ m

- What is the SNR at the receiver?



RADAR EQUATION

Radar Example

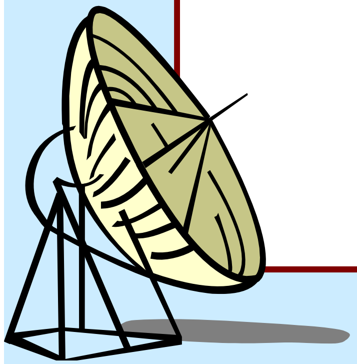
- The received signal level is

$$P_R = \frac{P_T \cdot G_T \cdot G_R \cdot \sigma_t \cdot \lambda^2}{(4\pi)^3 d^4}$$

- This can be computed in dBW as

P_R = 0 dBW + 18 dB + 18 dB + 0 dBsm +
20log(0.15) dBsm – 30 log(4π) - 40log(2000)dBm^4
(-16.5 dBsm) (- 33 dB) (–132 dBm^4)

P_R = -145.5 dBW or –115.5 dBm



RADAR EQUATION

Radar Example

- The receiver noise power is

$$N = kT_oBF$$

or,

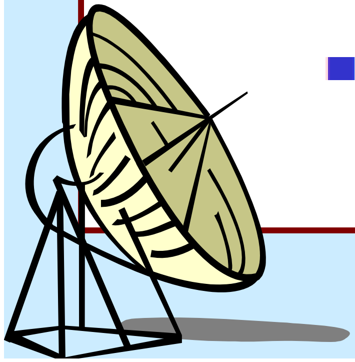
N_{dBm} = -174 dBm/Hz + 10log(50,000)dB-Hz + 5 dB

(47 dB-Hz)

$$N_{dBm} = -122 \text{ dBm}$$

- And the SNR is

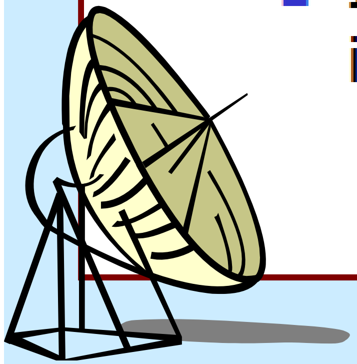
P_R – NdBm = -115.5 dBm – (-122 dBm) = 6.5 dB



RADAR EQUATION

Comments

- Note that the received power is inversely proportional to R^4, so doubling the distance reduces the signal level by 12 dB
- The round-trip path loss is **NOT** equal to 3 (or 6 dB) more than the one-way path loss.
- It is **double** the one-way loss in dB (i.e. loss is squared)

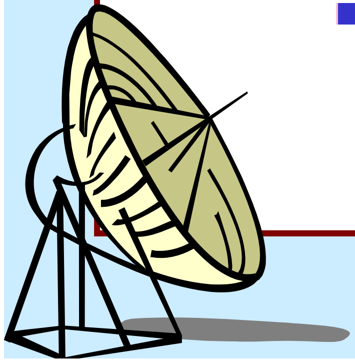


RADAR EQUATION

Pulse Radar

- Conventional pulse radar works by transmitting a short RF pulse and measuring the time delay of the return
- The bandwidth of the matched filter receiver is ~ 1/τ where τ is the pulse width (this is used as the NEB in noise calculations)
- τ also determines the range resolution of the radar

$$\Delta r = \frac{c\tau}{2}$$



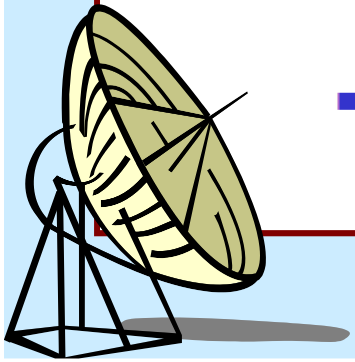
RADAR EQUATION

Pulse Radar

- Shorter pulses require larger receive bandwidths (more noise), provide less average power (less signal) but provide better range resolution
- The matched filter has an impulse response that matches the transmitted pulse
- The range to the target is

$$R = \frac{c \cdot \Delta t}{2}$$

- Where Δt is the elapsed time between transmission and reception of the pulse



RADAR EQUATION

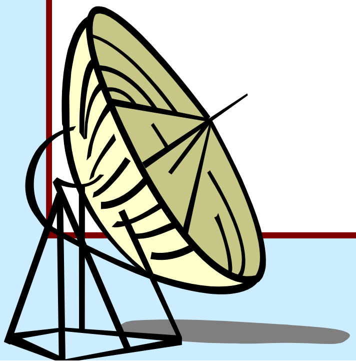
Pulse Radar

- The pulses are usually transmitted periodically. This period is called the PRI or the PRT
- The pulse repetition frequency is

$$\mathrm{PRF} \equiv \frac{1}{\mathrm{PRI}}$$

- The PRI defines the maximum unambiguous range of the system

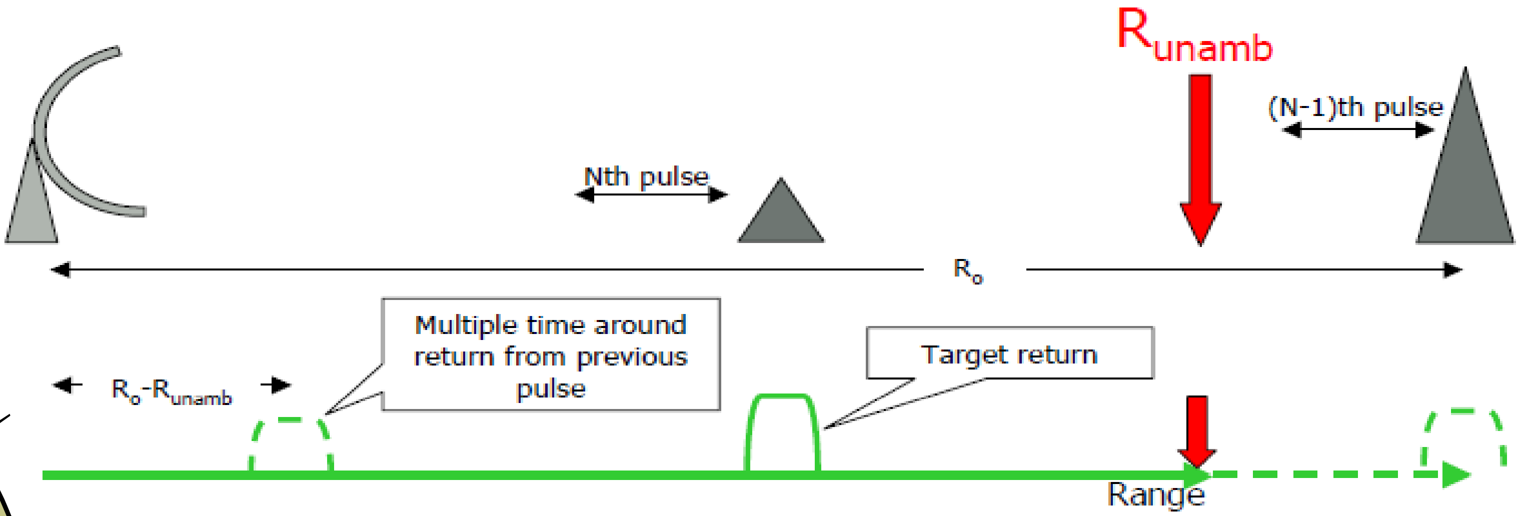
$$R_{unamb} = \frac{c \cdot PRI}{2}$$

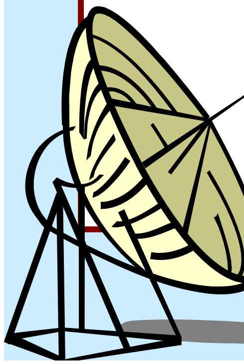


RADAR EQUATION

Pulse Radar

- A large target beyond the unambiguous range may be interpreted as a close target

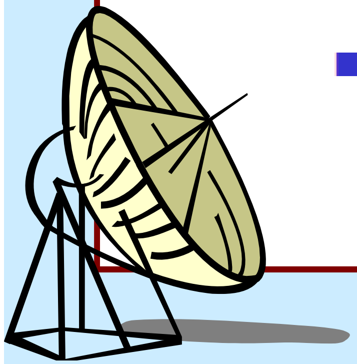




RADAR EQUATION

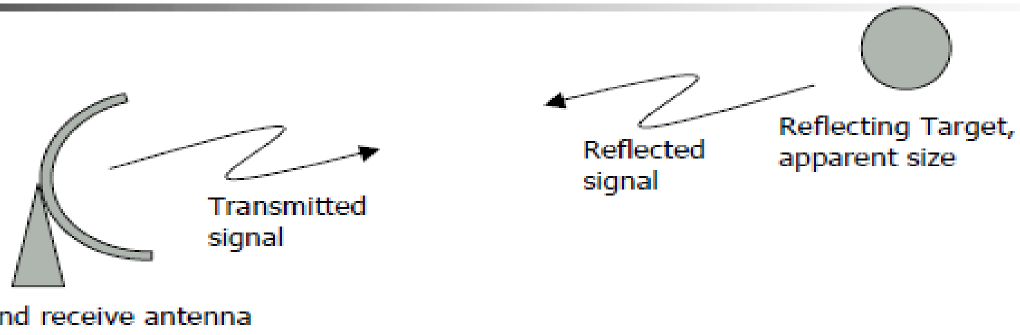
Pulse Radar

- For multiple time around returns to be an issue, the RCS of the distant reflector must usually be large
- Ideally, we would like R_{unamb} to be well beyond the maximum detection range of the radar
- In practice there are ways to mitigate the effect of these returns.

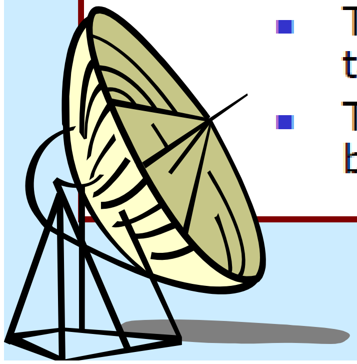


RADAR EQUATION

Typical Radar Geometry



- A typical radar system consists of a co-located pulsed transmitter and a receiver, usually sharing an antenna
- A pulse is transmitted and then the receiver listens for the return, similar to sonar
- The strength of the return signal depends upon the distance to the target and its (electrical) size
- The radar determines the distance to the target from the time delay before receiving the reflected pulse



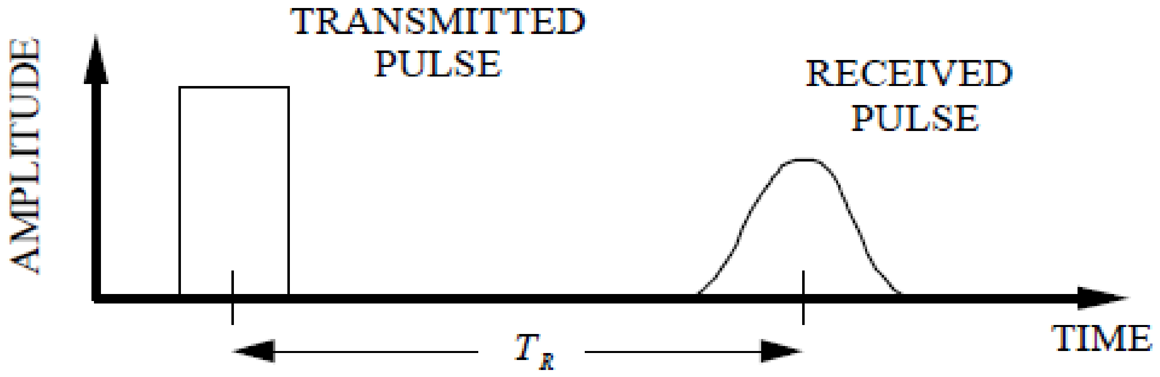
TIME DELAY RANGING

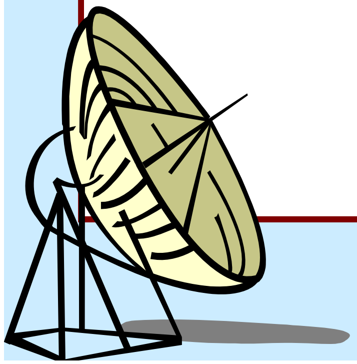
- Target range is the fundamental quantity measured by most radars. It is obtained by recording the round trip travel time of a pulse, T_R , and computing range from:

$$\text{Bistatic: } R_t + R_r = cT_R$$

$$\text{Monostatic: } R = \frac{cT_R}{2} \quad (R_t = R_r = R)$$

where $c = 3\text{x}10^8$ m/s is the velocity of light in free space.

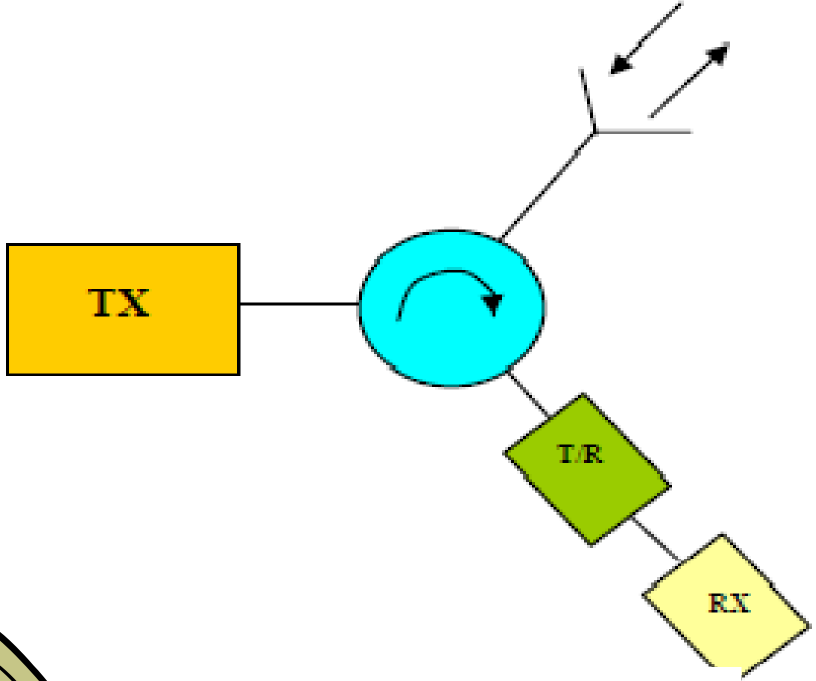


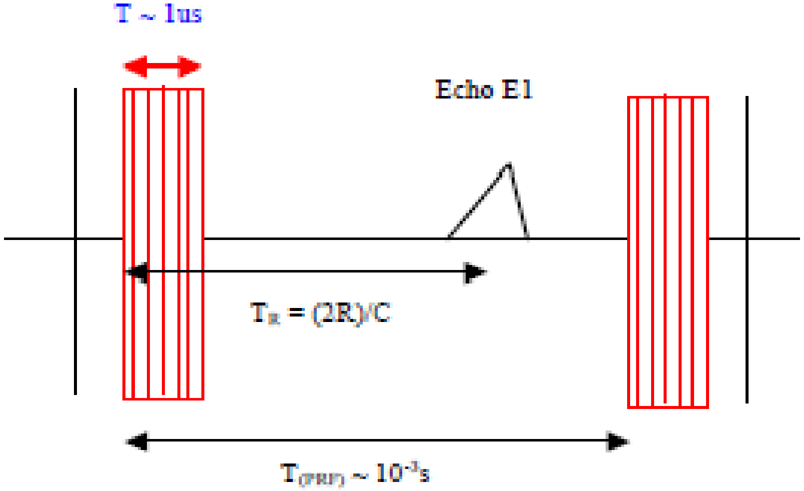


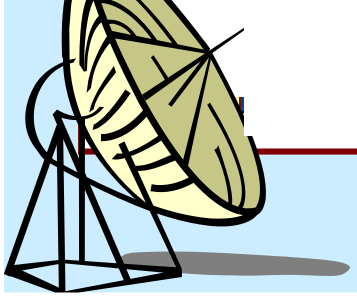
PULSE RADAR

Pulsed radar

- short pulses (pulse length ~ 1µs) of RF radiation are transmitted with relatively long intervals (*T(PRF)*) ~ ms) between them. *PRF* is the pulse repetition frequency







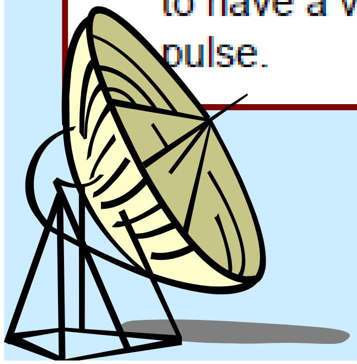
PULSE RADAR CONTINUED

- the *maximum unambiguous range* of the radar occurs when $T_R = T(PRF)$. For longer ranges the echo returns *after* the transmission of the next pulse.

$$R(\text{unambiguous}) = cT(PRF)/2 = c/2PRF$$

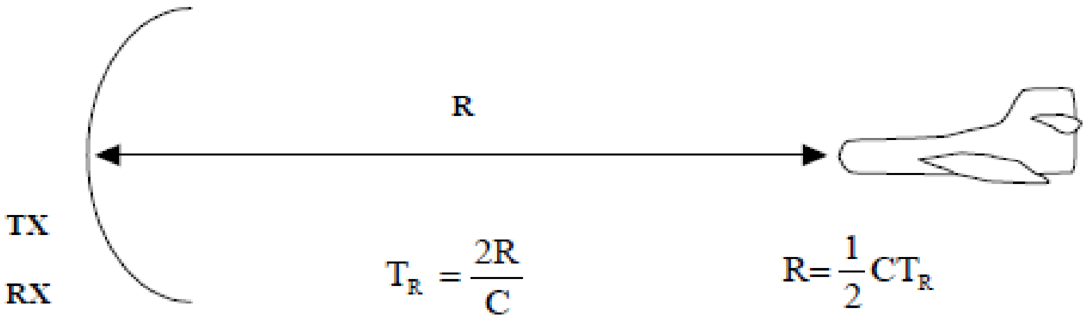
- the *blind range* of the radar occurs when the echo signal arrives back when the next pulse is being transmitted and the receiver is disabled - ie $T_R = T(PRF)$. This is the same as the maximum unambiguous range.
- to avoid the blind range and to distinguish targets that are beyond the maximum unambiguous range a *variable* PRF should be used.

If we *combine* the reflections from *several pulses,* targets with $R < R(\text{unambiguous})$ will all have the same time delay with respect to the transmitted signal, but those will appear to have a variable delay, because they actually originated from an *earlier* transmitted pulse.



PULSE RADAR CONTINUED

- the time delay between the transmitted and reflected signal T_R gives the range to the target

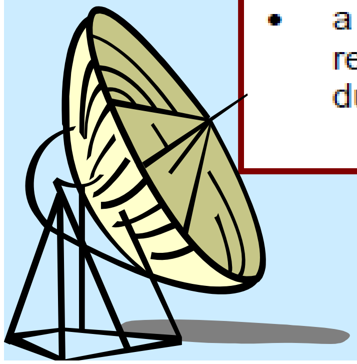


$$T_R = \frac{2R}{C}$$

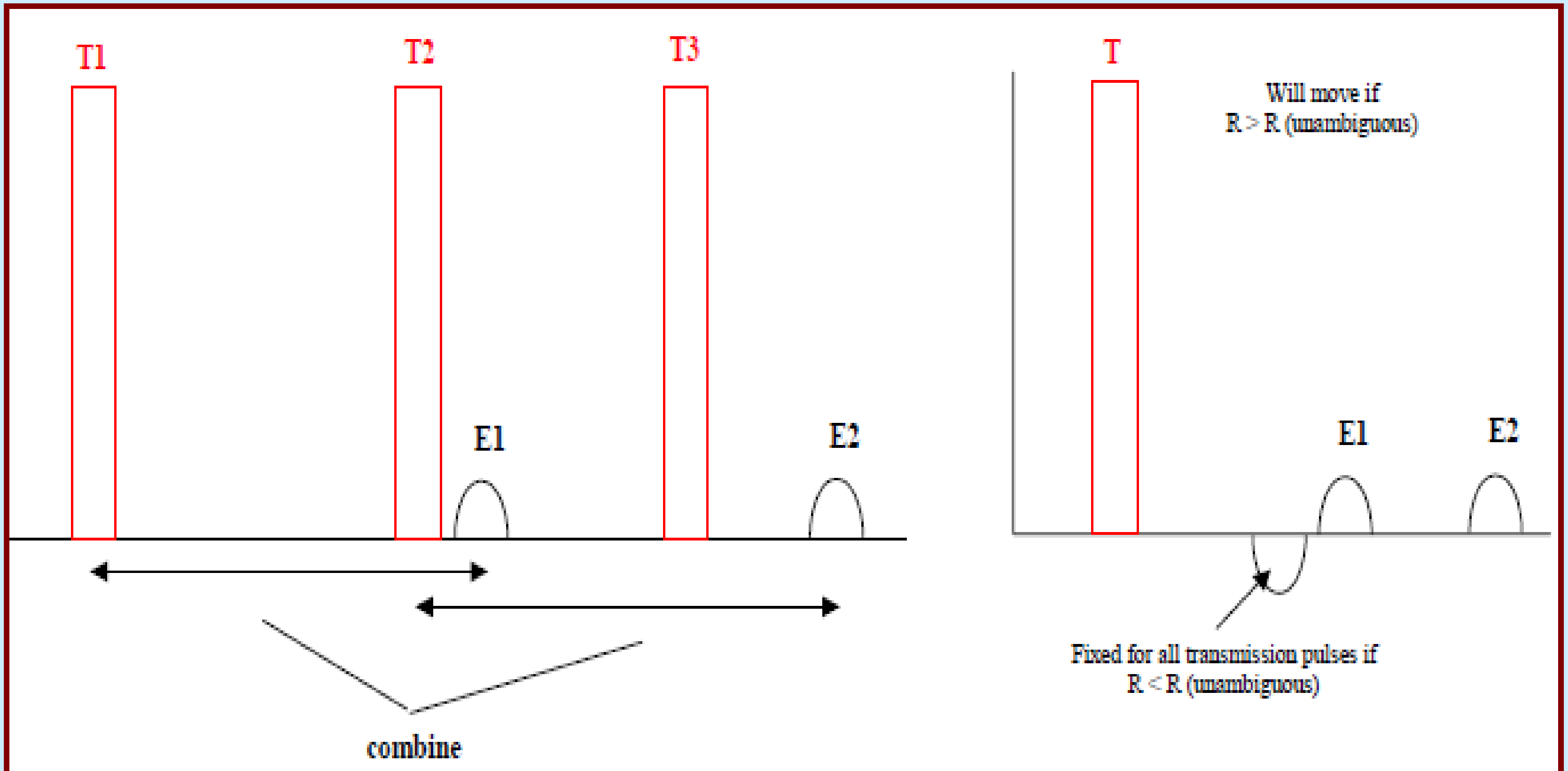
$$R = \frac{1}{2} C T_R$$

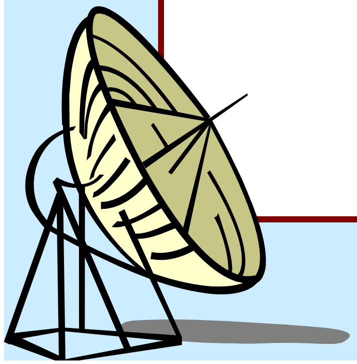
Figure 10 Transmitted and reflected signals

- each time delay of 1µs corresponds to an increase in range of 150m
- a T/R cell is connected between the transmitter and the receiver to protect the sensitive receiver from the high power pulses from the transmitter. This disables the receiver during pulse transmission



PULSE RADAR CONTINUED

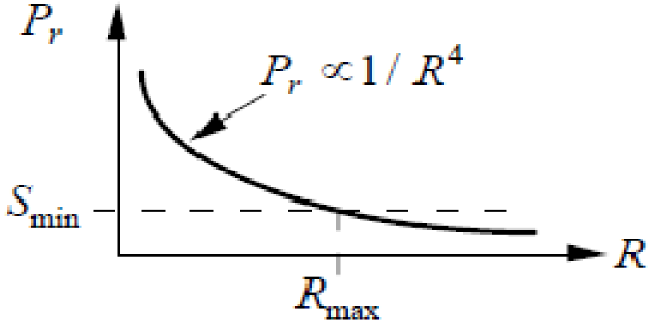


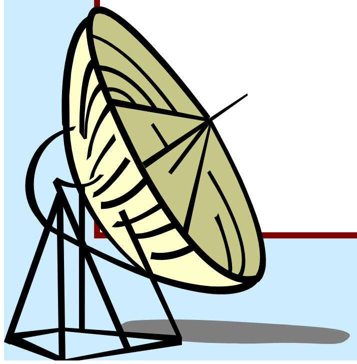


MINIMUM DETECTION RANGE

- The minimum received power that the radar receiver can "sense" is referred to a the minimum detectable signal (MDS) and is denoted $S_{\min}$.
- Given the MDS, the maximum detection range can be obtained:

$$P_r = S_{\min} = \frac{P_t G_t G_r \sigma \lambda^2}{(4\pi)^3 R^4} \Rightarrow R_{\max} = \left(\frac{P_t G_t G_r \sigma \lambda^2}{(4\pi)^3 S_{\min}} \right)^{1/4}$$





PULSED WAVEFORM

- In practice multiple pulses are transmitted to:
  1. cover search patterns
  2. track moving targets
  3. integrate (sum) several target returns to improve detection
- The pulse train is a common waveform

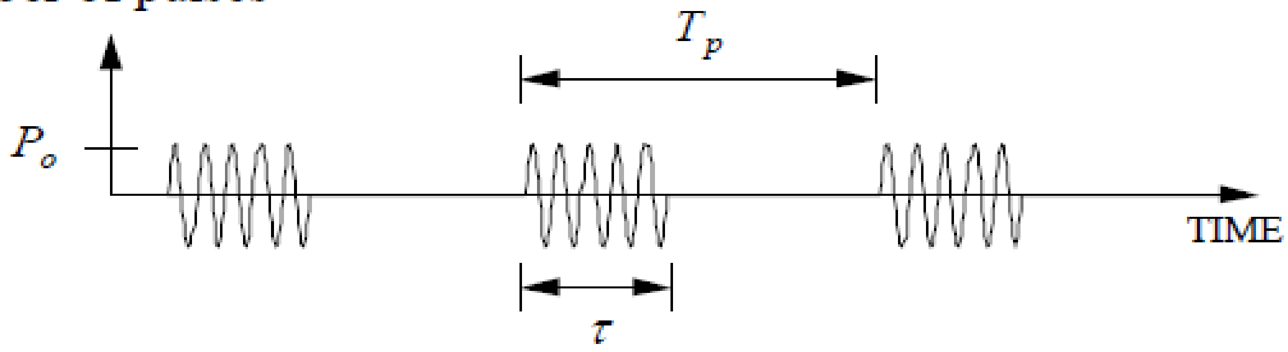
P_o = peak instantaneous power (W)

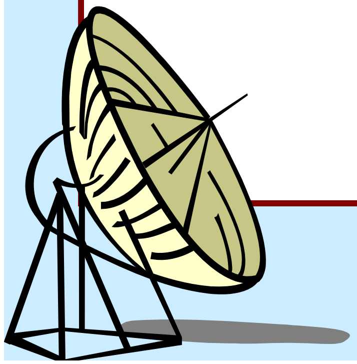
τ = pulse width (sec)

$f_p = 1/T_p$, pulse repetition frequency (PRF, Hz)

T_p = interpulse period (sec)

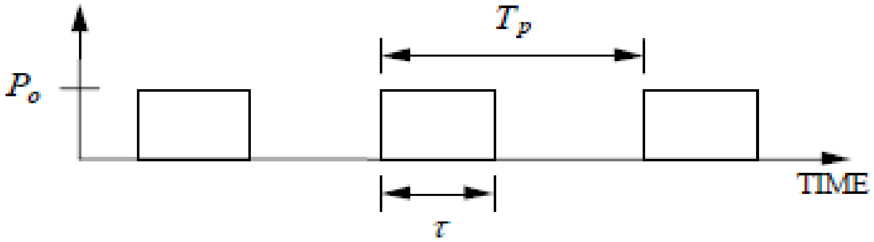
N = number of pulses



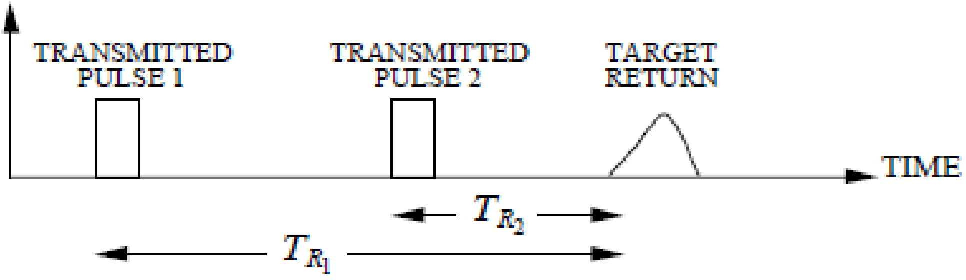


RANGE AMBIGUITIES

- For convenience we omit the sinusoidal carrier when drawing the pulse train

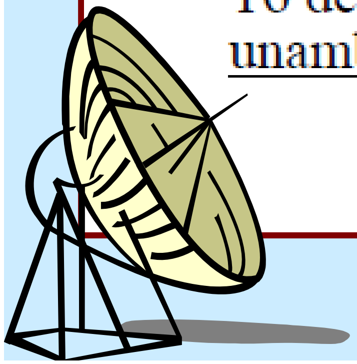


- When multiple pulses are transmitted there is the possibility of a range ambiguity.



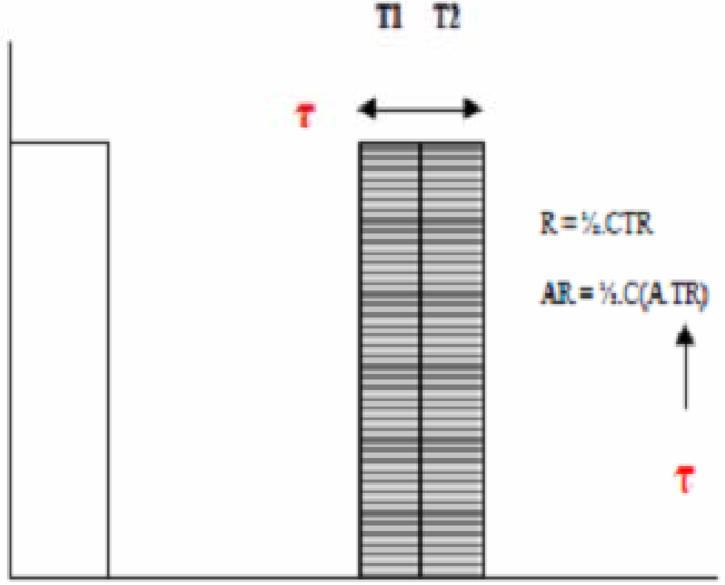
- To determine the range unambiguously requires that $T_p \geq \frac{2R}{c}$. The unambiguous range is

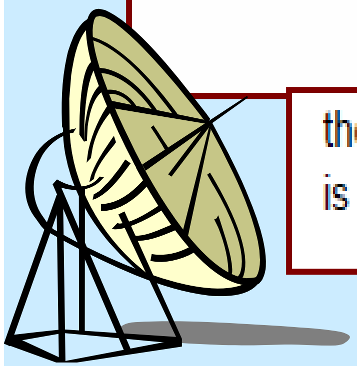
$$R_u = \frac{cT_p}{2} = \frac{c}{2f_p}$$



RADAR RANGE RESOLUTION

the *radar range resolution* is the ability of the radar to distinguish two targets with similar ranges. The resolution is determined by the pulse duration τ. The smallest time interval that the radar can resolve is τ which gives a range resolution of $c\tau/2$. If τ= 1μs the range resolution is 150m.

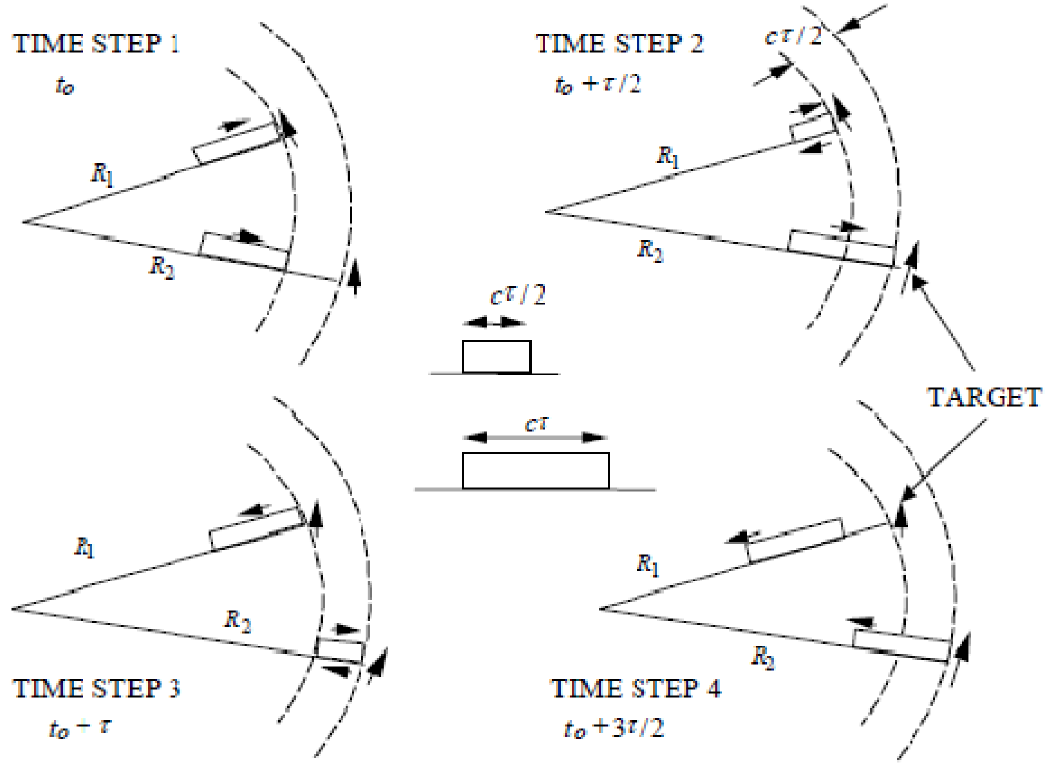


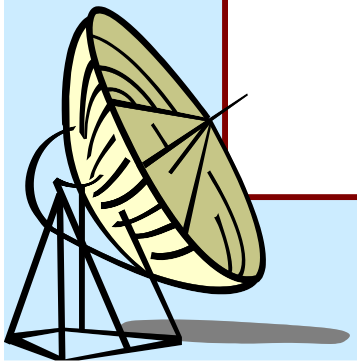


the *angular resolution* of the radar is determined by the beamwidth of the antenna, which is in turn set by the frequency of operation and the antenna diameter θ (radians)≈ λ/D.

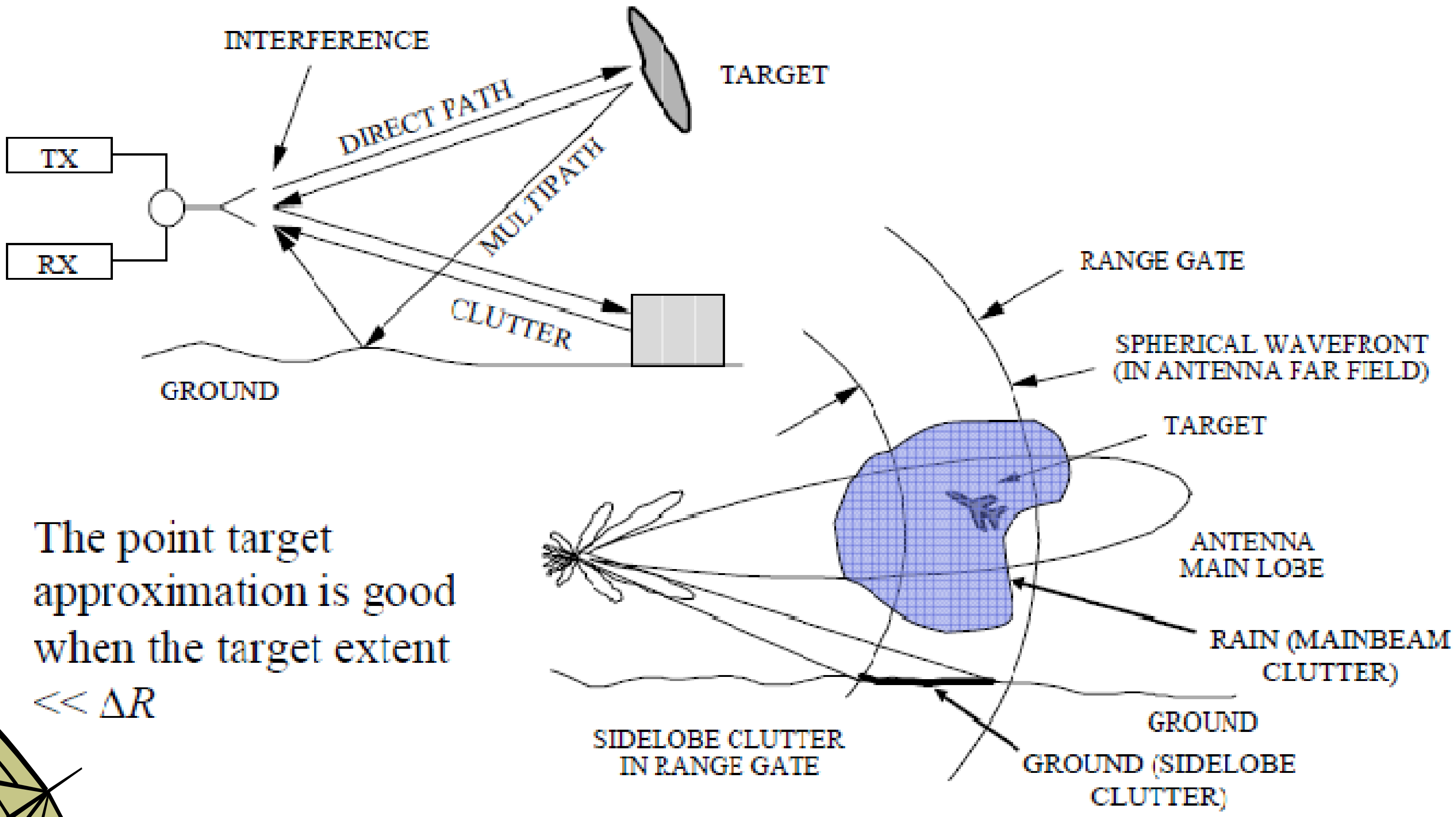
RANGE RESOLUTION

- Two targets are resolved if their returns do not overlap. The range resolution corresponding to a pulse width τ is $\Delta R = R_2 - R_1 = c\tau/2$.





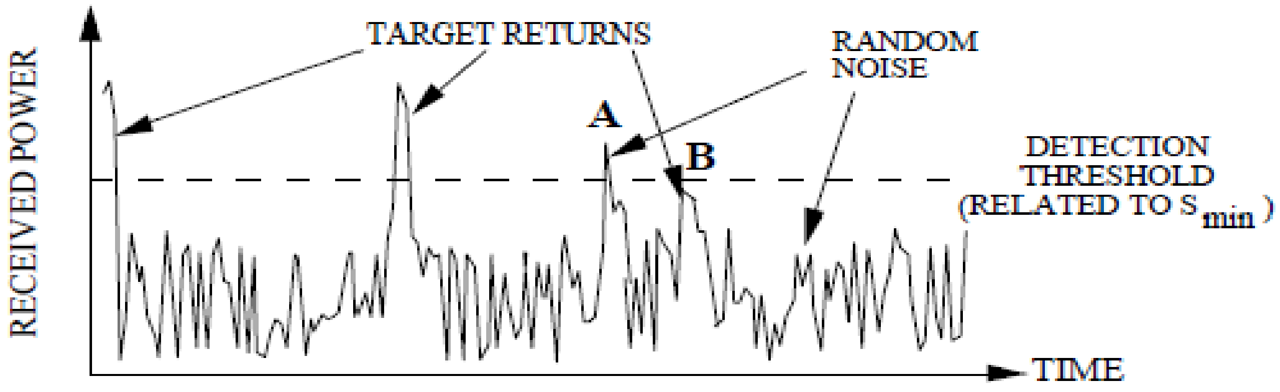
CLUTTER AND INTERFERENCE



The point target approximation is good when the target extent $<< \Delta R$

THERMAL NOISE

- In practice the received signal is "corrupted" (distorted from the ideal shape and amplitude) by thermal noise, interference and clutter.
- Typical return trace appears as follows:



- Threshold detection is commonly used. If the return is greater than the detection threshold a target is declared. **A** is a false alarm: the noise is greater than the threshold level but there is no target. **B** is a miss: a target is present but the return is not detected.

THERMAL NOISE POWER

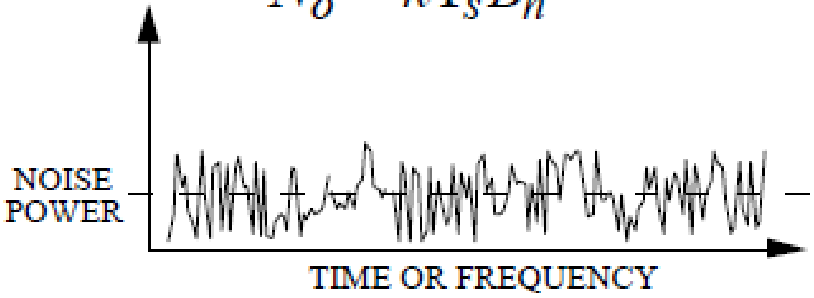
- Consider a receiver at the standard temperature, T_o degrees Kelvin (K). Over a range of frequencies of bandwidth B_n (Hz) the available noise power is

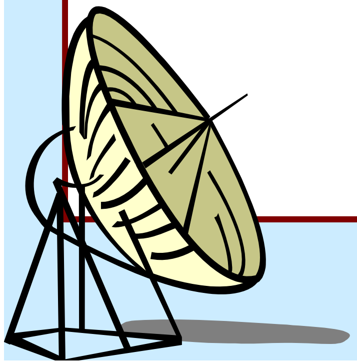
$$N_o = kT_oB_n$$

where $k_B = 1.38\times10^{-23}$ (Joules/K) is Boltzman's constant.

- Other radar components will also contribute noise (antenna, mixer, cables, etc.). We define a system noise temperature T_s, in which case the available noise power is

$$N_o = kT_sB_n$$





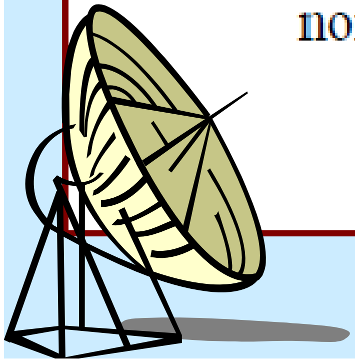
SIGNAL TO NOISE RATIO

- Considering the presence of noise, the important parameter for detection is the signal-to-noise ratio (SNR)

$$\mathrm{SNR} = \frac{P_r}{N_o} = \frac{P_t G_t G_r \sigma \lambda^2 G_p L}{(4\pi)^3 R^4 k_B \mathrm{T}_s B_n}$$

- Factors have been added for processing gain G_p and loss L
- Most radars are designed so that $B_n \approx 1/\tau$
- At this point we will consider only two noise sources:
  1. background noise collected by the antenna (T_A)
  2. total effect of all other system components (T_o, system effective noise temperature)

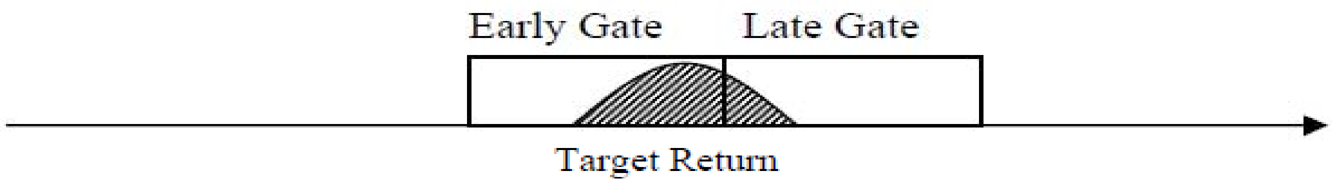
$$\mathrm{T}_s = \mathrm{T}_\mathrm{A} + \mathrm{T}_e$$

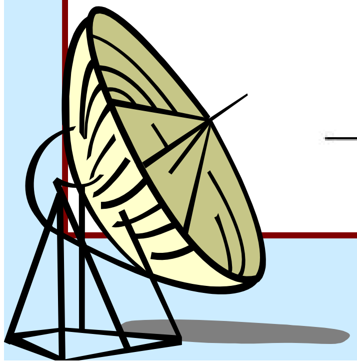


RANGE MEASUREMENT

Range Measurement

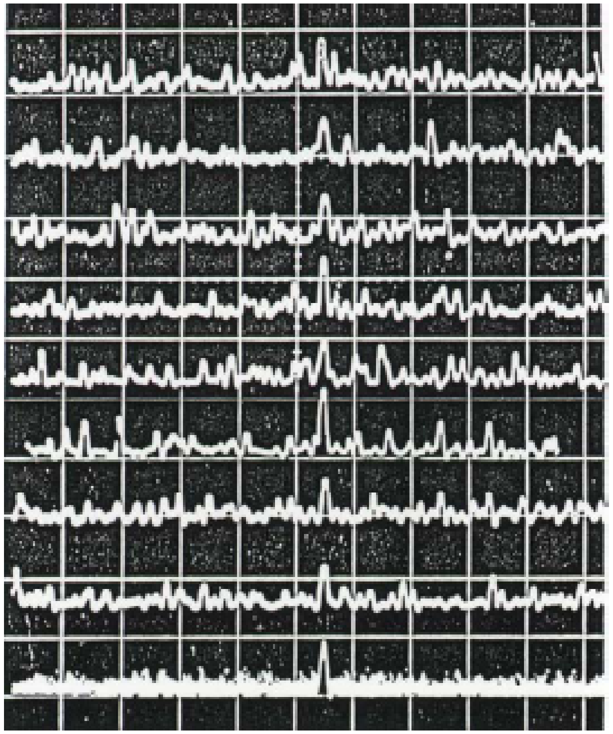
- Target range can be estimated with an accuracy better than the pulse width by using a split-gate tracker
- By comparing the energy in the early and late gates, an estimate of the target position is obtained



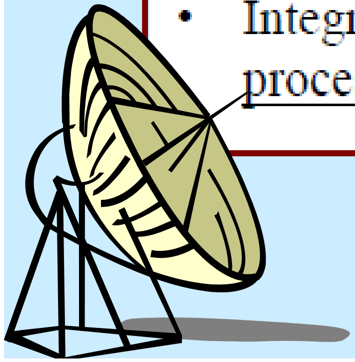


INTEGRATION OF PULSES

- Noncoherent integration (postdetection integration): performed after the envelope detector. The magnitudes of the returns from all pulses are added. SNR increases approximately as $\sqrt{N}$.
- Coherent integration (predetection integration): performed before the envelope detector (phase information must be available). Coherent pulses must be transmitted. The SNR increases as N.
- The last trace shows a noncoherent integrated signal.
- Integration improvement an example of processing gain.



From Byron Edde, *Radar: Principles, Technology, Applications*, Prentice-Hall



INTEGRATION OF RADAR PULSES

NO OF PULSES RETURNED FROM A POINT TGT, $n_B = \frac{\theta_B}{\theta_S} . f_p$

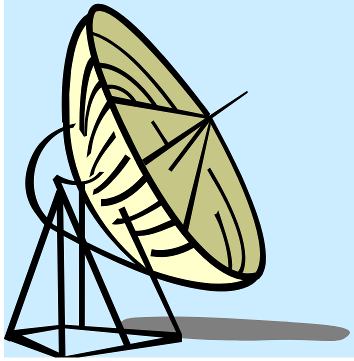
θ_B = ANT BW (DEG)

f_p = PRF

θ_S = ANT SCANNING RATE , DEG / SEC. ($\theta s = 6\omega_r$

ω_r = ANT SCN RATE , RPM

- ALL PRACTICAL INTEGRATION TECHNIQUES EMPLOY SOME SORT OF STORAGE DEVICE



INTEGRATION

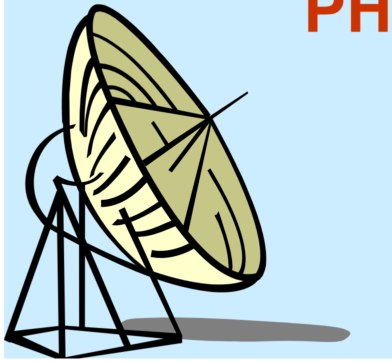
PREDETECTION

(COHERENT)

POST DETECTION

(NON COHERENT)

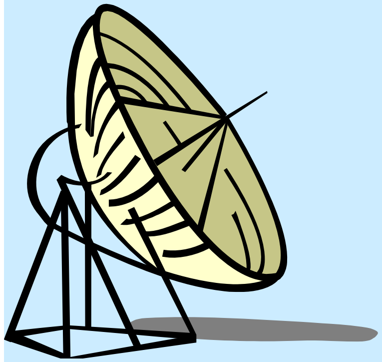
- **PREDETECTION INTEGRATION REQUIRES THAT PHASE OF THE ECHO SIGNAL BE PRESERVED.**



INTEGRATION CONTINUED

- POSTDETECTION INTEGRATION IS NOT CONCERNED WITH PRESERVING RF PHASE.

- POST DETECTION INTEGRATION IS LESS EFFICIENT THAN PREDETECTION INTEGRATION

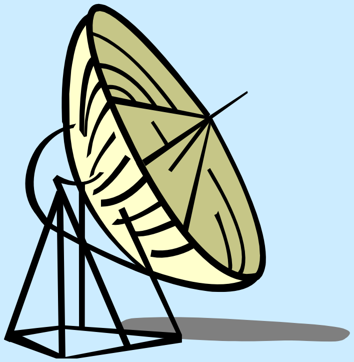


INTEGRATION CONTINUED

- **PREDETECTION INTEGRATION**

  S / N RATIO = n* S/N RATIO OF A SINGLE PULSE

  (FOR n PULSES INTEGRATED)



INTEGRATION CONTINUED

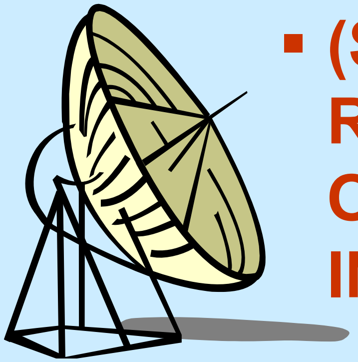
POST DETECTION INTEGRATION

- S / N RATIO WILL BE LESS THAN THE PREDETECTION CASE .
- THE LOSS IN INTEGRATION EFFICIENCY IS CAUSED BY NON – LINEAR ACTION OF SECOND DETECTOR , WHICH CONVERTS SOME OF SIGNAL ENERGY TO NOISE ENERGY.

INTEGRATION EFFICIENCY

- $$E_i(n) = \frac{(S/N)_I}{n\left(\frac{S}{N}\right)_n}$$

- (S/N)I = VALUE OF S/N RATIO OF A SINGLE PULSE REQUIRED TO PRODUCE GIVEN PROBABILITY OF DETECTION (n=I)



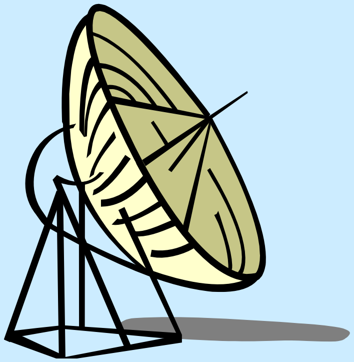
- (S/N)n = VALUE OF S/N RATIO PER PULSE REQUIRD TO PRODUCE SAME PROBABILITY OF DETECTION WHEN n PULSES ARE INTEGRATED.

INTEGRATION IMPROVEMENT FACTOR ($I_{i(n)}$)

I_i (n) = IMPROVEMENT IN S/N RATIO WHEN n PULSES ARE INTEGRATED POST DETECTION

= n $E_{i(n)}$

I_i (n) FOR PREDETECTION INTEGRATION) = n



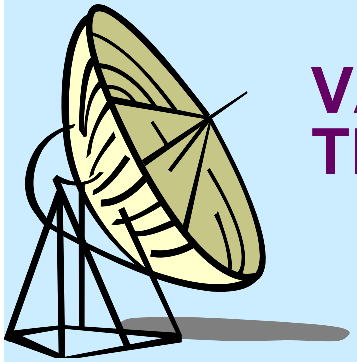
RADAR RANGE EQUATION (WITH n PULSES INTEGRATED)

$$R^4{}_{MAX} = \frac{P_t\, G\, A_e\, \sigma}{(4\pi)^2\, K\, T_O\, B_n F_n\, (S/N)n}$$

(S/N) n –S/N RATIO OF ONE OF n PULSES INTEGRATED

SUBSTITUTING $E_i(n) = \frac{(S/N)_1}{n(S/N)_n}$

$$R^4{}_{MAX} = \frac{P_t\, G\, Ae\, \sigma\, n\, EI(n)}{(4\pi)^2\, K\, T_O\, B_n\, F_n\, (S/N)_I}$$



VALUES OF $(S/N)_I$ AND n $E_i(n)$ ARE FOUND FROM THE AVAILABLE DATA (FIGURES /GRAPHS)

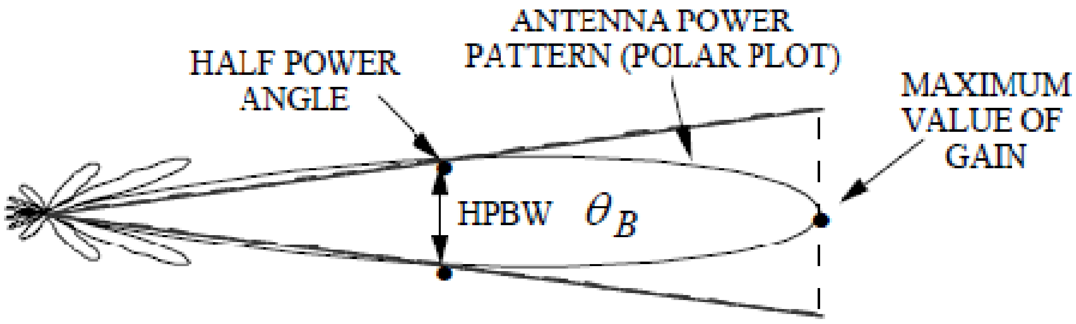
DWELL TIME

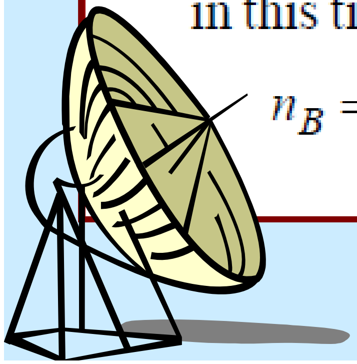
- Simple antenna model: constant gain inside the half power beamwidth (HPBW), zero outside. If the aperture has a diameter D with uniform illumination $\theta_B \approx \lambda / D$.
- The time that the target is in the beam (dwell time, look time, or time on target) is t_{ot}

$$t_{\text{ot}} = \theta_B / \dot{\theta}_s$$

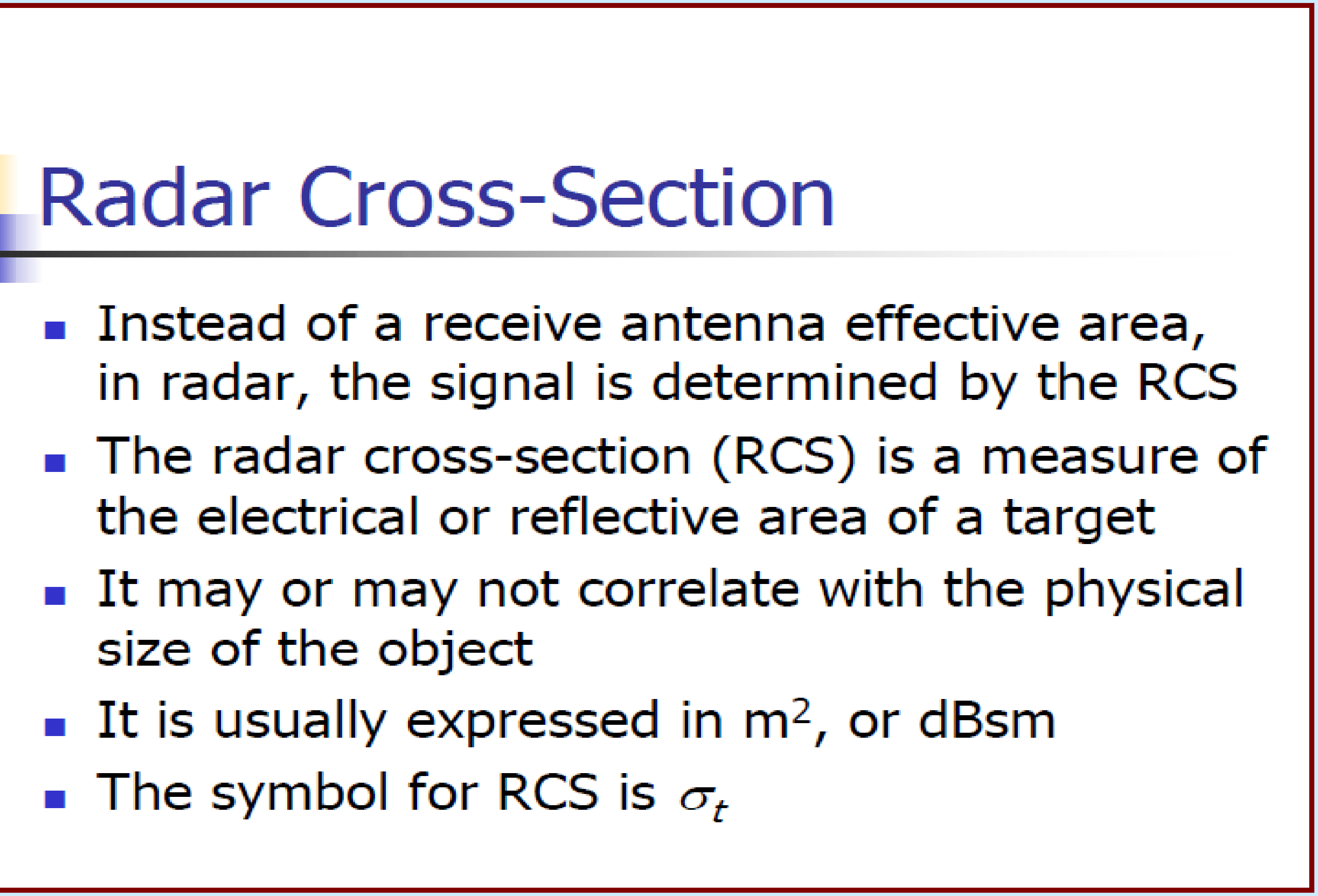
- The beam scan rate is ω_s in revolutions per minute or $\frac{d\theta_s}{dt} = \dot{\theta}_s$ in degrees per second.
- The number of pulses that will hit the target in this time is

$$n_B = t_{\text{ot}} f_p$$



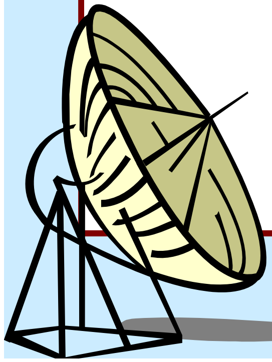


RADAR CROSS - SECTION



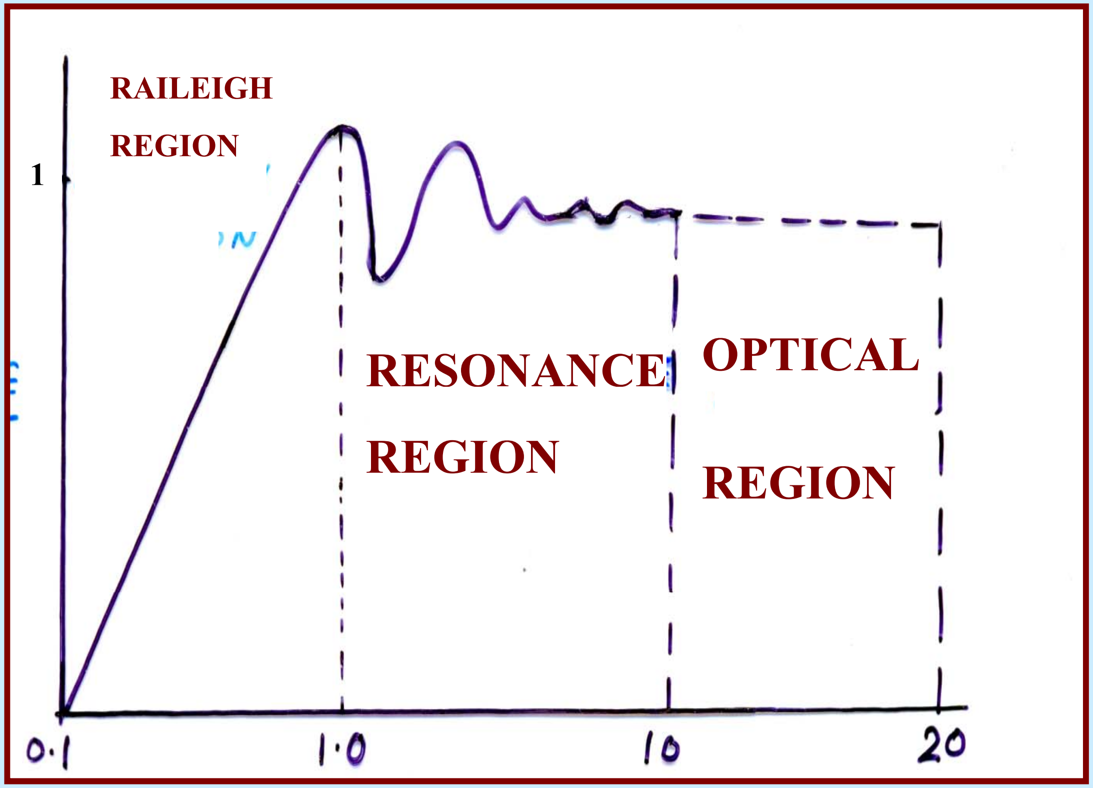
Radar Cross-Section

- Instead of a receive antenna effective area, in radar, the signal is determined by the RCS
- The radar cross-section (RCS) is a measure of the electrical or reflective area of a target
- It may or may not correlate with the physical size of the object
- It is usually expressed in m^2, or dBsm
- The symbol for RCS is σ_t



RADAR CROSS SECTION OF TARGETS (σ)

$$\frac{\sigma \text{ SPHERE}}{\Pi a^2}$$



$$\longrightarrow 2\Pi\theta / \lambda$$

σ IS A MEASURE OF TARGETS'S SIZE ,SHAPE & COMPOSITION.

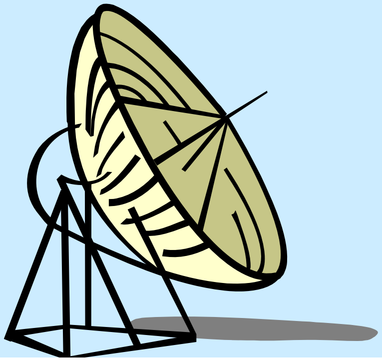
RADAR CROSS SECTION OF TARGET

- RAYLEIGH REGION $\{(2\Pi a / \lambda) << 1\}$
- $\sigma \alpha f^4$

σ IS DETERMINED MORE BY VOLUME OF TARGET THAN ITS SHAPE.

- OPTICAL REGION $\{(2\Pi a / \lambda) >> 1\}$

SCATTERING FROM A/C & SHIPS AT MW FREQUENCY IS IN OPTICAL REGION.



RADAR X SECTION IS AFFECTED MORE BY SHAPE OF THE OBJECTS THAN ITS PROJECTED AREA.

RADAR CROSS SECTION OF TARGET

RESONANCE REGION $\{(2\Pi a / \lambda) = 1\}$

RADAR CROSS SECTION OSCILLATES AS A FUNCTION OF FREQUENCY.

SIMPLE TARGETS : SPHERE, CYLINDER, FLAT PLATE ROD,CONE.

- 0.3 m (1ft) SQUARE PLATE HAS $\sigma = 113\ m^2$ WHEN VIEWED NORMAL TO THE SURFACE.

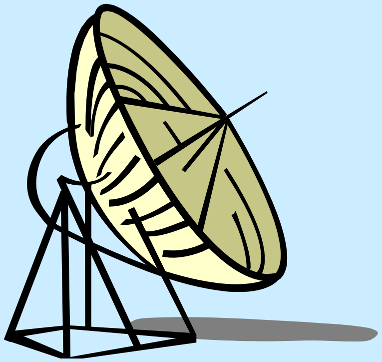
RADAR CROSS SECTION OF TARGET

EFFECT OF TARGET SHAPE:

IN OPT REGION ($f\uparrow$) , λ IS SMALL COMPARED TO OBJECT DIMENSIONS , SHAPE OF A OBJECT HAS A FAR GREATER EFFECT ON σ THAN DOES ITS PHYSICAL SIZE.

AT 3 GHZ : $1 m^2$ FLAT PLATE = $1000\ m^2$ (σ)

: $1 m^2$ CONE SPHERE = $0.001\ m^2$ (σ)

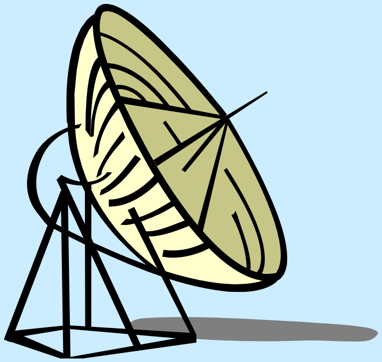


RADAR CROSS SECTION OF TARGET

NOTE: CHANGES IN RADAR CROSS - SECTION BY AS MUCH AS IS 15 dB CAN OCCUR FOR A CHANGE IN ASPECT OF ONLY 1/3° IN CASE OF AN AIRCRAFT.

COMPLEX TARGETS

AIRCRAFT, MISSILE, SHIP GROUND VEHICLES, BUILDINGS etc.



RADAR CROSS-SECTION AT MINIMUM FREQUENCY

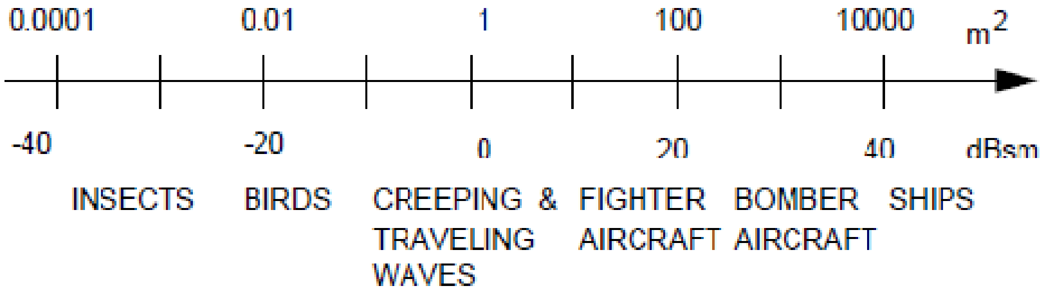
TARGET OBJECT	SQ M
SMALL SINGLE ENGINE AIRCRAFT	1
SMALL TIGHTER/ 4 PASSENGER JET	2
LARGE FIGHTER	6
LARGE BOMBER	40
JUMBO JET	100
HELICOPTER	3
AUTOMOBILE	100
BICYCLE / MAN	2/1

RADAR CROSS-SECTION AT MINIMUM FREQUENCY

TARGET OBJECT	SQ M
LARGE BIRD / MEDIUM BIRD	10^{-2}/ 10^{-3}
LARGE INSECT/ SMALL INSECT	10^{-4} / 10^{-5}
10,000 TOW SHIP	10,000 m^2

RADAR CROSS SECTION

- Typical values:

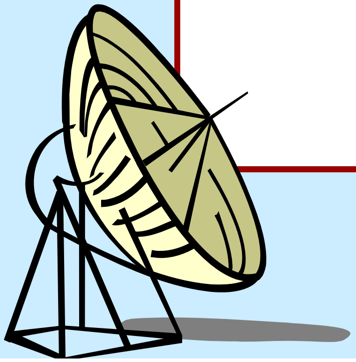


- Fundamental equation for the RCS of a "electrically large" perfectly reflecting surface of area *A* when viewed directly by the radar

$$\sigma \approx \frac{4\pi A^2}{\lambda^2}$$

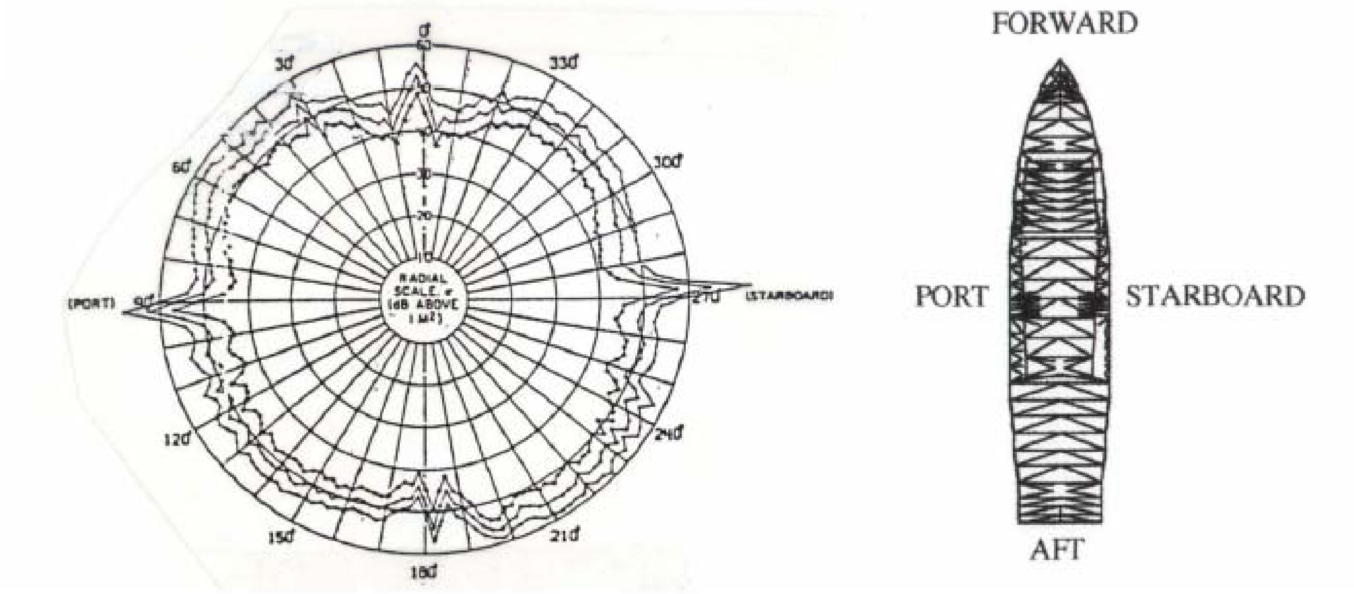
- Expressed in decibels relative to a square meter (dBsm):

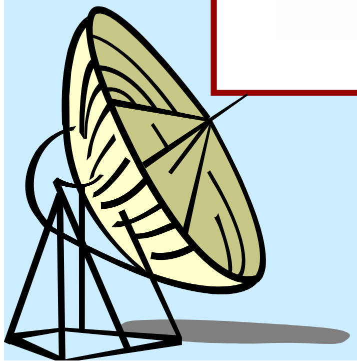
$$\sigma_{\text{dBsm}} = 10\log_{10}(\sigma)$$



RCS TARGET TYPES

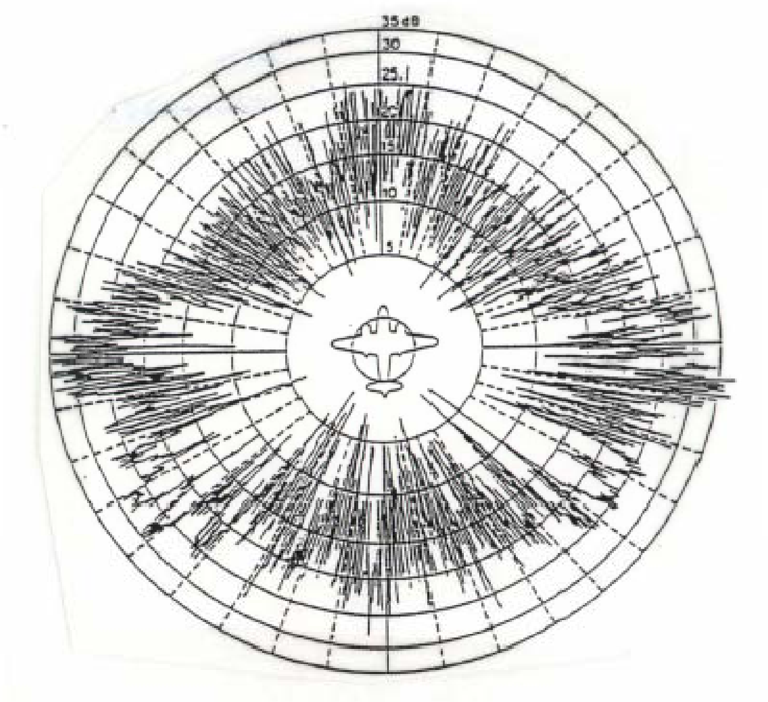
- A few dominant scatterers (e.g., hull) and many smaller independent scatterers
- S-Band (2800 MHz), horizontal polarization, maximum RCS = 70 dBsm





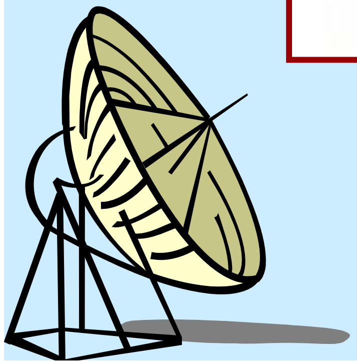
RCS TARGET TYPES

- Many independent random scatterers, none of which dominate (e.g., large aircraft)



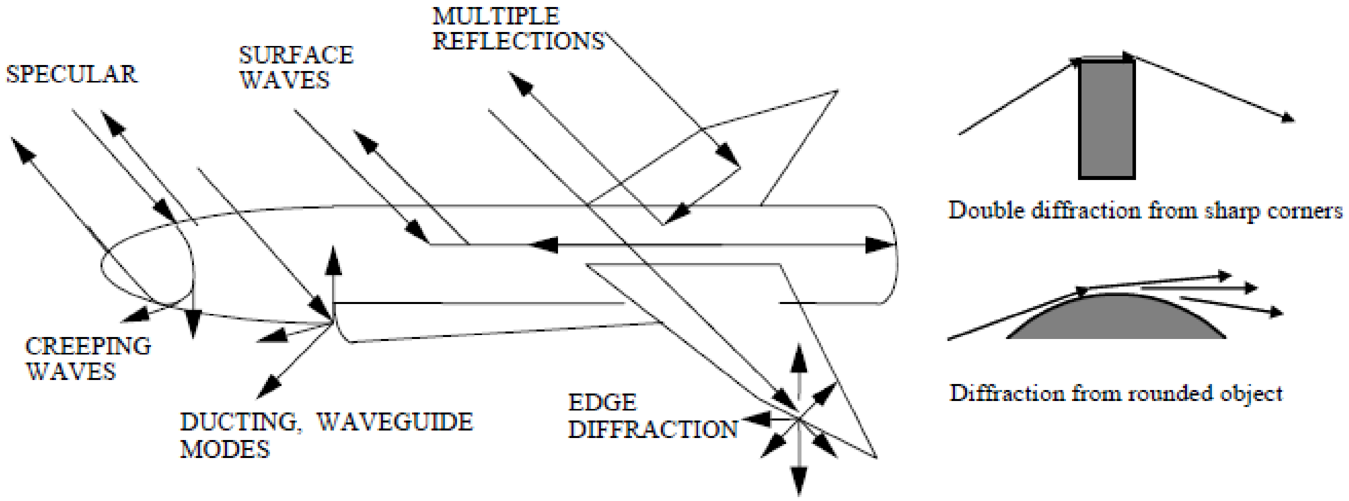
From Skolnik

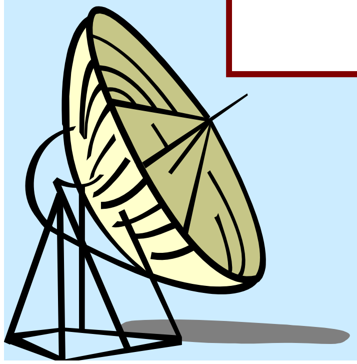
- S-Band (3000 MHz)
- Horizontal Polarization
- Maximum RCS = 40 dBsm



SCATTERING MECHANISMS

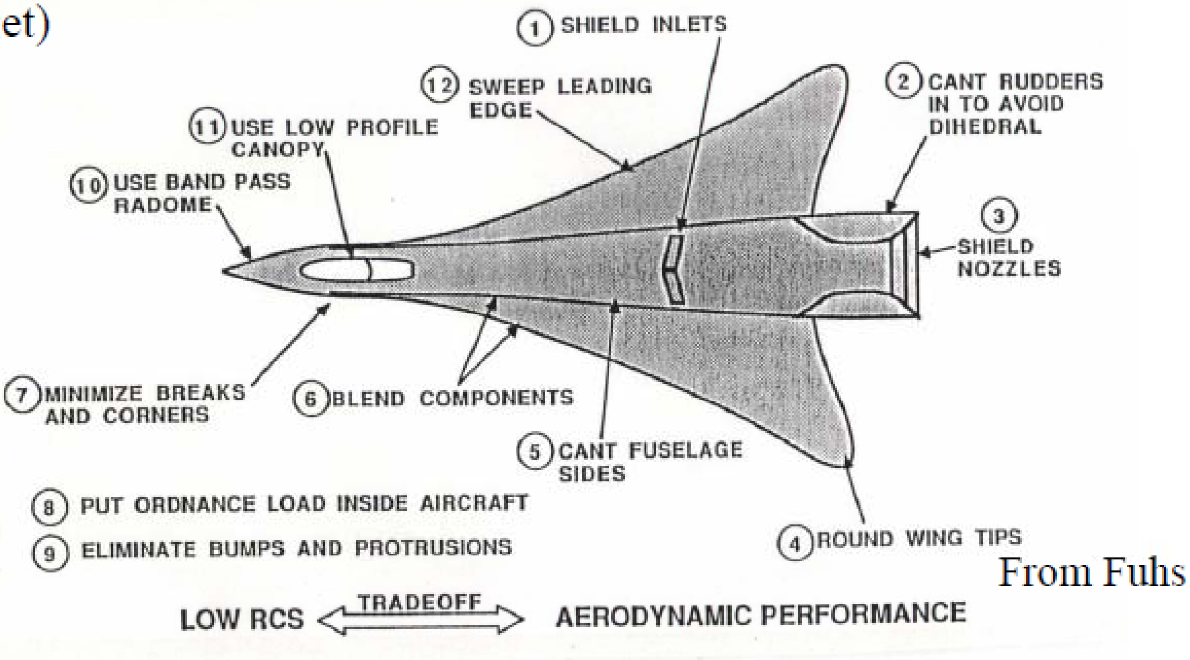
- Scattering mechanisms are used to describe wave behavior. Especially important at radar frequencies:
  specular = "mirror like" reflections that satisfy Snell's law
  surface waves = the body surface acts like a transmission line
  diffraction = scattered waves that originate at abrupt discontinuities



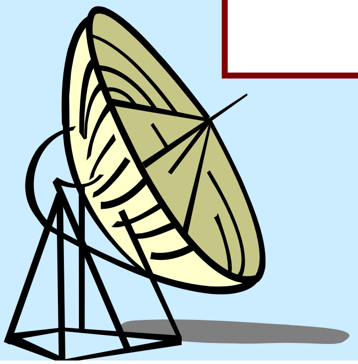


RCS REDUCTION METHOD

- Shaping (tilt surfaces, align edges, no corner reflectors)
- Materials (apply radar absorbing layers)
- Cancellation (introduce secondary scatterers to cancel the “bare” target)



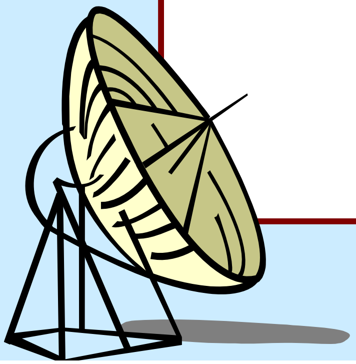
From Fuhs



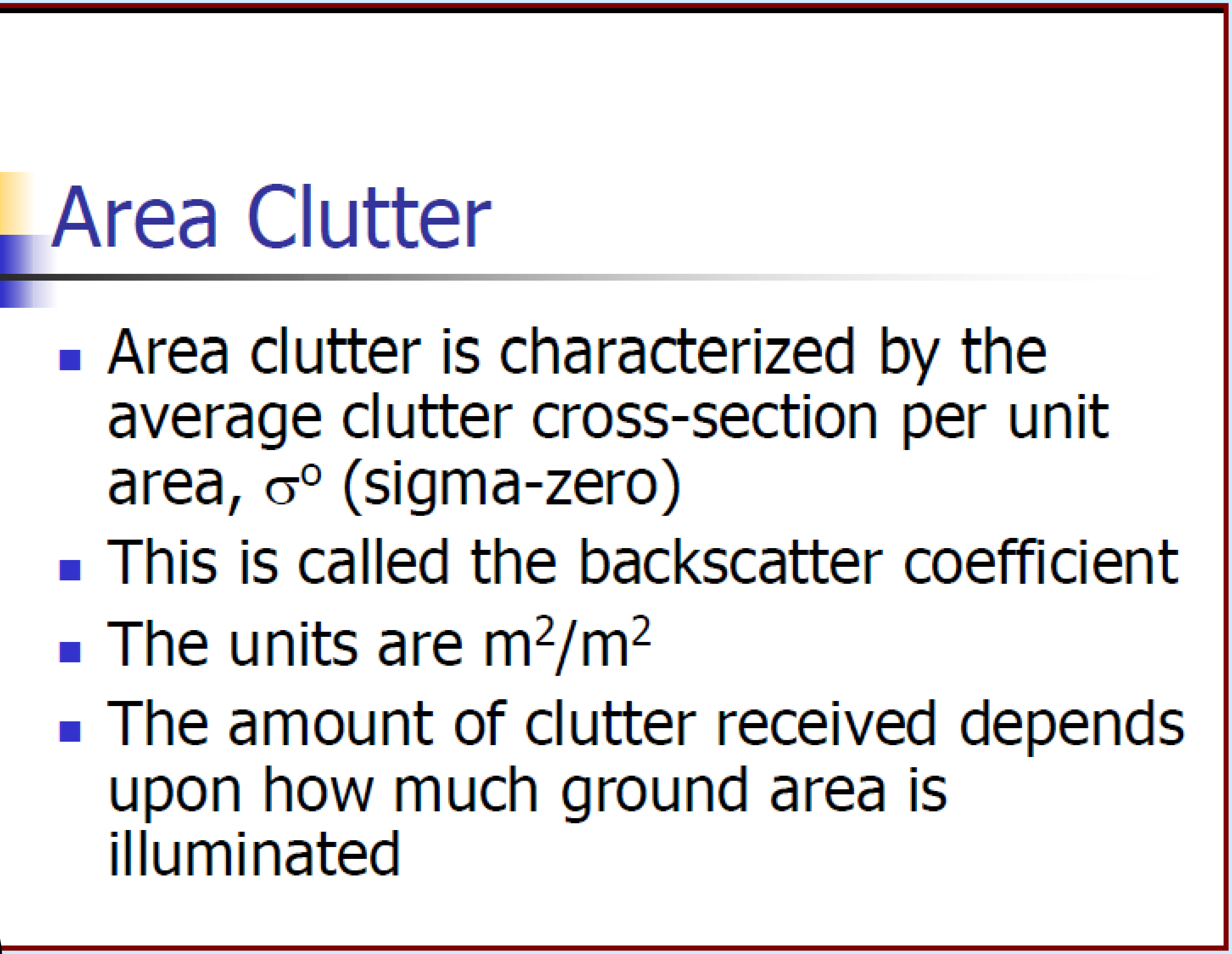
RADAR CLUTTER

Radar Clutter

- Clutter is defined as any unwanted radar echo
- Ground target returns will include ground clutter (*area clutter*)
- Airborne target returns may include *volume clutter* from precipitation in the propagation path

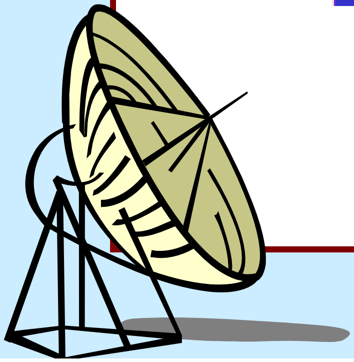


AREA CLUTTER



Area Clutter

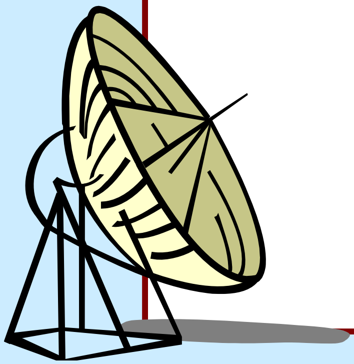
- Area clutter is characterized by the average clutter cross-section per unit area, σ^o (sigma-zero)
- This is called the backscatter coefficient
- The units are m^2/m^2
- The amount of clutter received depends upon how much ground area is illuminated



WAYS TO MITIGATE CLUTTER

Ways to Mitigate Clutter

- Narrow antenna beams
- Short pulses
- Averaging multiple “looks” when the clutter has a short correlation time such as vegetation
- Make use of Doppler
  - If the target is moving, it is possible to take multiple looks and then filter the sequence (FFT) to extract the moving target
  - If the radar is stationary, the clutter will be centered at the zero Doppler bin

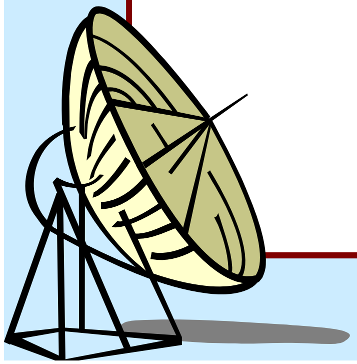


VOLUME CLUTTER

Volume Clutter

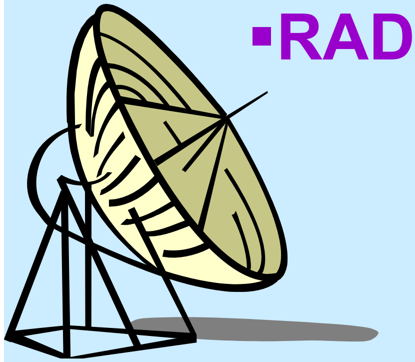
- When considering volume clutter, the overall volume of clutter that is illuminated depends upon
  - Range gate length
  - Range to the range gate of interest
  - Azimuth and elevation beamwidth of the antenna
- The volume of the clutter cell will be approximately

$$V = (\pi/4)\cdot(c\tau/2)\cdot R\cdot\theta_{EL}\cdot R\cdot\theta_{AZ}\ \ m^3$$



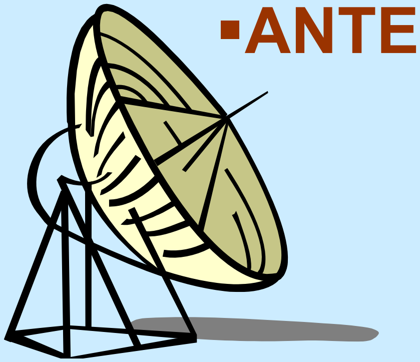
FACTORS THAT AFFECT RADAR PERFORMANCE

- SIGNAL RECEPTION
- RECEIVER BANDWIDTH
- PULSE SHAPE
- POWER RELATION
- BEAM WIDTH
- PULSE REPETITION FREQUENCY
- ANTENNA GAIN
- RADAR CROSS SECTION OF TARGET



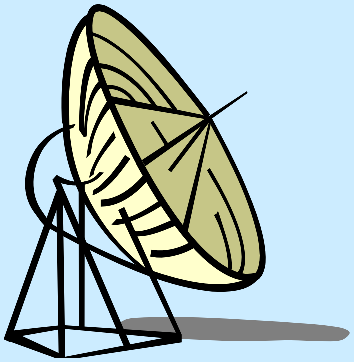
FACTORS THAT AFFECT RADAR PERFORMANCE

- SIGNAL-TO-NOISE RATIO
- RECEIVER SENSITIVITY
- PULSE COMPRESSION
- SCAN RATE
  - MECHANICAL
  - ELECTRONIC
  - CARRIER FREQUENCY
- ANTENNA APERTURE



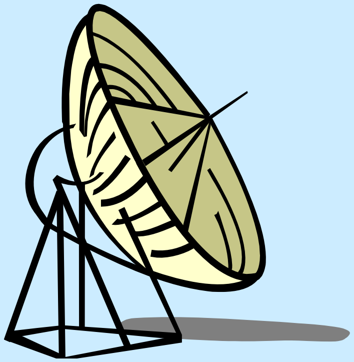
PULSE EFFECTS ON RADAR PERFORMANCE

- PULSE SHAPE
- PULSE WIDTH
- PULSE COMPRESSION
- PULSE POWER



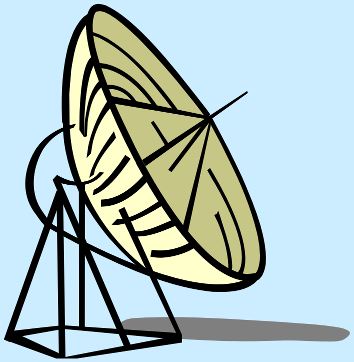
PULSE SHAPE

- DETERMINES RANGE ACCURACY AND MINIMUM AND MAXIMUM RANGE.
- IDEALLY WE WANT A PULSE WITH VERTICAL LEADING AND TRAILING EDGES.
- VERY CLEAR SIGNAL – EASILY DISCERNED WHEN LISTENING FOR THE ECHO.



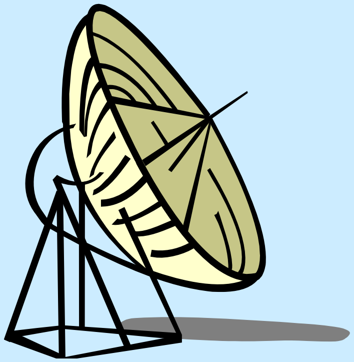
PULSE WIDTH

- DETERMINES THE RANGE RESOLUTION.
- DETERMINES THE MINIMUM DETECTION RANGE.
- THE NARROWER THE PULSE, THE BETTER THE RANGE RESOLUTION.



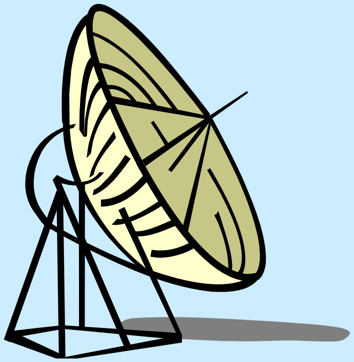
PULSE COMPRESSION

- INCREASES FREQUENCY OF THE WAVE WITHIN THE PULSE.
- ALLOWS FOR GOOD RANGE RESOLUTION WHILE PACKING ENOUGH POWER TO PROVIDE A LARGE MAXIMUM RANGE.



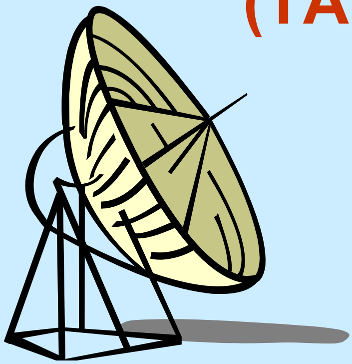
PULSE POWER

- HIGH PEAK POWER IS DESIRABLE TO ACHIEVE MAXIMUM RANGES.
- LOW POWER MEANS SMALLER AND MORE COMPACT RADAR UNITS AND LESS POWER REQUIRED TO OPERATE.



OTHER FACTORS AFFECTING PERFORMANCE

- **SCAN RATE AND BEAM WIDTH**
  - **NARROW BEAM REQUIRE SLOWER ANTENNA ROTATION RATE.**
- **PULSE REPETITION FREQUENCY**
  - **DETERMINES RADARS MAXIMUM RANGE (TACTICAL FACTOR).**



OTHER FACTORS AFFECTING PERFORMANCE

- CARIER FREQUENCY
    - DETERMINES ANTENNA SIZE, BEAM DIRECTIVITY AND TARGET SIZE.

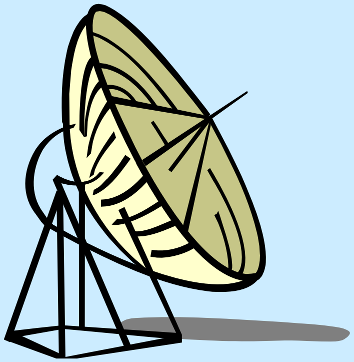
- RADAR CROSS SECTION (WHAT THE RADAR CAN SEE(REFLECT))
    - FUNCTION OF TARGET SIZE, SHAPE, MATERIAL, ANGLE AND CARRIER FREQUENCY.

SYSTEM LOSSES

TYPE 1

- PLUMBING LOSS
- BEAM SHAPE LOSS
- SCANNING LOSS
- LIMITING LOSS
- COLLAPSING LOSS
- STRADLING LOSS
- PROPAGATION EFFECTS

CAN BE CALCULATED

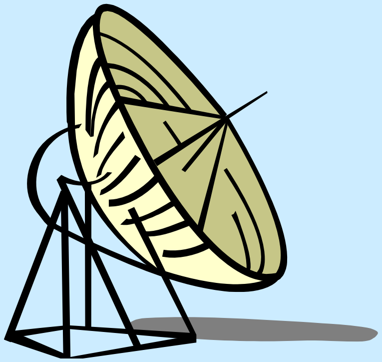


SYSTEM LOSSES

TYPE II:

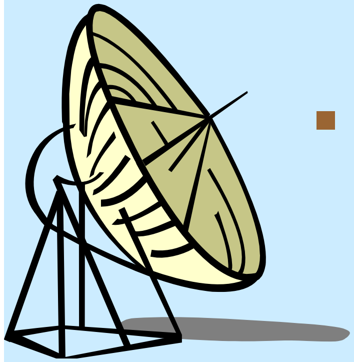
- FIELD DEGRADATOIN
- NON IDEAL EQUIPMENT
- OPERATOR FATIGUE

NOT EASILY
SUBJECT
TO
CALCULATION



PLUMBING LOSS

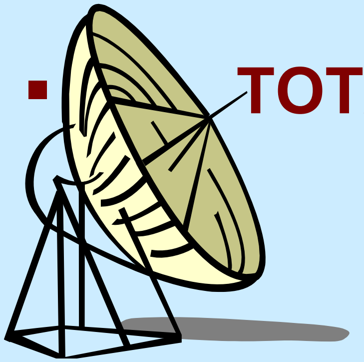
- TRANSMISSION LINE LOSS; LESSER AT LOWER RADAR FREQUENCIES
- CONNECTOR LOSS:
- INSERTION LOSS: LOSS DUE TO INSERTION OF COMPONENT INTO TRANSMISSION LINE (DULPEXER)- 1dB APPROX



  - ARC LOSS

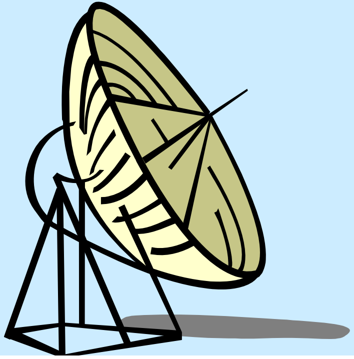
EXAMPLE- PLUMBING LOSS

TRANS LINE LOSS (TWO WAY)	1.0 dB
LOSS DUE TO POOR CONNECTION	0.5 dB
ROTARY JOINT LOSS	0.4 dB
DUPLEXER LOSS	1.5 dB
TOTAL (PLUMBING LOSS)	3.4 dB



BEAM SHAPE LOSS

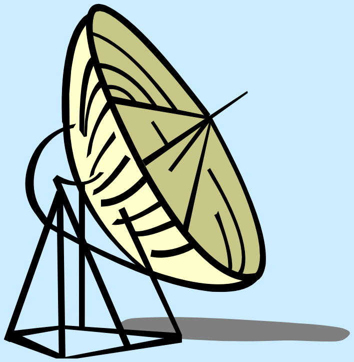
- ANTENNA GAIN(G)-ASSUMED CONSTANT (MAX) BUT IT IS NOT SO.
- ACTUALLY GAIN CHANGES FROM PULSE TO PULSE
- IF WE INTEGRATE 11 PULSES, ALL LYING UNIFORMLY BETWEEN 3 DB BANDWIDTH, THE LOSS IS 1.96 DB



SCANNING LOSS

- WHEN ANENNA SCANS RAPIDLY ENOUGH THAT THE GAIN ON TRANSMIT IS NOT THE SAME AS THE GAIN ON RECEIVE.

- SCANNING LOSS IS IMPORTANT FOR RAPID- SCAN ANTENNAS OR VERY LONG RANGE RADARS.



LIMITING LOSS

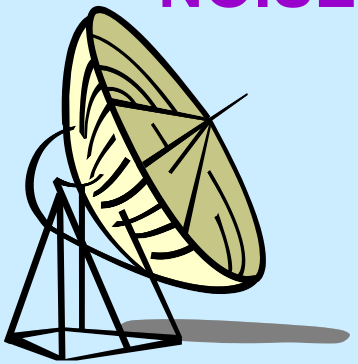
- LIMITING IN RADAR RX CAN LOWER THE PROBABILITY OF DETECTION.

- SOME SPECIAL PURPOSE RX'S DO USE LIMITING (EX-FOR PULSE COMPRESSION).

- LIMITING LOSS= FRACTION OF A DB.

COLLAPSING LOSS

- THIS LOSS RESULTS WHEN RADAR INTEGRATES ADDITIONAL NOISE SAMPLES ALONGWITH WANTED (S/N) PULSES.
- IT ALSO HAPPENS WHEN O/P OF TWO RADAR RX’S ARE COMBINED AND ONLY ONE CONTAINS SIGNAL AND OTHER CONTAINS NOISE.



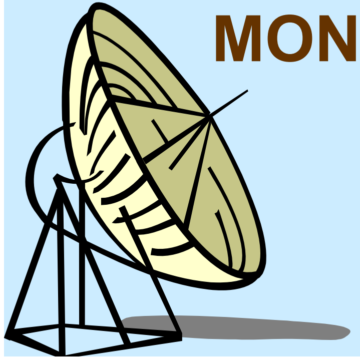
STRADLING LOSS

- IN RANGE GATE TRACKING:
- GATES MAY BE WIDER THAN THE OPTIMUM.
- TARGETS MAY NOT BE AT THE CENTRE OF RANGE GATES.
- THESE TWO FACTORS INTRODUCE ADDITIONAL NOISE AND HENCE DEGRADATION IN PERFORMANCE.

FIELD DEGRADATION = 3 dB

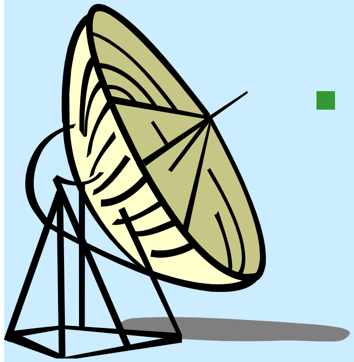
FACTORS CONTRIBUTING TO FIELD DEGRADATION

- POOR TUNING
- WEAK TUBES
- WATER IN TRANSMISSION LINES
- INCORRECT MIXER- CRYSTAL CURRENT
- POOR RECEIVER NOISE FIGURE
- LOOSE CABLE CONNECTION ETC
  - REMEDY: BUILT IN AUTOMATIC PERFORMANCE MONITORING EQUIPMENT.



NON-IDEAL EQUIPMENT

- POOR QUALITY TRANSMITTING TUBES
- TRANSMITTER POWER DIFFERS FROM DESIGN VALUE(=2 dB)
- VARIATION IN RECEIVER NOISE FIGURE
  - NON- MATCHED FILTER (=1 dB)

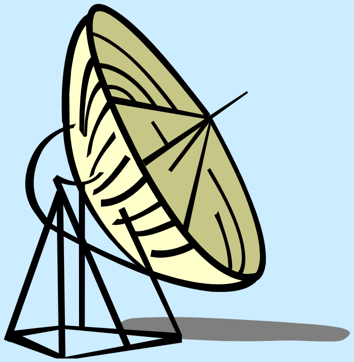


OPERATOR LOSS

- OPERATOR EFFICIENCY FACTOR $p_0=0.7(P_d)^2$

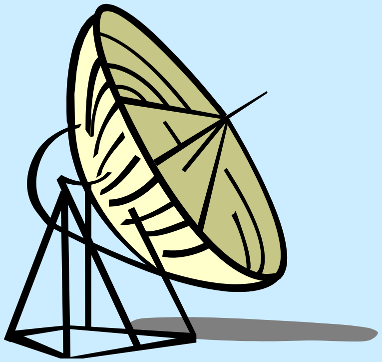
P_d =SINGLE SCAN PROB. OF DETECTION.

- OPERATOR SHOULD BE FULLY TRAINED TO CORRECT ANY LOSS IN OPERATOR PERFORMANCE.



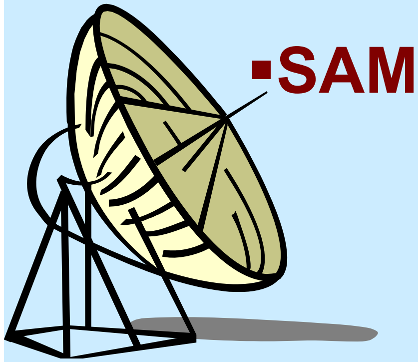
SYSTEM LOSSES

- LOSS DUE TO INTEGRATION OF PULSES.
- MICROWAVE PLUMBING LOSS.
- TRANSMISSION LINE LOSS. (1.4 - 2.08 Db/100 ft.)
- LOSS DUE TO TARGET CROSS SECTION FLUCTUATIONS.
- DUPLEX LOSS. (≈ 2dB).
    - ANTENNA LOSSES.
    - BEAM SHAPE LOSS.
    - SCANNING LOSS.
    - RADOME LOSS (1.2 Db).
    - PHASED ARRARY LOSS



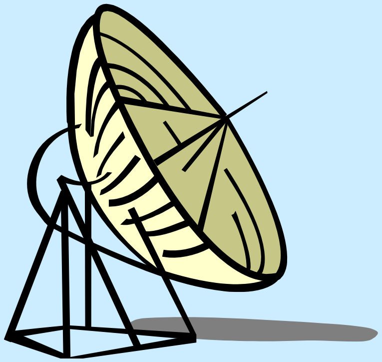
SYSTEM LOSSES

- SIGNAL PROCESSING LOSS
- NON MATCHED FILTERS (.5dB-1dB)
- CFAR RECEIVER (2dB)
- AUTOMATIC INTEGRATORS (1.5dB-2dB)
- THRESHOLD SETTING (FRACTION OF A dB)
- LIMITTING LOSS (1 dB)
- STRADLING LOSS (RANGE)
  - SAMPLING LOSS (≈2dB)



SYSTEM LOSSES

- COLLAPSING LOSS
- LOSSES IN DOPPLER PROCESSING RADAR
- EQPT DEGRADATION (1dB-3dB)
- PROPOGATION EFFECTS
- ECLIPSING LOSS



SYSTEM LOSSES

- MICROWAVE PLUMBING LOSS
  - TRANSMISSION LINE LOSS

FREQUENCY BAND	ATTENUATION dB/100ft LOWEST TO HIGHEST FREQUENCY
L	·201 - ·136
S	1·102 - ·752
C	2·08 - 1·44
X	6·45 - 4·48
KU	9·51 - 8·31

SYSTEM LOSSES

- DUPLEXER LOSS : 2dB APPROX.

EXAMPLE : S BAND (3GHZ) RADAR

TWO WAY MICROWAVE PLUMBING LOSS.

100 ft (WAVE GUIDE)	1.0dB
DUPLEXER	2.0dB
ROTARY POINT	0.8dB
CONNECTORS, BENDS & OTHER RF DEVICES	0.7dB

TOTAL	4.5dB

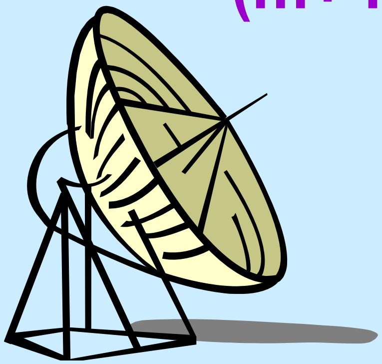
SYSTEM LOSSES

COLLAPSING LOSS : (LC)

THIS LOSS IS THE DEGRADATION THAT RESULTS WHEN RADAR INTEGRATES ADDITIONAL NOISE PULSES ALONG WITH SIGNAL PLUS – NOISE PULSES.

$$Lc\ (m, n) = \boxed{\frac{Li\ (m+n)}{Li\ (n)}}$$

WHERE Li (m+ n) = INTERNAL LOSS FOR (m+ n) PULSES.



Li (n) = INTERNAL LOSS FOR n PULSES.

m = NOISE PULSES

N = SIGNAL TO NOISE PULSES

SYSTEM LOSSES

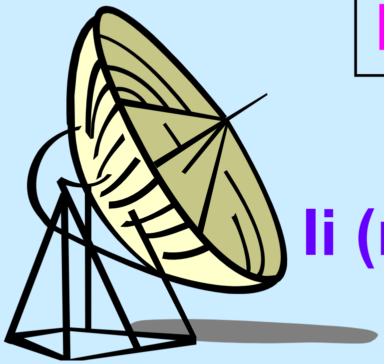
INT LOSS (Li) = $\boxed{10 \log \left\{ 1/ Ei\ (n) \right\}}$

WHERE Ei = INTEGRATION EFFICIENCY (POST DETECTION)

$$Ei\ (n) = \boxed{\frac{\text{(S/N) RATIO PER PULSE}}{\text{REQUIRED (S/N) RATIO PER PULSE}}}$$

WHEN n PULSES ARE INTEGRATED

PREDETECTION INFORMATION LOSS

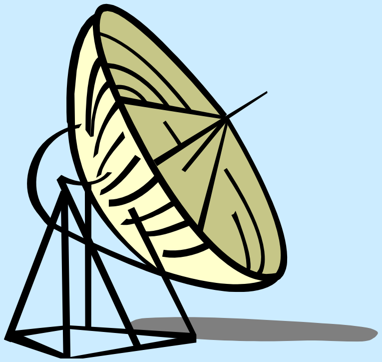


Ii (n) = INT IMPROVEMENT FACTOR

= n Ei (n)

SYSTEM LOSSES

NOTE : FOR SAME INTEGRATED SIGNAL TO NOISE RATIO ; POST DETECTION INTEGRATION REQUIRES MORE PULSES THAN PRE – DETECTION; ASSUMING THE SIGNAL –TO-NOISE RATIO PER PULSE IN THE TWO CASES IS THE SAME.

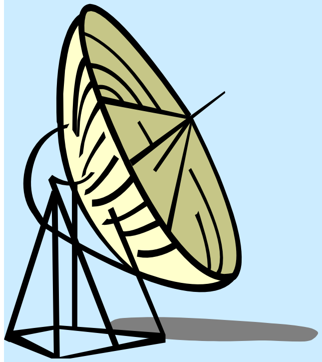


PROPOGATION EFFECTS

PROPOGATION EFFECTS CAN INCREASE / DECREASE THE FREE SPACE RANGE.

FACTORS – PROPOGATION

- REFLECTION FROM EARTH'S SURFACE.(FORWARD SCATTERING)
- REFRACTION INCREASES THE RANGE
- DUCT PROPOGATION INCREASES THE RANGE



- PROPOGATION EFFECTS ARE ACCOUNTED FOR SEPARATELY AND ARE NOT CONSIDERED A PART OF THE SYSTEM LOSSES.

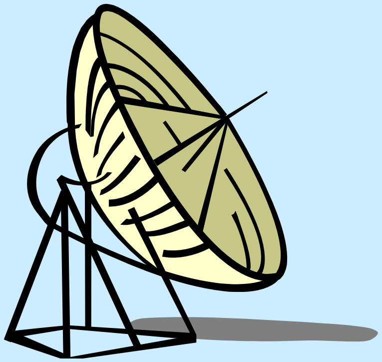
PROPOGATION EFFECTS

F^4, THE PROPOGATION FACTOR INCLUDES THE EFFECT OF LOBING OF ELEVATION ANT PATTERN , DUE TO REFLECTION FROM EARTH'S SURFACE AND OTHER FACTORS EXCEPT ATTENUATION.

DIFFRACTION – (APPLIES AT LF- SDDOM USED FOR RADAR APPLICATIONS)

ATTENUATION – (LITTLE EFFECT ON MW PROPOGATION)

EXTERNAL NOISE – INCREASE THE Rx NOISE LEVEL (HOSTILE JAMMING)

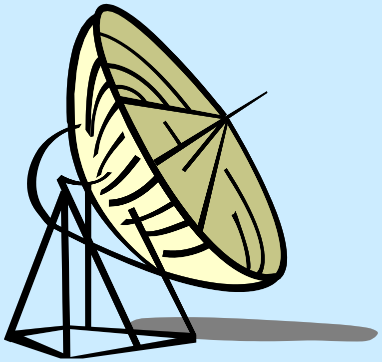


PROPOGATION EFFECTS

ATMOSPHERE LENS – EFFECT LOSS

THE VARIATION OF REFRACTIVEINDEX WITH ATTITUDE CAUSES THE ATMOSPHERE TO ACT AS A

-VE LENS THAT DECREASES THE RADIATED ENERGY INCIDENT ON A TARGET.

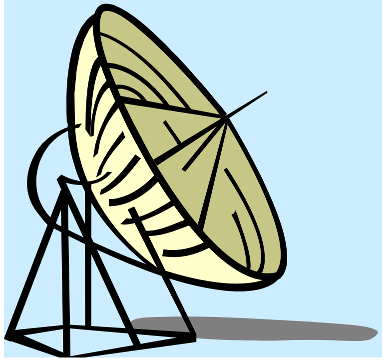


FARADAY ROTATION OF POLARISATION:

(α 1 / f^2)

PROPAGATION EFFECTS

- DECREASING DENSITY OF THE ATMOSPHERE WITH INCREASING ALTITUDE RESULTS IN BENDING OR REFRACTION OF RADAR WAVES.
- BENDING USUALLY RESULTS IN AN INCREASE IN THE RADAR LOS. THIS IS EQUIVALENT TO EARTH HAVING 4/3 TIMES ITS ACTUAL RADIUS .



PROPAGATION EFFECTS

EFFECT OF NON – FREE – SPACE PROPAGATION

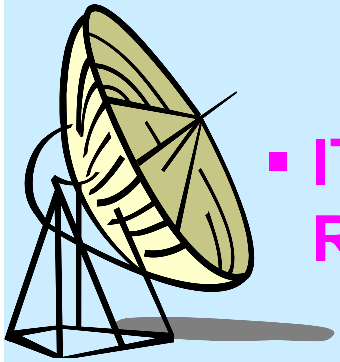
- ATTENUATION OF RADAR WAVES THROUGH ATMOSPHERE.
- REFRACTION OF RADAR WAVES BY EARTH'S ATMOSPHERE.

  LOBE STRUCTURE DUE TO INTERFERENCE BETWEEN DIRECT WAVE AND REFLECTED WAVE FROM GROUND .

SUPER- REFRACTION / DUCTING

- RADAR RANGE GETS CONSIDERABLY INCREASED DUE TO SUPER REFRACTION / DUCTING.

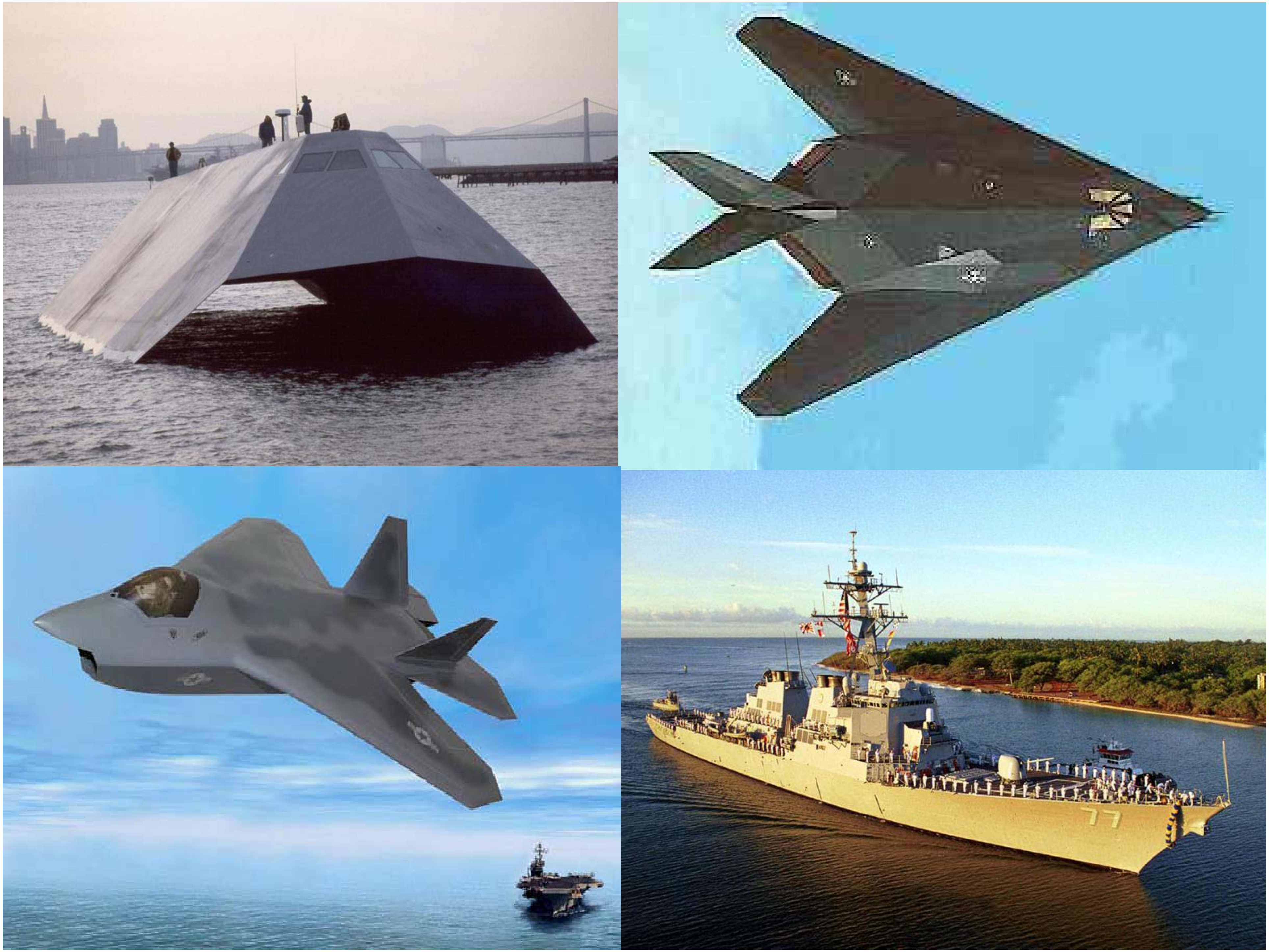
- DUCT IS FORMED WHEN UPPER AIR IS WARM AND DRY IN COMPARISON WITH AIR AT SURFACE .
    - TEMP INVERSION – TEMP INCREASES WITH HEIGHT



    - IT DEGRADES THE PERFORMANCE OF MTI RADAR (CLUTTER SEEN AT EXTENDED RANGE)

EFFECT OF REFLECTION FROM EARTH'S SURFACE

- ENERGY PROPAGATES DIRECTLY FROM RADAR TO TARGET.
- ENERGY ALSO TRAVELS TO TARGET VIA A PATH THAT INCLUDES A REFLECTION FROM GROUND.
  - THE DIRECT AND GROUND REFLECTED WAVES INTERFERE AT TGT CONSTRUCTIVELY OR DESTRUCTIVELY TO PRODUCE REINFORCEMENT OR NULLS.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