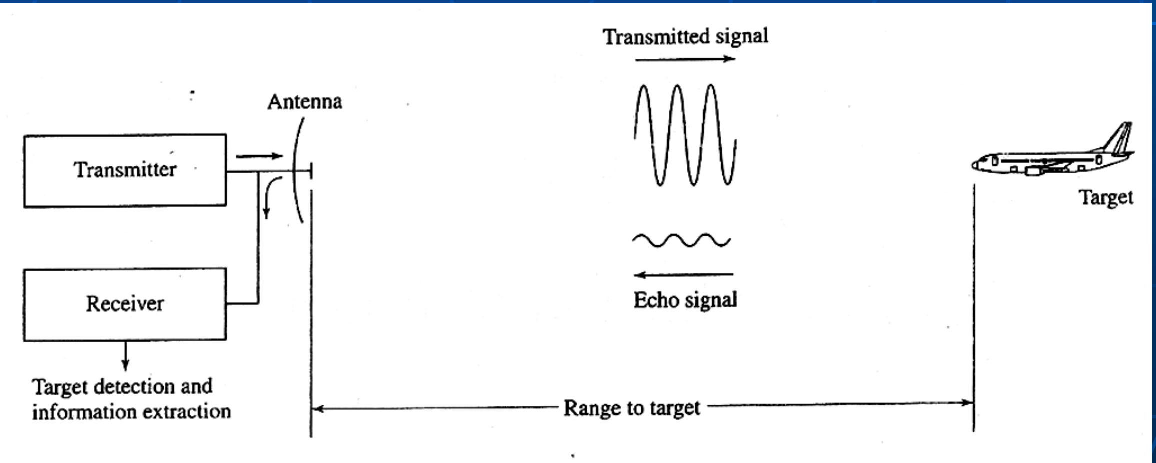
# RADAR AND NAVIGATIONAL AIDS

# What is RADAR?

- The word radar is an abbreviation for RAdio Detection And Ranging
- Radar is an **electromagnetic systems** used for **detection and location of objects** such as aircraft, ship, vehicles, people, natural environment etc.
- Radar systems use modulated waveforms and directive antennas to **transmit electromagnetic energy** into a specific volume in space to search for targets.
- Objects (targets) within a search volume will **reflect portions of this energy** (radar returns or echoes) back to the radar.
- **These echoes** are then processed (Afterwards they are called as **video signals**) by the radar receiver to extract target information such as **range, velocity, angular position,** and other target identifying characteristics.

# Radar Principles

- Transmitter generates and transmits electromagnetic wave (sine or pulse).
- A portion of it is reflected back by the target (object you want to identify).
- The radiated portion is collected by the radar antenna and processed.
- One antenna can be used for both transmission and reception.



Basic principle of radar.

# RADAR BLOCK DIAGRAM AND OPERATION

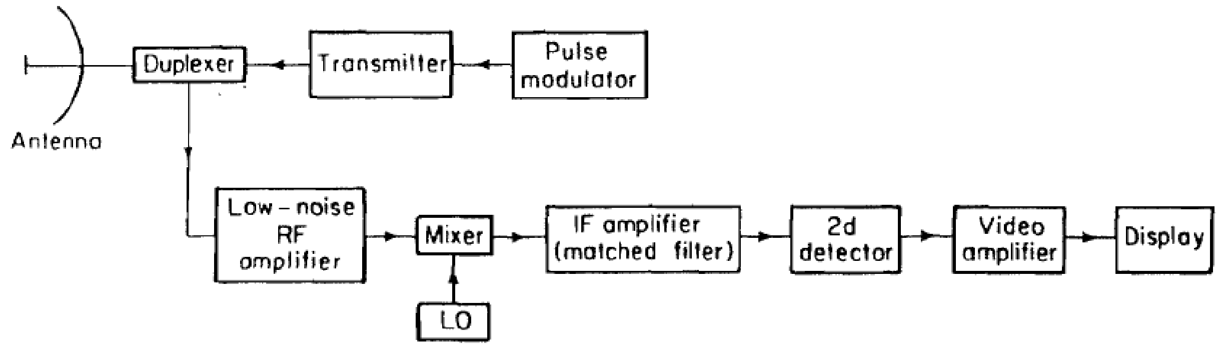



**Figure 1.2** Block diagram of a pulse radar.

- transmitter - oscillator, - magnetron, -" pulsed"-(turned on and on) by the modulator to generate a repetitive train of pulses.
- Example: to detect aircraft at ranges of 100 or 200 nmi you need
    - peak power of the order of a megawatt,
    - a pulse width of several microseconds,
    - pulse repetition frequency of several hundred pulses per second.
- The waveform generated by the transmitter travels via a transmission line to the antenna, where it is radiated into space.
- A single antenna is generally used for both transmitting and receiving.

# Duplexer

- The duplexer protects the receiver from high transmission power.
- consist of two gas-discharge devices, one known as a TR (transmit-receive) and the other an ATR

(anti-transmit-receive).

- The TR protects the receiver during transmission and the ATR directs the echo signal to the receiver during reception.
- Solid-state ferrite circulators and receiver protectors with gas-plasma TR devices and/or diode limiters are also employed as duplexers.

# Receiver

- The receiver is usually of the **superheterodyne type.**
- The first stage **low-noise RF amplifier**, such as a **parametric amplifier or a low-noise transistor.**
- The mixer and local oscillator (LO) convert the RF signal to an intermediate frequency(IF).
  - A typical" IF amplifier for an air-surveillance radar might have a center frequency of 30 or 60 MHz and a bandwidth of the order of one megahertz.
- The IF amplifier should be designed **as a matched filter** - frequency-response function - maximize the
  - sigtial-to-mean-noise-power ratio
- This occurs when the
  - magnitude of the frequency-response function = the magnitude of the echo signal spectrum
  - the phase spectrum of the matched filter = negative of the phase spectrum of the echo signal
- In a radar whose signal waveform approximates a rectangular pulse, the conventional IF filter bandpass characteristic approximates a matched filter when the product of the IF bandwidth B and the pulse width r is of the order of unity, that is, Br=- 1.

# $2^{nd}$ Detector & Display

- Demodulates the pulse modulation
- Amplified by the video amplifier
- Displayed on a CRT- This is a special CRT called PPI-plan position indicator

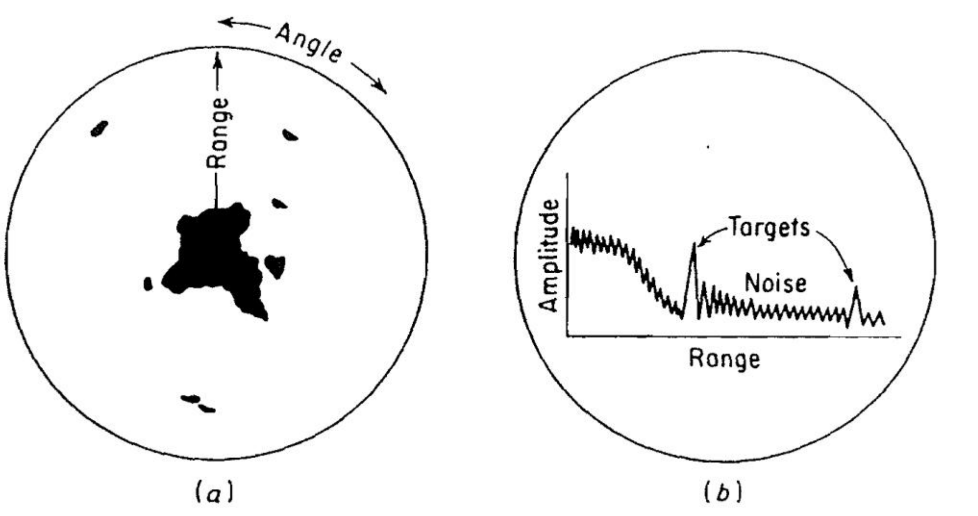



**Figure 1.3** (*a*) **PPI** presentation displaying range vs. angle (intensity modulation); (*b*) A-scope presentation displaying amplitude vs. range (deflection modulation).

# Display

- The most common form of cathode-ray tube display is the **plan position indicator, or PPI** which **maps in polar coordinates** the location of the target in azimuth and range.
- This is an intensity-modulated display in which the amplitude of the receiver output modulates the electron-beam intensity (z axis) as the electron beam is made to sweep outward from the center of the tube.
- The beam rotates in angle in response to the antenna position.
- **B-scope display** is similar to the PPI except that it utilizes **rectangular**, rather than polar, coordinates to display range vs. angle.
- Both the B-scope and the PPI, being intensity modulated, have limited dynamic range.
- **A Scope-** which plots target .amplitude axis) vs. range axis), for some fixed direction. This is a deflection-modulated display. It is more suited for tracking-radar application than for surveillance radar.

# Radar Frequencies

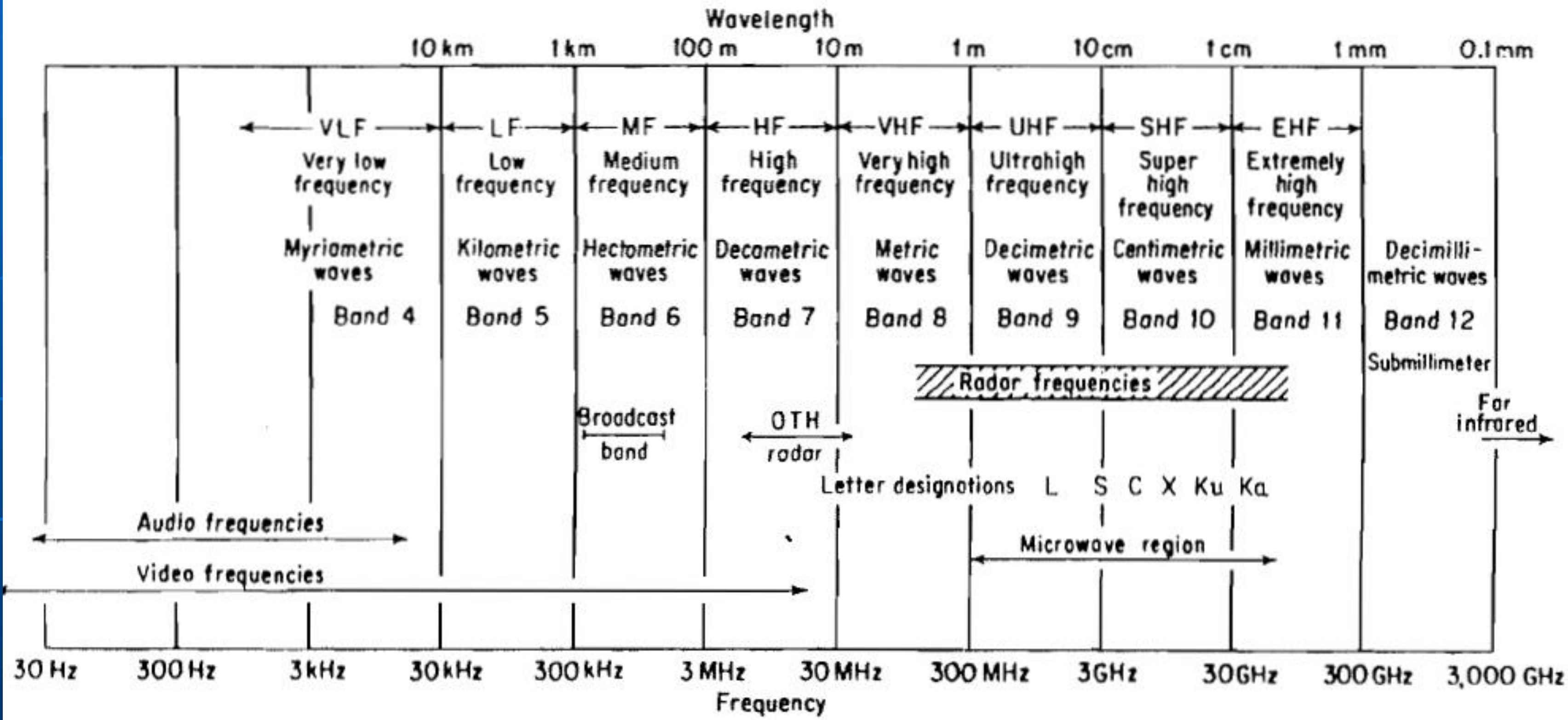



**Figure 1.4** Radar frequencies and the electromagnetic spectrum.

# Applications of Radar

Table 2.2 Radar Band Characteristics and Applications

| *Frequency Band* | *Characteristics* | *Applications* |
| --- | --- | --- |
| HF | Reflects off ionosphere | OTH radar |
| VHF, UHF | Very large antennas<br>Ionosphere distorts propagation | Search radar |
| UHF, L | Large antennas | Search radar |
| S, C | Moderate size antennas<br>Moderate measurement precision | Multifunction radar |
| X, $K_U$, K | Small antennas<br>Precision measurement | Tracking radar<br>Airborne radar |
| $K_U$, K, $K_A$ | Very small antennas<br>Good measurement precision<br>Atmospheric and rain loss | Short-range radar<br>Precision-guidance radar |
| V, W, and millimeter | Severe atmospheric and rain loss | Space-to-space radar |

- Air Traffic control
- Aircraft navigation
- Ship safety
- Remote Sensing
- Law enforcement
- Military

# Range- Distance from you and the target!

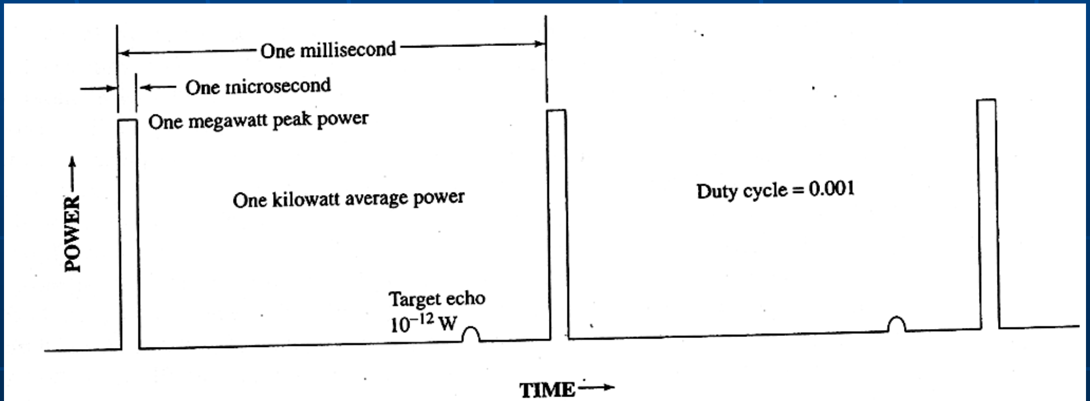
- The range of the object is found by the time the pulse takes to travel to and from the detected object

**Range to a Target** The most common radar signal, or waveform, is a series of short-duration, somewhat rectangular-shaped pulses modulating a sinewave carrier. (This is sometimes called a *pulse train.*) The range to a target is determined by the time $T_R$ it takes the radar signal to travel to the target and back. Electromagnetic energy in free space travels with the speed of light, which is $c = 3 \times 10^8$ m/s. Thus the time for the signal to travel to a target located at a range $R$ and return back to the radar is $2R/c$. The range to a target is then

$$R = \frac{cT_R}{2} \qquad [1.1]$$

# Maximum unambiguous range

- We send a train of pulses. Not a single pulse. A pulse is sent and reflected back as echo
- We have to wait to get for the echo before we send the next one
- If not the echo for the first pulse we sent will become echo for the second one. This is called second time around pulse
- Due to this the target may look near (as you get the echo immediately for the send pulse: this echo was for the first pulse!!!!)
- So the pulse repetition frequency (PRF) is important and it determines the maximum unambiguous range
  - $R_{un} = cTp/2 = c/ 2fp$



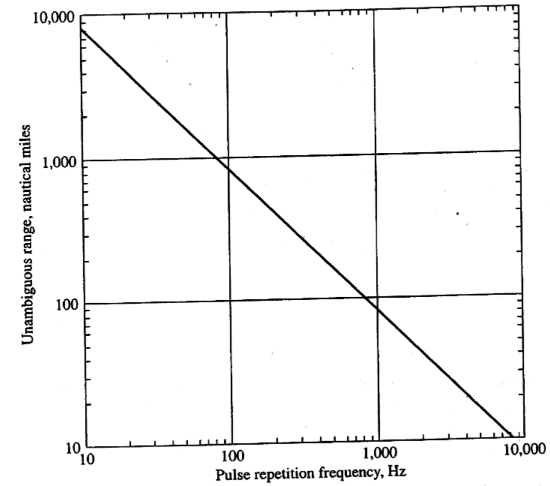




**Figure 1.2** Plot of Eq. (1.2), the maximum unambiguous range $R_{un}$ as a function of the pulse repetition frequency $f_p$.

# To increase the range

- Transmitted power is increased
- Gain of the antenna should be high
- Large antenna for reception
- The receiver should be sensitive to weak signals (should pick them)
- **Range equation** is an important derivation we are going to do to calculate the range.

# Radar Equation

- The radar equation relates the range of a radar to the characteristics of the transmitter, receiver, antenna, target, and environment.
- It is useful for determining the maximum distance from the radar to the target
- it can serve both as a tool for understanding radar operation and as a basis for radar design.
- However it **cannot give the precise value**. Why??
  - **Statistical nature of noise and signal**
  - **Fluctuation & uncertainty of the target**
  - **Propagation effect of the wave**
  - **Losses**
- Are affecting the calculation
- We will consider each one separately.

If the power of the radar transmitter is denoted by $P_t$, and if an isotropic antenna is used (one which radiates uniformly in all directions), the *power density* (watts per unit area) at a distance $R$ from the radar is equal to the transmitter power divided by the surface area $4\pi R^2$ of an imaginary sphere of radius $R$, or

$$\text{Power density from isotropic antenna} = \frac{P_t}{4\pi R^2} \tag{1.3}$$

Radars employ directive antennas to channel, or direct, the radiated power $P_t$ into some particular direction. The *gain* $G$ of an antenna is a measure of the increased power radiated in the direction of the target as compared with the power that would have been radiated from an isotropic antenna. It may be defined as the ratio of the maximum radiation intensity from the subject antenna to the radiation intensity from a lossless, isotropic antenna with the same power input. (The radiation intensity is the power radiated per unit solid angle in a given direction.) The power density at the target from an antenna with a transmitting gain $G$ is

$$\text{Power density from directive antenna} = \frac{P_t G}{4\pi R^2} \tag{1.4}$$

The measure of the amount of incident power intercepted by the target and reradiated back in the direction of the radar is denoted as the radar cross section $\sigma$, and is defined by the relation

$$\text{Power density of echo signal at radar} = \frac{P_t G}{4\pi R^2} \frac{\sigma}{4\pi R^2} \tag{1.5}$$

The radar cross section $\sigma$ has units of area. It is a characteristic of the particular target and is a measure of its size *as seen by the radar*. The radar antenna captures a portion of the echo power. If the effective area of the receiving antenna is denoted $A_e$, the power $P_r$ received by the radar is

$$P_r = \frac{P_t G}{4\pi R^2} \frac{\sigma}{4\pi R^2} A_e = \frac{P_t G A_e \sigma}{(4\pi)^2 R^4} \tag{1.6}$$

The maximum radar range $R_{max}$ is the distance beyond which the target cannot be detected. It occurs when the received echo signal power $P_r$ just equals the minimum detectable signal $S_{min}$. Therefore

$$R_{max} = \left[ \frac{P_t G A_e \sigma}{(4\pi)^2 S_{min}} \right]^{1/4} \tag{1.7}$$

This is the fundamental form of the radar equation. Note that the important antenna parameters are the transmitting gain and the receiving effective area.

Antenna theory gives the relationship between the transmitting gain and the receiving effective area of an antenna as

$$G = \frac{4\pi A_e}{\lambda^2} \tag{1.8}$$

Since radars generally use the same antenna for both transmission and reception, Eq. (1.8) can be substituted into Eq. (1.7), first for $A_e$ then for $G$, to give two other forms of the radar equation

$$R_{\max} = \left[\frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 S_{\min}}\right]^{1/4} \tag{1.9}$$

$$R_{\max} = \left[\frac{P_t A_e^2 \sigma}{4\pi \lambda^2 S_{\min}}\right]^{1/4} \tag{1.10}$$

These three forms (Eqs. 1.7, 1.9, and 1.10) illustrate the need to be careful in the interpretation of the radar equation. For example, from Eq. (1.9) it might be thought that the range of a radar varies as $\lambda^{1/2}$, but Eq. (1.10) indicates a $\lambda^{-1/2}$ relationship, and Eq. (1.7) shows the range to be independent of $\lambda$. The correct relationship depends on whether it is assumed the gain is constant or the effective area is constant with wavelength. Furthermore, the introduction of other constraints, such as the requirement to scan a specified volume in a given time, can yield a different wavelength dependence.

# The Radar Equation- Considerations of various parameters

- As I pointed out earlier there are many factors which we have to consider in the range equation. They affect the calculation.
- But we can model them and mathematically find the model and insert in the range equation.
- Noise is in the system and it is random. So we have to have probability.
- If affects the detection. So we have to get SNR
- Pulse repetition frequency
- Cross section of the target exposed to the wave we send

# Detection of Signals in Noise
(MINIMUM DETECTABLE SIGNAL)

- Noise affects the systems
- The weakest signal which can be detected by radar is called as minimum detectable signal and it is included in the radar equation.

> target is present

**-----→ received signal-----→ Threshold--→**

< target is absent

- This is called threshold detection

# Threshold detection: two problems

- **false alarm:** if the threshold is set as low then the noise may be detected as target
- **Missed detection:** If the threshold is set high then real target will be missed.
  - However we use matched filter which will increase the SNR.
  - So we conclude that SNR is an important factor and more analysis is needed.

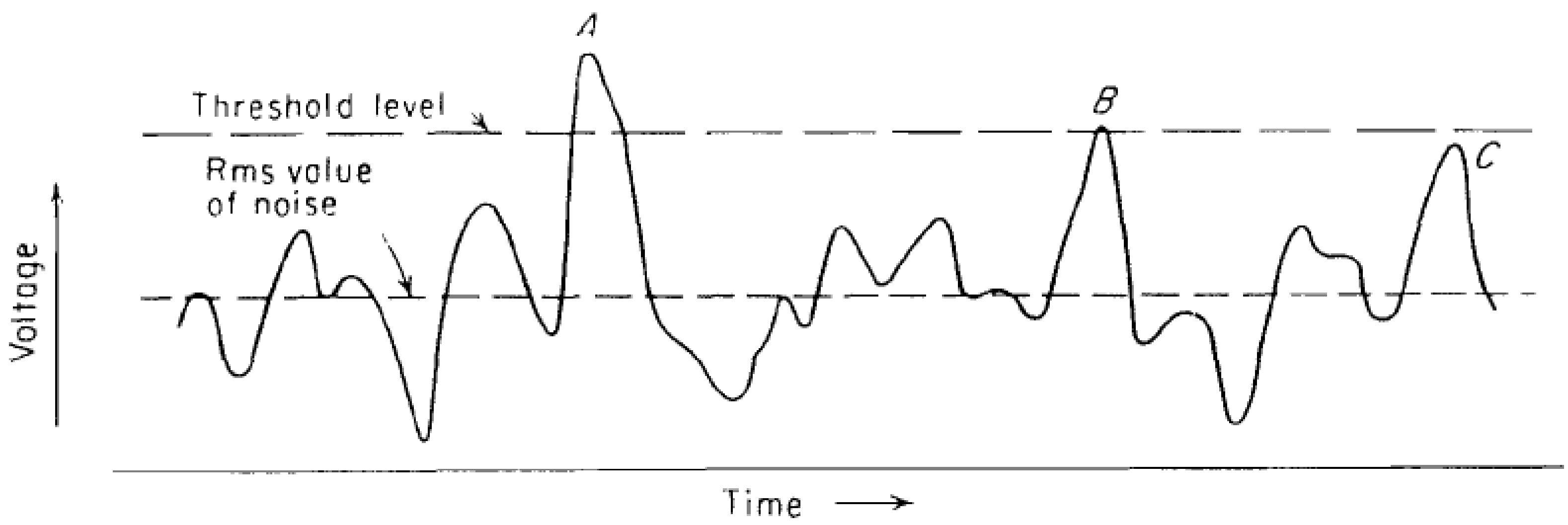



**Figure 2.1** Typical envelope of the radar receiver output as a function of time. *A*, and *B*, and *C* represent signal plus noise. *A* and *B* would be valid detections, but *C* is a missed detection.

# Receiver Noise and the Signal-to-Noise Ratio

- My aim is to find $S_{min}$ and **insert it in the radar equation**
- Most receivers are super heterodyne.
- The noise is mostly internal. It is thermal or Johnson noise. Its value is 1.38 X $10^{-23}$ J/deg. Noise figure is to be derived and defined below

$$F_n = \frac{\text{noise out of practical receiver}}{\text{noise out of ideal receiver at std temp } T_0} = \frac{N_{out}}{kT_0BG_a} \quad [2.4]$$

where $N_{out}$ = noise out of the receiver, and $G_a$ = available gain. The noise figure is defined in terms of a standard temperature $T_0$, which the IEEE defines as 290 K (62°F). This is close to room temperature.

The available gain $G_a$ is the ratio of the signal out, $S_{out}$, to the signal in, $S_{in}$, with both the output and input matched to deliver maximum output power. The input noise, $N_{in}$, in an ideal receiver is equal to $kT_0B_n$. The definition of noise figure given by Eq. (2.4) therefore can be rewritten as

$$F_n = \frac{S_{in}/N_{in}}{S_{out}/N_{out}} \quad [2.5]$$

This equation shows that the noise figure may be interpreted as a measure of the degradation of the signal-to-noise ratio as the signal passes through the receiver.

Rearranging Eq. (2.5), the input signal is

$$S_{in} = \frac{kT_0BF_nS_{out}}{N_{out}} \quad [2.6]$$

If the minimum detectable signal $S_{min}$ is that value of $S_{in}$ which corresponds to the minimum detectable signal-to-noise ratio at the output of the IF, $(S_{out}/N_{out})_{min}$, then

$$S_{min} = kT_0BF_n\left(\frac{S_{out}}{N_{out}}\right)_{min} \qquad [2.7]$$

Substituting the above into Eq. (2.1), and omitting the subscripts on $S$ and $N$, results in the following form of the radar equation:

$$R^4_{max} = \frac{P_tGA_e\sigma}{(4\pi)^2kT_0BF_n(S/N)_{min}} \qquad [2.8]$$

For convenience, $R_{max}$ on the left-hand side is usually written as the fourth power rather than take the fourth root of the right-hand side of the equation.

The minimum detectable signal is replaced in the radar equation by the *minimum detectable signal-to-noise ratio* $(S/N)_{min}$. The advantage is that $(S/N)_{min}$ is independent of the receiver bandwidth and noise figure; ... it can be expressed in terms of the probability of detection and the probability of false alarm, two parameters that can be related to the radar user's needs.

# Probabilities of Detection

# and Probability of False Alarm

**Probability of False Alarm** The receiver noise at the input to the IF filter (the terms *filter* and *amplifier* are used interchangeably here) is described by the gaussian probability density function with mean value of zero,

$$p(v) = \frac{1}{\sqrt{2\pi\Psi_0}} \exp\left(-\frac{v^2}{2\Psi_0}\right) \tag{2.20}$$

where $p(v)\,dv$ is the probability of finding the noise voltage $v$ between the values of $v$ and $v + dv$ and $\Psi_0$ is the mean square value of the noise voltage (mean noise power). S. O. Rice has shown in a *Bell System Technical Journal* paper[9] that when gaussian noise is passed through the IF filter, the probability density function of the envelope $R$ is given by a form of the Rayleigh pdf:

$$p(R) = \frac{R}{\Psi_0} \exp\left(-\frac{R^2}{2\Psi_0}\right) \tag{2.21}$$

The probability that the envelope of the noise voltage will exceed the voltage threshold $V_T$ is the integral of $p(R)$ evaluated from $V_T$ to $\infty$, or

$$\text{Probability } (V_T < R < \infty) = \int_{V_T}^{\infty} \frac{R}{\Psi_0} \exp\left(-\frac{R^2}{2\Psi_0}\right) dR = \exp\left(\frac{-V_T^2}{2\Psi_0}\right) \tag{2.22}$$

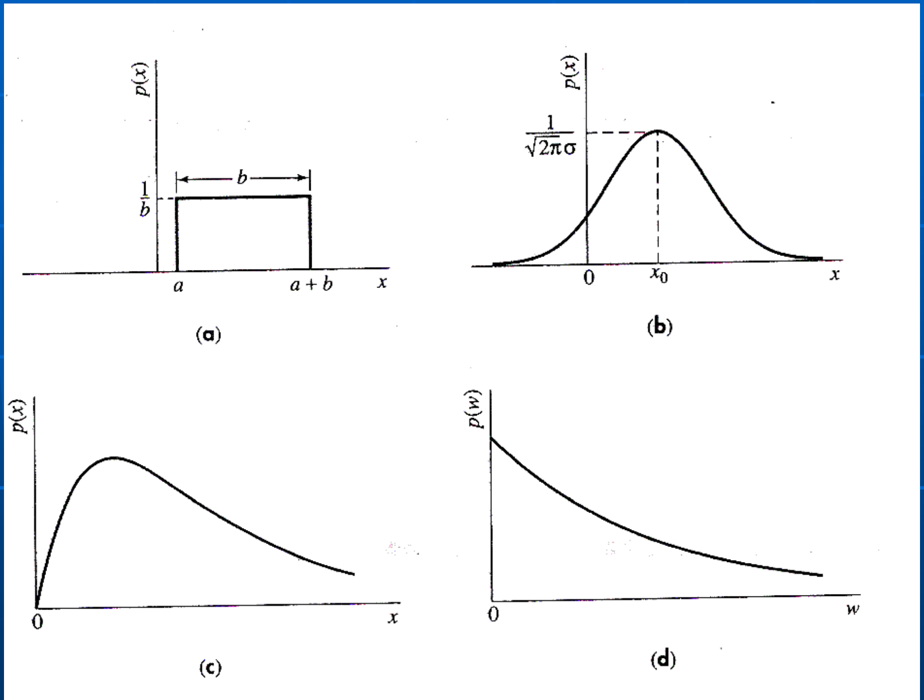
This is the *probability of a false alarm* since it represents the probability that noise will cross the threshold and be called a target when only noise is present. Thus, the probability of a false alarm, denoted $P_{fa}$, is

$$P_{fa} = \exp\left(-\frac{-V_T^2}{2\Psi_0}\right) \tag{2.23}$$

By itself, the probability of false alarm as given by Eq. (2.23) does not indicate whether or not a radar will be troubled by excessive false indications of targets. The time between false alarms is a better measure of the effect of noise on radar performance.

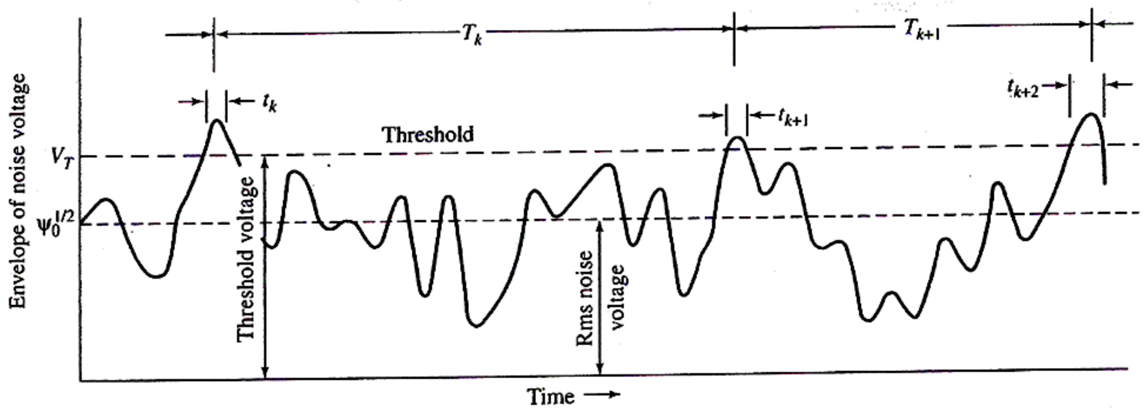
# Probability Density Functions

- Below are some of the probability density functions we use in the radar.




- Examples of PDFs: a: Uniform b: Gaussian c: Raleigh voltage d: Exponential(Raleigh power)

# False alarm time



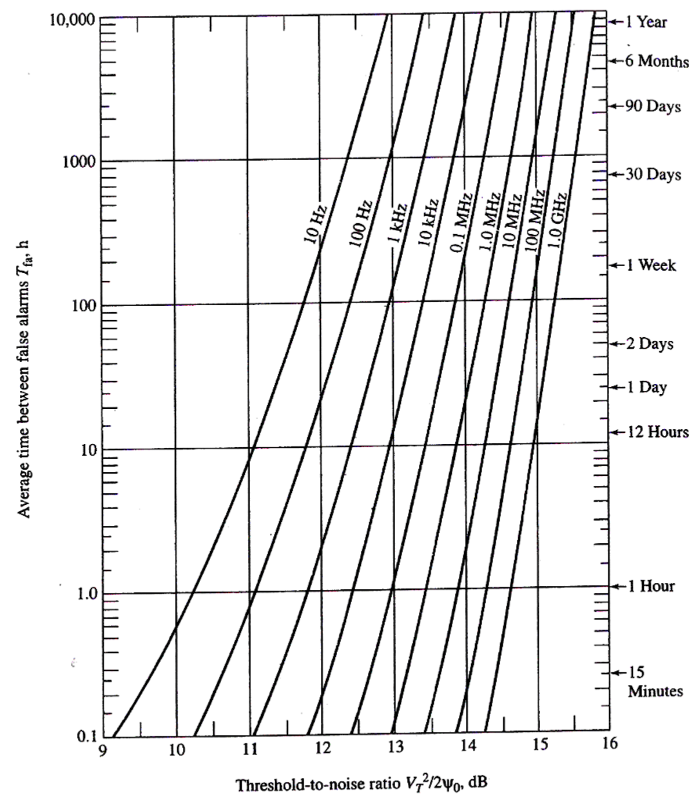

Envelope of the receiver output with noise alone, illustrating the duration of false alarms and the time between false alarms.

Figure illustrates the occurrence of false alarms. The average time between crossings of the decision threshold when noise alone is present is called the *false-alarm time*, $T_{fa}$, and is given by

$$T_{fa} = \lim_{N \to \infty} \frac{1}{N} \sum_{k=1}^{N} T_k \qquad [2.24]$$

where $T_k$ is the time between crossings of the threshold $V_T$ by the noise envelope. The false-alarm time is something a radar customer or operator can better relate to than the probability of false alarm. The false-alarm probability can be expressed in terms of false-alarm time by noting that the false-alarm probability $P_{fa}$ is the ratio of the time the envelope is actually above the threshold to the total time it could have been above the threshold, or

$$P_{fa} = \frac{\sum_{k=1}^{N} t_k}{T_{fa}} = \frac{\langle t_k \rangle_{av}}{T_{fa}} = \frac{1}{T_{fa} B} \qquad [2.25]$$



# Will false alarm affect our detection?

The false-alarm probabilities of radars are generally quite small since a decision as to whether a target is present or not is made every $1/B$ second. The bandwidth $B$ is usually large, so there are many opportunities during one second for a false alarm to occur. For example, when the bandwidth is 1 MHz (as with a 1-$\mu$s pulse width) there are 1 million decisions made every second as to whether noise or signal plus noise is present. If there were to be, on average, one false alarm per second, the false-alarm probability would be $10^{-6}$ in this specific example.

# Integration of Radar Pulses

- This is the method of using **more than one pulse in detection**
- Using n pulses instead of **one pulse** increases the SNR

The number of pulses returned from a point target by a scanning radar with a pulse repetition rate of $f_p$ Hz, an antenna beamwidth $\theta_B$ degrees, and which scans at a rate of $\dot{\theta}_s$ degrees per second is

$$n = \frac{\theta_B f_p}{\dot{\theta}_s} = \frac{\theta_B f_p}{6\omega_r} \qquad [2.31]$$

where $\omega_r$ = revolutions per minute (rpm) if a 360° rotating antenna. The number of pulses received $n$ is usually called *hits per scan* or *pulses per scan*. It is the number of pulses within the one-way beamwidth $\theta_B$. Example values for a long-range ground-based air-surveillance radar might be 340-Hz pulse repetition rate, 1.5° beamwidth, and an antenna rotation rate of 5 rpm (30°/s). These numbers, when substituted into Eq. (2.31), yield $n = 17$ pulses per scan.

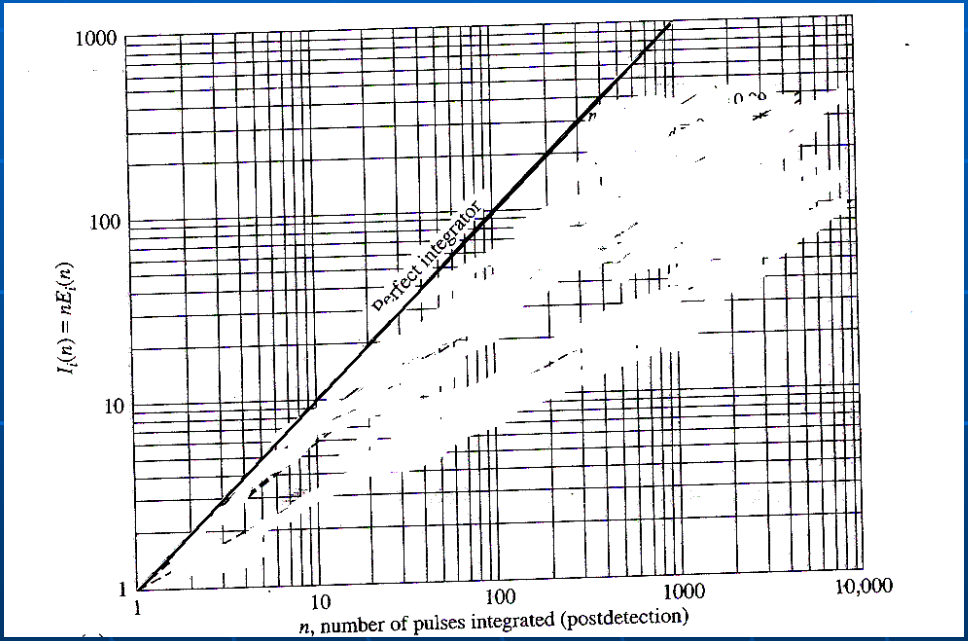
The process of summing all the radar echoes available from a target is called *integration* (even though an *addition* is actually performed).

If $n$ pulses, all of the same signal-to-noise ratio, were perfectly integrated by an ideal lossless predetection integrator, the integrated signal-to-noise (power) ratio would be exactly $n$ times that of a single pulse.

# Fitting the gain we got into radar equation

This is the efficiency we gain

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




- Note: We have two levels of detection one is called predetection and other is post detection.
- This integration of pulses give more efficiency in predetection.

Previously the radar equation was

$$R^4_{\max} = \frac{P_t G A_e \sigma}{(4\pi)^2 k T_0 B F_n (S/N)_{\min}}$$

Now substituting we get

$$R^4_{\max} = \frac{P_t G A_e \sigma n E_i(n)}{(4\pi)^2 k T_0 B F_n (S/N)_1}$$

# Radar Cross Section of Targets

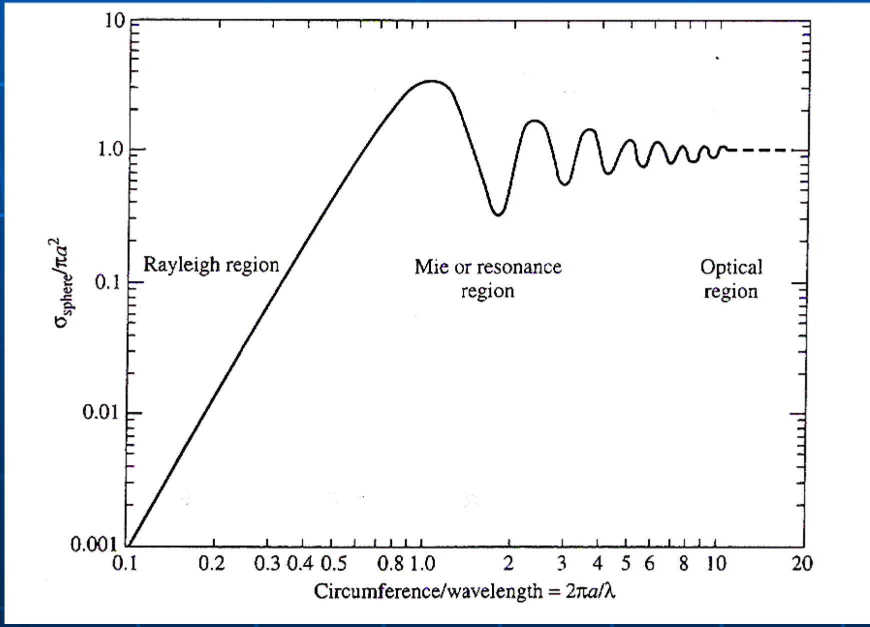
- **σ** is the radar cross section.
- It is the area covered and it will be proportional to the magnitude wave reflected. So we can define this parameter in dB
- Since the wave is covering a volume/ area we can define this parameter as

$$\sigma = \frac{power\_reflected}{power\_incident / 4\pi} = 4\pi R^2 \mid E_r \mid^2$$

- This power reflected can be found by solving Maxwell's equation.
- Radar wavelength and dimension of the target are two important parameters which define this
  - If the wavelength is larger than the dimension of the target Raleigh scattering occurs. Example rain
  - if the Wavelength is smaller than the target the scattering lies in the optical region. Example aircraft
- If the wavelength and the object is of same dimension then it is in the **resonance region**

# Sphere:

- Here the σ is directly proportional to $f^4$ in resonance region
- σ nearly equal in resonance region
- σ very small. No scattering only a small bright spot is seen.(if you take a photograph of a polished metal ball, you will see only a small bright spot: not the ball)

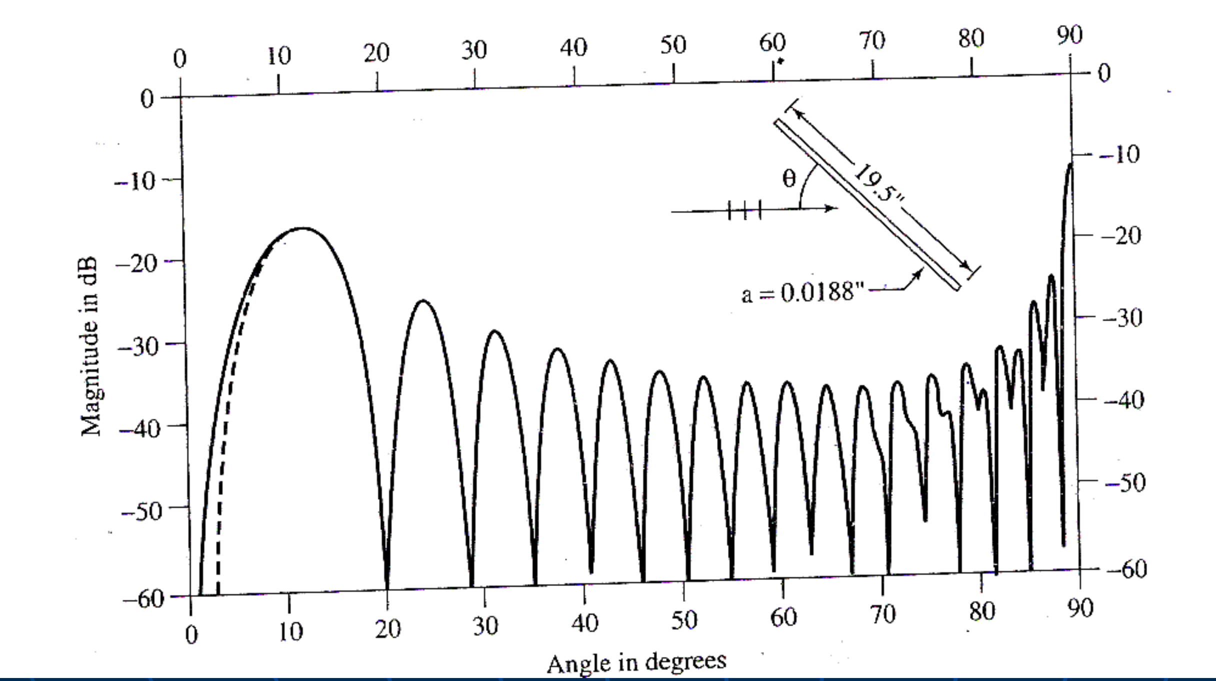



At resonance it oscillates.

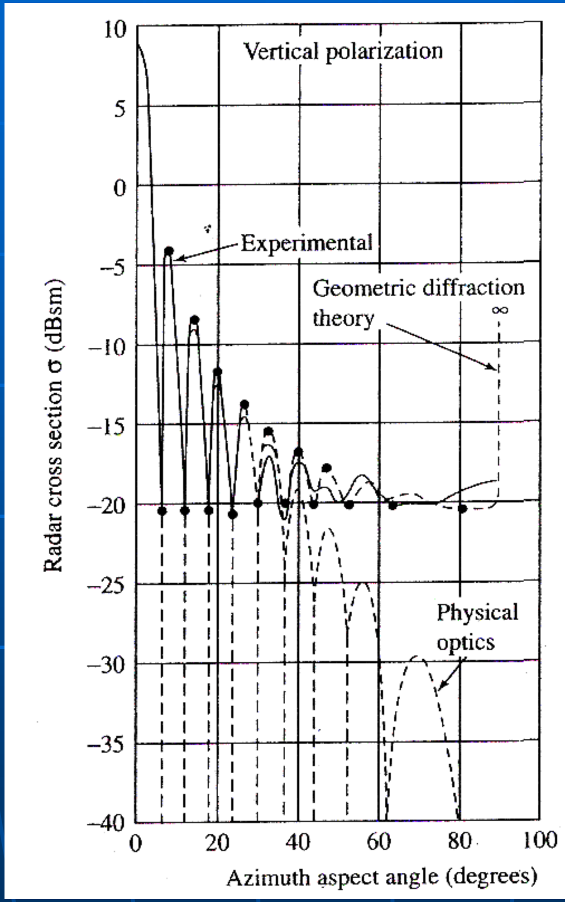
Attains maximum at $\frac{2\pi a}{\lambda}=1$

# A thin rod

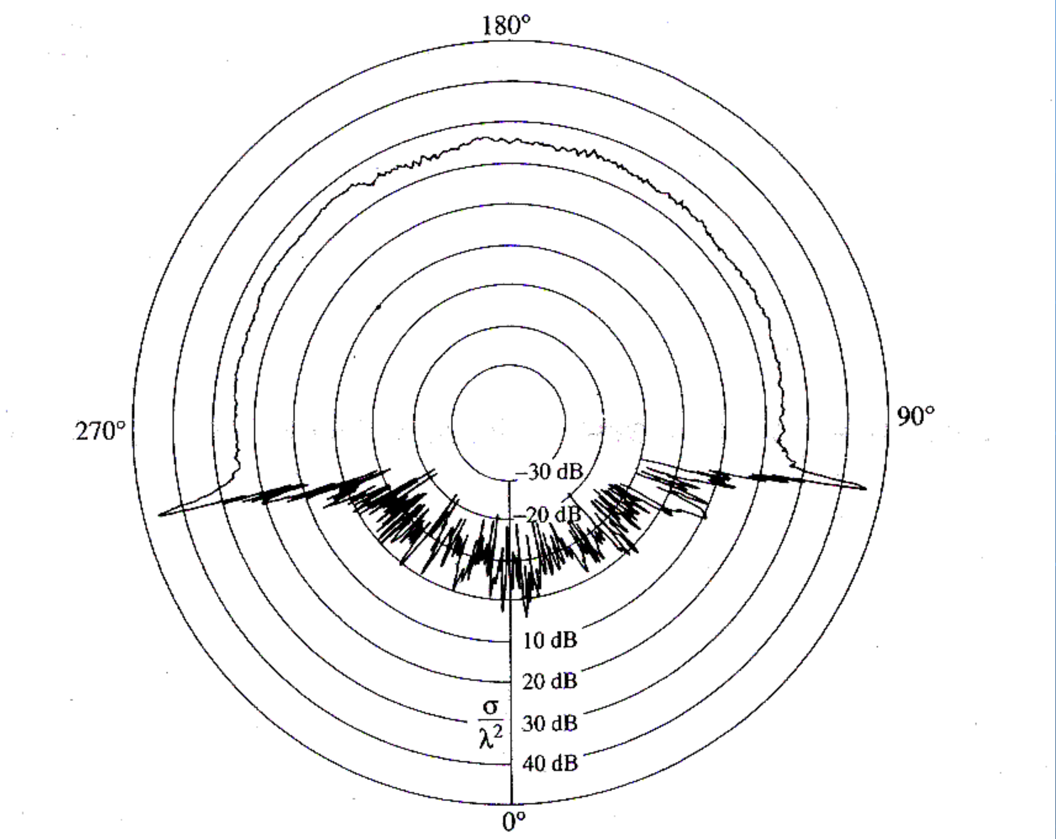
- Here the reflected wave(scattered wave/echo) depends on the angle at which the rod is viewed



# Square flat plate

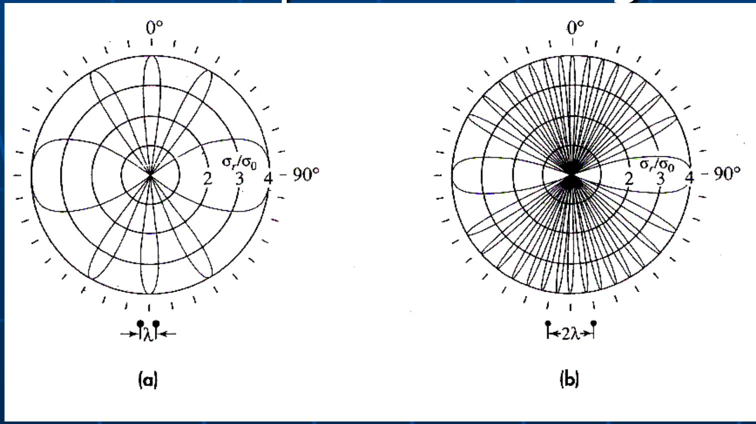


# Large Cone Sphere



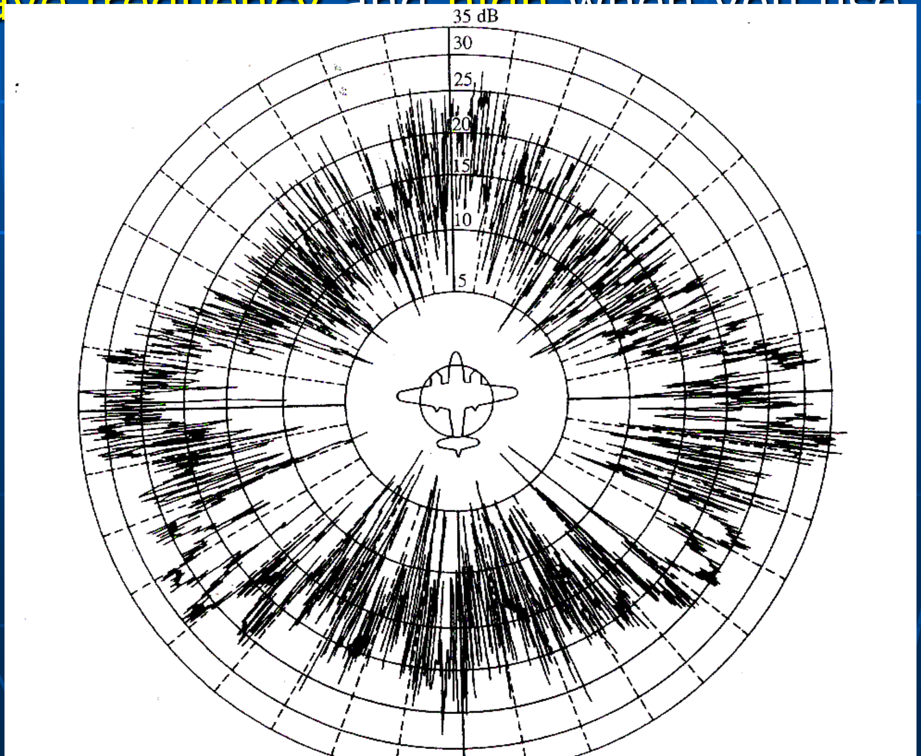
# Complex targets

- Aircrafts, buildings, missiles are some examples
- It depends on the viewing angle and frequency (wavelength)
- One complex target will have two or more surfaces which scatters the incoming waveform
- They can be each modeled as cone, sphere, flat or rod shaped.
- So we can **calculate them individually and add them together.**
- That is the reason we studied the above separately
- We should also note that the phase of each signal reflected will be different and depend on the angle
- Here we see two scatters showing the change in the magnitude with respect to change in the viewing angle

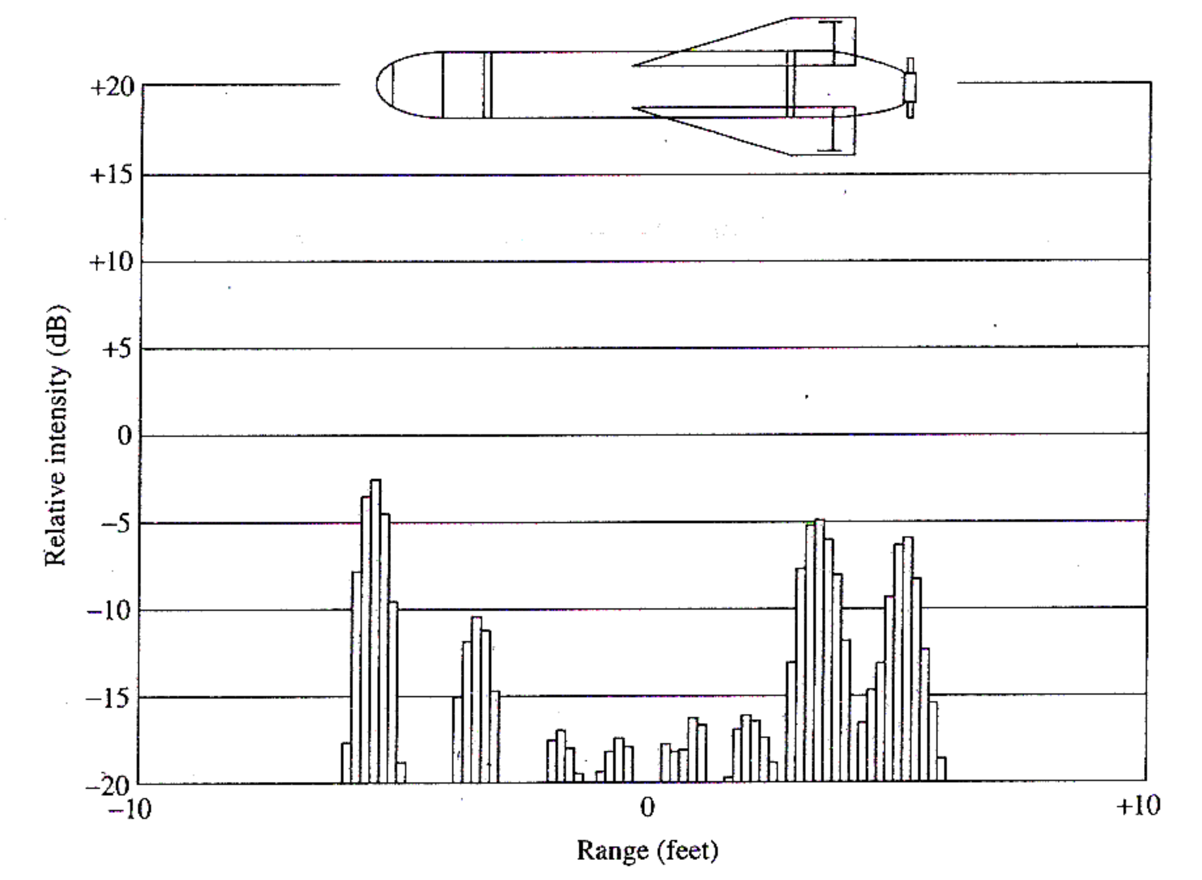


# An Aircraft

- The scattering shown as polar plot.
- We see more signals are reflected back when viewed along
  - Sideways: Flat surface
  - Nose and tail. Cone and sphere
- Engine will modulate the echo signal.
- The fluctuations in the reflected signal are low when you use microwave frequency and high when you use low frequency.



# A missile



# Radar cross Section Fluctuations

- The fluctuations are due to the following reasons
  - Change in viewing angle
  - Individual scatters
  - Echo from each scatter will have different amplitude and phase
  - Multiple reflections
  - Shadowing one scatter by another
  - Phase shift of more than 2*pi causes amplitude changes
- **Take more scans** and see the results. This is one of the solutions.

# Four Swirling model

- To study the fluctuations in detail **Four Swirling model** is used

- **Case 1:**
  - Each scan give constant amplitude but different correlation
  - This is called slow fluctuations (Scan to Scan fluctuations)
  - Raleigh scatters belong to this category
- **Case 2**
  - Each pulse give different output
  - Each of them independent
- **Case 3:**
  - Same as case 1 but different pdf
- **Case 4:**
  - Fluctuations is pulse to pulse and same pdf as case 3
  - The fluctuation affect the probability of detection
  - Fluctuations are usually small.
- We see the four cases using a diagram and we see that case 1 will create more problems

# Inference from all the models

- The probability-density function assumed in cases 1 and 2 applies to a complex target consisting of arbitrary independent scatterers of approximately equal echoing areas.
- Although, in theory, the number of independent scatterers must be essentially infinite, in practice the number may be as few as four or five.
- The probability-density function assumed in **cases 3 and 4** is more indicative of targets that can be **represented as one large reflector together with other small reflectors**.
- In all the above cases, the value of cross section to be substituted in the radar equation is the average cross section σ
- The **signal-to-noise ratio needed** to achieve a specified probability of detection without exceeding a specified false-alarm probability can be calculated for each model of target behavior.
- For purposes of comparison, the no fluctuating cross section will he called ***case*** 5.

# A comparison

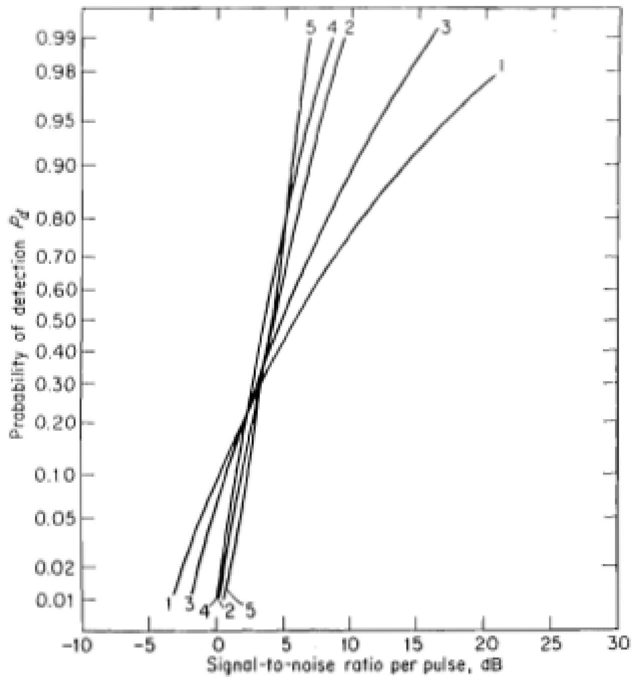



**Figure 2.22** Comparison of detection probabilities for five different models of target fluctuation for $n = 10$ pulses integrated and false-alarm number $n_f = 10^8$. (*Adapted from Swerling.*[37])

# Additional SNR required for a particular performance

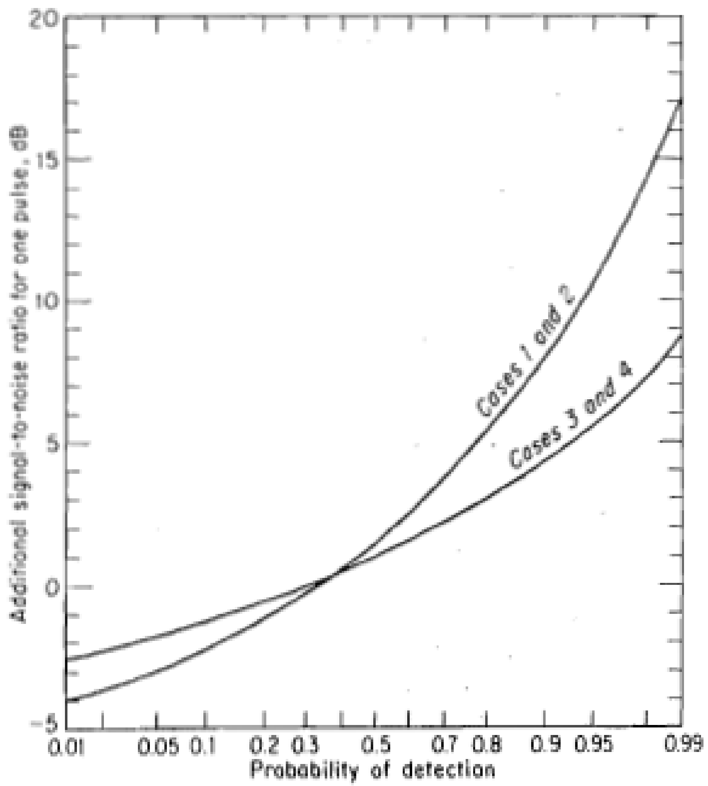



**Figure 2.23** Additional signal-to-noise ratio required to achieve a particular probability of detection, when the target cross section fluctuates, as compared with a nonfluctuating target; single hit, $n = 1$. (To be used in conjunction with Fig. 2.7 to find $(S/N)_1$.)

## 2.9 TRANSMITTER POWER

The power $P_t$ in the radar equation (2.1) is called by the radar engineer the *peak power*. The peak pulse power as used in the radar equation is not the instantaneous peak power of a sine wave. It is defined as the power averaged over that carrier-frequency cycle which occurs at the maximum of the pulse of power. (Peak power is usually equal to one-half the maximum instantaneous power.) The *average* radar power $P_{av}$ is also of interest in radar and is defined as the average transmitter power over the pulse-repetition period. If the transmitted waveform is a train of rectangular pulses of width $\tau$ and pulse-repetition period $T_p = 1/f_p$, the average power is related to the peak power by

$$\boxed{P_{av} = \frac{P_t \tau}{T_p} = P_t \tau f_p} \tag{2.43}$$

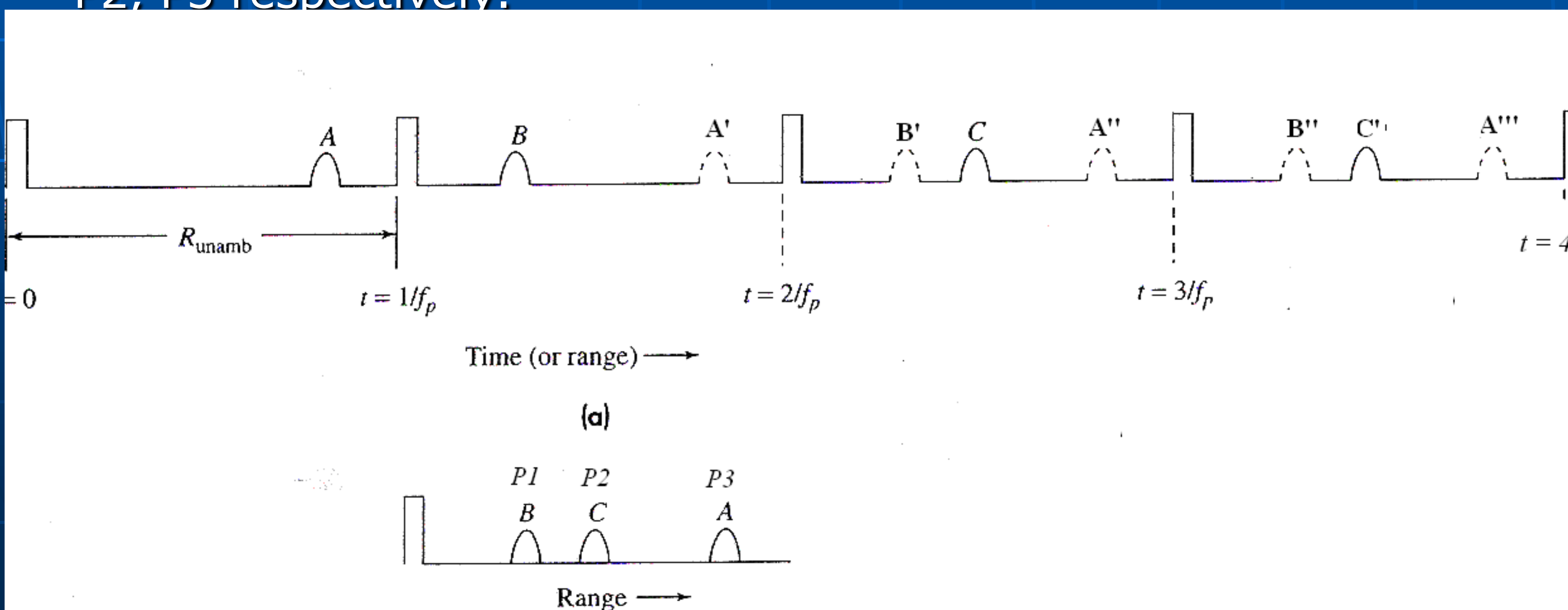
The ratio $P_{av}/P_t$, $\tau/T_p$, or $\tau f_p$ is called the *duty cycle* of the radar. A pulse radar for detection of aircraft might have typically a duty cycle of 0.001, while a CW radar which transmits continuously has a duty cycle of unity.

Writing the radar equation in terms of the average power rather than the peak power, we get

$$\boxed{R_{max}^4 = \frac{P_{av} G A_e \sigma n E_i(n)}{(4\pi)^2 k T_0 F_n (B_n \tau)(S/N)_1 f_p}} \tag{2.44a}$$

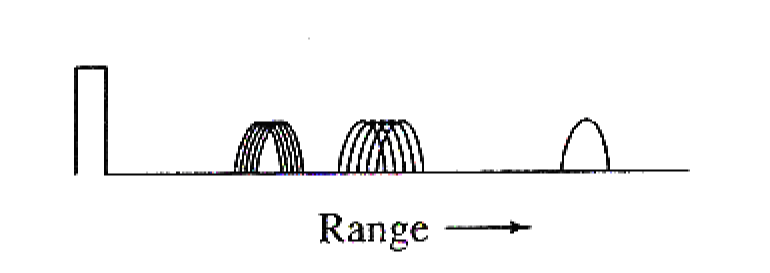
# PULSE REPETITION FREQUENCY AND RANGE AMBIGUITIES

- Suppose you are trying to detect the object A.
- It is in unambiguous range. So we get the echo after the pulse repetition.
- If suppose there are other two objects B and C which we are not interested, at distance above the unambiguous and twice.
- The echoes from these objects will also be seen on the A scope.
- Since we are integrating the pulses, we see pulses in position P1, P2, P3 respectively.



# Solution

- One method of distinguishing multiple-time-around echoes from unambiguous echoes is to operate with a varying pulse repetition frequency.
- The echo signal from an unambiguous range target will appear at the same place on the A-scope on each sweep no matter whether the prf is modulated or not.
- However, echoes from multiple-time-around targets will be spread over a finite range



The antenna gain $G$ is a measure of the power radiated in a particular direction by a directive antenna to the power which would have been radiated in the same direction by an omnidirectional antenna with 100 percent efficiency. More precisely, the power gain of an antenna used for transmission is

$$\boxed{G(\theta, \phi) = \frac{\text{power radiated per unit solid angle in azimuth } \theta \text{ and elevation } \phi}{\text{power accepted by antenna from its generator}/4\pi}} \tag{2.45}$$

Note that the antenna gain is a function of direction. If it is greater than unity in some directions, it must be less than unity in other directions.

# SYSTEM LOSSES

- losses that occur throughout the radar system.
- The losses reduce the signal-to-noise ratio at the receiver output.
- They may be of two kinds, Depending upon whether or not they can be predicted
- The antenna beam-shape loss, collapsing loss, and losses in the microwave plumbing are examples of losses which can be calculated.
- Losses not readily subject to calculation and which
- are less predictable include 'those due to field degradation and to operator fatigue or lack of operator motivation.

# Plumbing loss.

- i. Transmission line losses
  - For low frequency the losses is high
  - For high frequency the losses is high
  - So keep the distance between antenna and receiver short as possible
  - The loss is taken twice as the signal is transmitted and received
- ii. Duplexer loss
  - It is a gas filled section used to protect the receiver form the transmitter.
  - The transmitter uses very high power and receiver we get only a small from from the reflected
  - So we use a waveguide shutter which produces loss it can be upto 2dB

# 2. Antenna losses

*Beam-Shape Loss* The antenna gain that appears in the radar equation is assumed to be a constant equal to the maximum value. But in reality the train of pulses returned from a target by a scanning antenna is modulated in amplitude by the shape of the antenna beam, Only one out of *n* pulses has the maximum antenna gain *G*, that which occurs when the peak of the antenna beam is in the direction of the target.

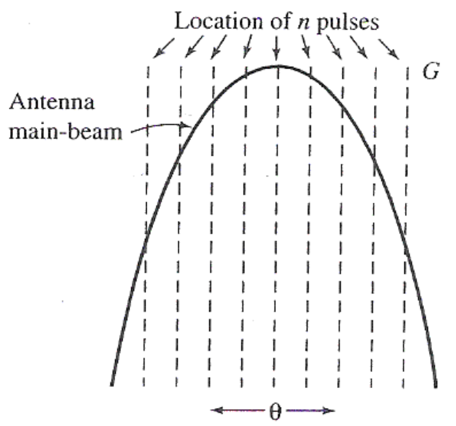



**Figure 2.26** Nature of the beam-shape loss. The simple radar equation assumes *n* pulses are integrated, all with maximum antenna gain *G*. The dashed lines represent *n* pulses with maximum gain, and the solid curve is the antenna main-beam pattern $G(\theta)$. Except for the pulse at the center of the beam, the actual pulses illuminate the target with a gain less than the maximum.

# Signal processing loss

*a. Detector Approximation:*

The output voltage signal of a radar receiver that utilizes a linear detector is

$$v(t) = \sqrt{v_I^2(t) + v_Q^2(t)}$$

where $(v_I, v_Q)$ are the in-phase and quadrature components. For a radar using a square law detector, we have $v^2(t) = v_I^2(t) + v_Q^2(t)$.

Since in real hardware the operations of squares and square roots are time consuming, many algorithms have been developed for detector approximation. This approximation results in a loss of the signal power, typically 0.5 to 1 dB.

*b. Constant False Alarm Rate (CFAR) Loss:*

In many cases the radar detection threshold is constantly adjusted as a function of the receiver noise level in order to maintain a constant false alarm rate. For this purpose, Constant False Alarm Rate (CFAR) processors are utilized in order to keep the number of false alarms under control in a changing and unknown background of interference. CFAR processing can cause a loss in the SNR level on the order of 1 dB.

*c. Quantization Loss:*

Finite word length (number of bits) and quantization noise cause an increase in the noise power density at the output of the Analog to Digital (A/D) converter. The A/D noise level is $q^2/12$, where $q$ is the quantization level.

# Other losses-

- Equipment degradation
- **Field degradation.**
- **Operator loss**

# Propagation effect

- The radar environment includes terrain and sea surfaces, the atmosphere (including precipitation), and the ionosphere. These may degrade radar observations and performance by producing clutter and other spurious returns, signal attenuation, and bending of the radar-signal path.
- • Terrain and sea surfaces, which may produce target masking, radar clutter, and multipath interference;
- • Precipitation, principally rain, which may produce signal attenuation and clutter returns;
- • The troposphere, which may produce refraction that bends the radar signal path, signal attenuation, and a lens loss;
- • The ionosphere, which may produce refraction that bends the radar signal path, signal fluctuation and attenuation, waveform dispersion, and rotation of signal polarization.