UNIT-IV

IMAGE RADARS

➢ INTRODUCTION

- Imaging radar is **an application of radar which is used to create 2D images, typically of landscapes**.
- Imaging radar provides its **light to illuminate** an area on the ground and take a picture at radio wavelengths.
- It uses an **antenna and digital computer** storage to record its images.
- Imaging radar is a kind of radar equipment which can be used for imaging.
- A typical radar technology includes emitting radio waves, receiving their reflection, and using this information to generate data.
- For imaging radar**, the returning waves are used to create an image.**

➢ HOW REFLECTED WAVES ARE CONVERTING INTO IMAGE::

- When the radio waves reflect off objects, this will make some changes in the radio waves and can provide data about the objects, including how far the waves traveled and what kind of objects they encountered.
- Using the acquired data, a computer can create a 3-D or 2-D image of the target.
- **Radar Images** are composed of many dots, or picture elements.
- Each pixel (picture element) in the radar image represents the radar backscatter for that area on the ground:

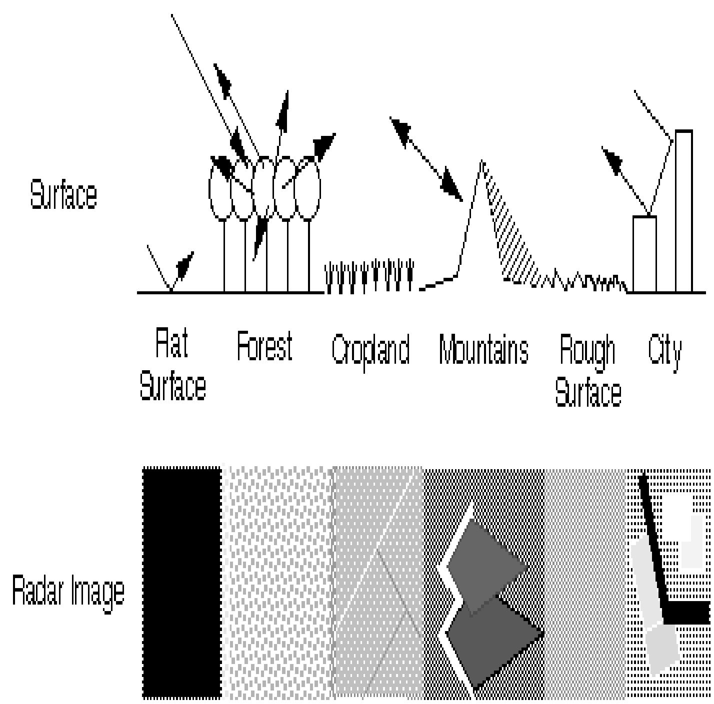
  → **Darker areas in the image represent low backscatter**

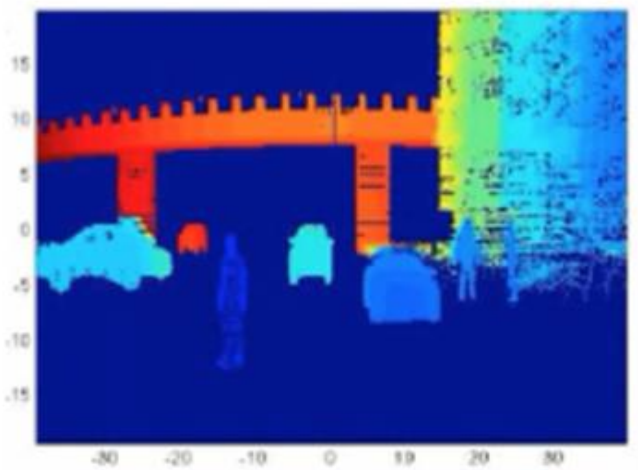
  → **Brighter areas represent high backscatter**.

- Bright features mean that a large fraction of the radar energy was reflected back to the radar, while dark features imply that very little energy was reflected.
- Backscatter for a target area at a particular wavelength will vary for a variety of conditions:
  a) Size Of The Scatterers In The Target Area,
  b) Moisture Content Of The Target Area,
  c) Polarization Of The Pulses, And
  d) Observation Angles.
- **Backscatter Will Also Differ When Different Wavelengths Are Used**

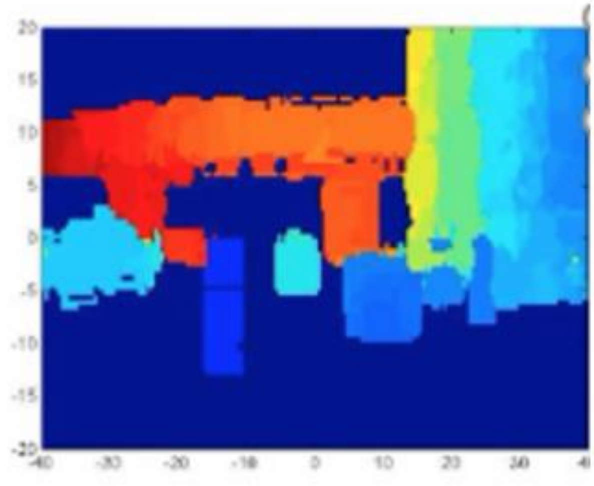
➢ ADVANTAGES OF IMAGE RADARS

a. It can operate in the presence of obstacles that obscure the target
b. It can penetrate ground (sand), water, or walls.





Lidar



High Resolution Radar

➢ RESOLUTION CONCEPT ::

Already we know about

1. RANGE RESOLUTION ::

- That the Radar will be able to say that there are two different targets with velocity Doppler frequency's fd_1 & fd_2

(or)

- Radar is able to find minimum distance between two targets with Doppler frequency's fd_1 & fd_2

$$\boxed{\Delta R = \frac{c * \Delta\tau}{2}}$$

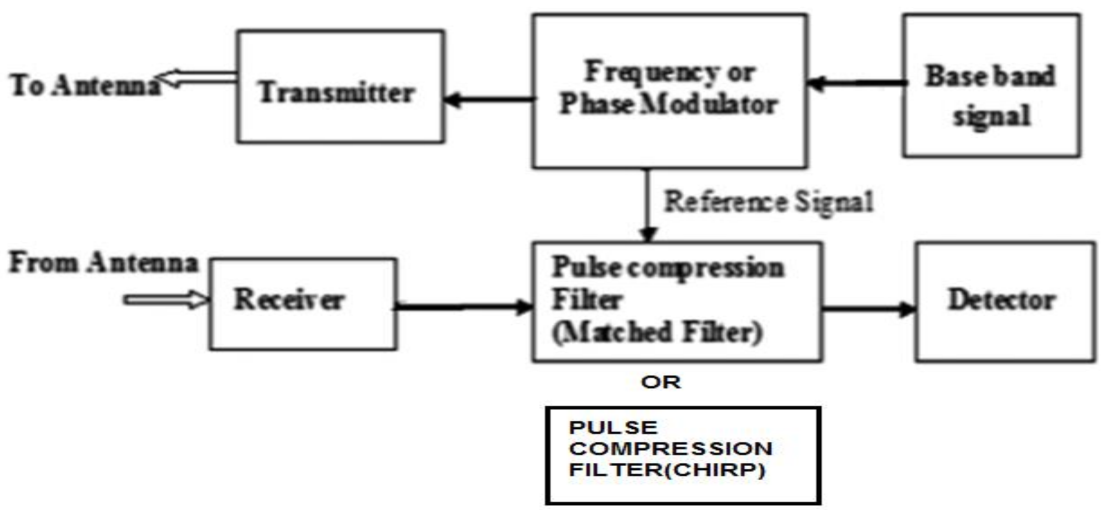
2. ANGULAR RESOLUTION::

- Radar angular resolution is the minimum distance between two equally large targets at the same range which radar is able to distinguish and separate to each other.

$$\boxed{S_A = 2RSin\left(\frac{\theta}{2}\right)}$$

➢ PULSE COMPRESSION

- Pulse compression is **a signal processing technique commonly used by radar to increase**
    a. **The range resolution**
    b. **The signal to noise ratio**.
- This is achieved by modulating the transmitted pulse and then correlating the received signal with the transmitted pulse.
- This method is also known as **intra-pulse modulation** (*modulation on the pulse, MOP*) because the transmitted pulse got a time-dependent modulation internally.



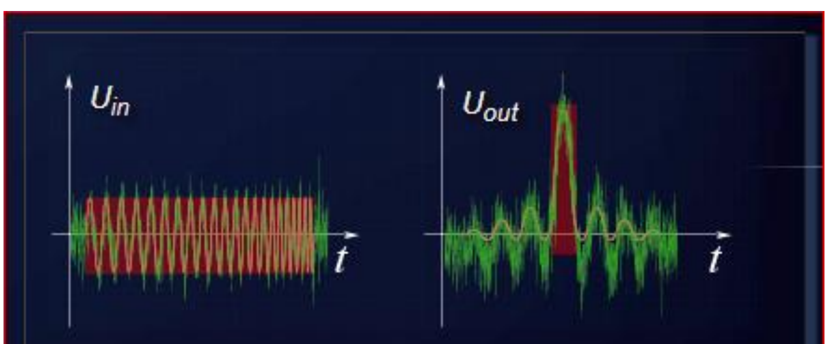


Figure 1: Input and output signals of a pulse compression stage, the received signal in noise is hardly noticeable, so the pulse compression results in a clear echo signal.

➢ RADAR IMAGING TECHNIQUES

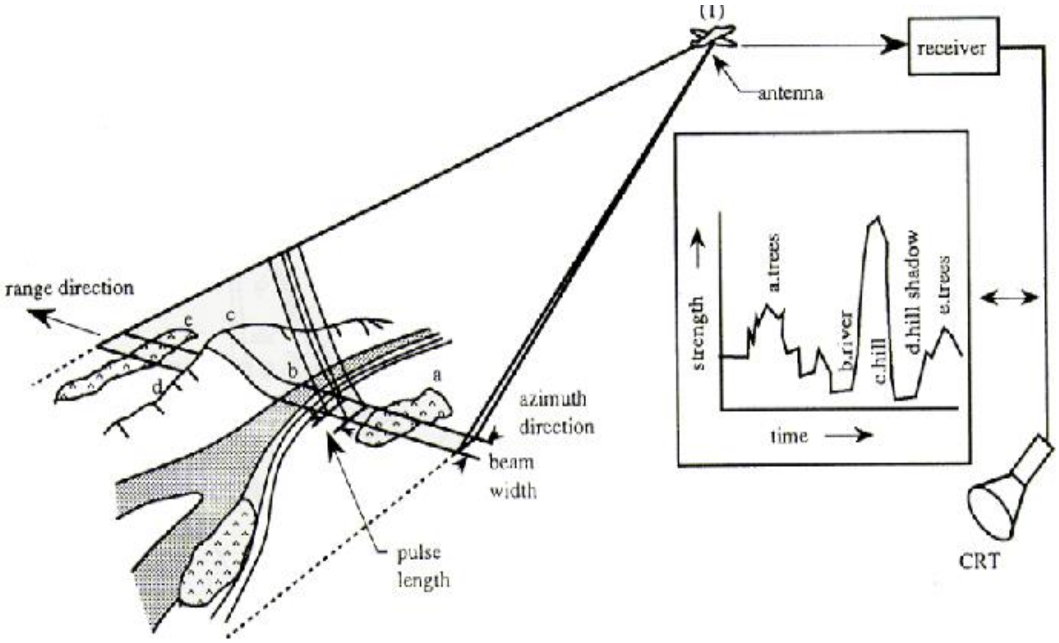
i. Real Aperture Radar

ii. Synthetic Aperture Radar (SAR)

iii. Inverse Synthetic Aperture Radar (ISAR) Imaging.

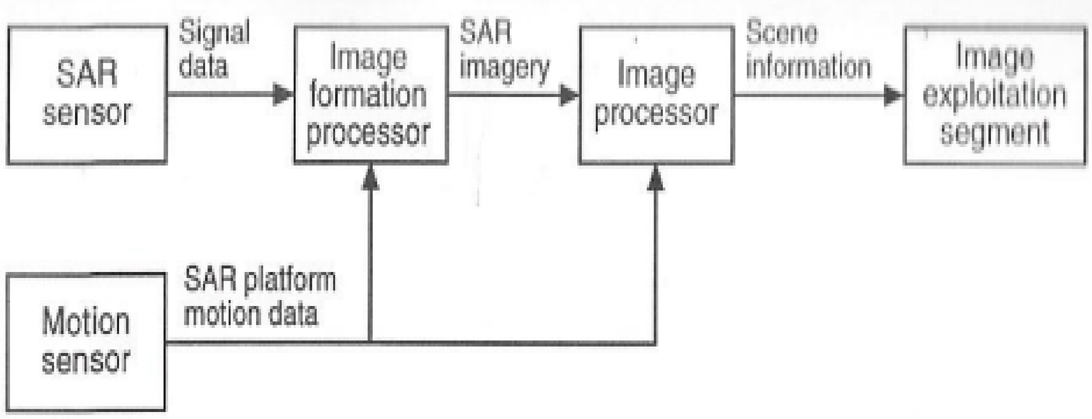
i. Real aperture radar (RAR)

- It is a form of radar that transmits a narrow angle beam of pulse radio wave in the range direction at right angles to the flight direction and receives the backscattering from the targets which will be transformed to a radar image from the received signals.
- Usually the reflected pulse will be arranged in the order of return time from the targets, which corresponds to the range direction scanning.
- The resolution in the range direction depends on the pulse width.
- The resolution in the azimuth direction is identical to the multiplication of beam width and the distance to a target.

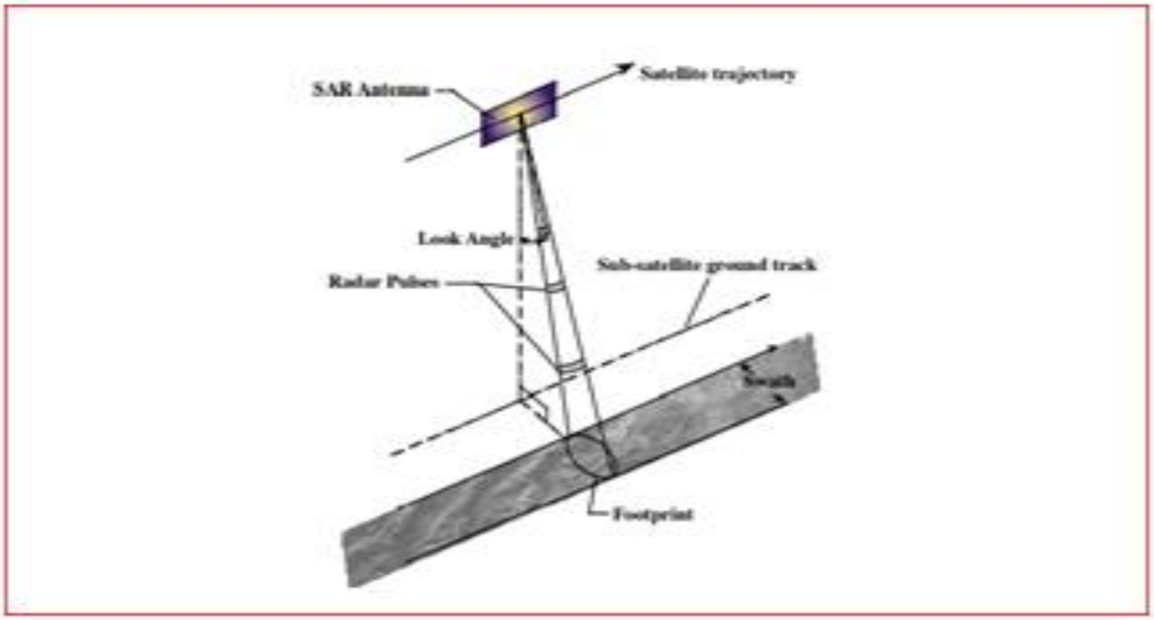


ii. Synthetic aperture radar (SAR)

- A synthetic aperture radar (SAR) is an active sensor that **first transmits microwave signals and then receives back the signals that are returned, or backscattered , from the Earth's surface**.
- The instrument measures distances between the sensor and the point on the Earth's surface where the signal is backscattered.
- A top-level view of a basic SAR system includes five blocks in below figure .
- The SAR sensor and the motion sensor constitute the real-time data collection resources.
- These resources provide radar signal data (backscattered from the illuminated scene) and auxiliary data describing SAR platform motion.
- The image formation processor (IFP) utilizes these two data screams to deliver SAR imagery to the image processor and subsequently to the image exploitation segment.
- The latter three blocks may also operate in real time.



gure 2.1 SAR system overview.



System Operation::

- A SAR generates and transmits a series of coded pulses at regular time interval as the radar platform to moves along its path.
- The ideal path is a straight line traversed at constant velocity.
- In a practical environment, variations from this ideal are inevitable. Measured changes in along-track velocity present no real difficulty.
- Small vertical and horizontal displacements from this ideal trajectory are acceptable if measured accurately.
- Larger, deliberate variations from the ideal path. such as chose by a SAR system engaging in a high acceleration "pop-up" maneuverable avoid detection, present a challenge to image formation; this challenge is a non planar motion effect.
- To accumulate the signals necessary to generate one fine-resolution image, the SAR sensor transmit pulses to interrogate the scene over an angular. interval inversely proportional to the required azimuth resolution.

- This interval is the coherent aperture time in the time domain, 1he synthetic aperture length in the time domain, or the azimuth processing aperture in the IFP.
- The illuminated scene reflects a fraction of the energy from each transmitted pulse back toward the radar sensor. The SAR receives and accepts the return signal within a selected time delay interval after pulse transmission; this interval is the range gate. The range gate corresponds to the range interval being imaged.

➢ In SAR imaging, the creation of a fine-resolution image from a sequence of received signals requires the following steps:

- Generate, transmit, and receive a wide bandwidth coded signal with a deterministic phase relationship from pulse to pulse;
- Measure and compensate for the relative translational and rotational motions between the radar antenna phase center (APC) and the scene or target.
- Format the data based on radar system parameters and data collection geometry;Compress the data in range and azimuth to achieve the desired resolution.

1. SAR Sensor

- The term *SAR sensor* encompasses all electronics required to generate. transmit, and receive SAR signals.
- It includes the radar antenna and data link, recording device. or physical interface to convey collected signals to the IFP.
- Typically. an airborne platform carries the SAR sensor, although an unnamed aerial vehicle (UAV) or a space vehicle is an acceptable platform as well.
- An ISAR sensor may be stationary or moving while it images a moving target.

2. Motion sensor

- Returning to fig above, a motion sensor is a vital sub system in high-performance SAR imaging system.

- The motion sensor provides data to estimate both short- term and long-term changes in the position of the SAR antenna. short- term refers to cyclical motion with a period less than a synthetic aperture time.
- And long-term refers to motions with a period greater than the aperture time.

3. IMAGE FORMATION PROCESSOR(IFP)

- The term IMAGE FORMATION PROCESSOR(IFP) encompasses the HW & SW elements which perform the data formatting and processing operations necessary to produce an image from SAR signal and data.
- Which performs include:

  a) Auxiliary data processing
  b) Compensation for non-ideal wave form generation and propagation effects.
  c) Azimuth filtering and presuming.
  d) Range deskew.
  e) Motion compensation operation.
  f) Image side lobe controlling.
  g) Two-dimensional FT (compression).
  h) Autofocus.
  i) Amplitude correction and radiometric calibrations.
  j) Geometrical distortion corrections.

4. IMAGE PROCESSOR

- The term Image processor encompasses image enhancement, feature extraction, registration with other SAR images or with other sensor data, automatic target detection ATD, and automatic target precognition ATR.
- Image processing may also include verity of multi-channel processing operation in SAR system having multiple T/R configurations.

5. IMAGE EXPLOITATION SEGMENTS

- The Image exploitation segment involve the extraction and use of information about the imaged scene to address a diversity of SAR applications.
- Image exploitation naturally includes the end user of the SAR system output products.
- Mission may include terrain mapping and imaging of targets: they involve Military, commercial, and civilian users.

➢ APPLICATIONS.

a) Intelligence gathering,

b) Battlefield,

c) Weapon guidance,

d) Vehicle identifications etc.

3. INVERSE APERTURE RADAR (ISAR)

- Inverse synthetic aperture radar (ISAR) is another kind of SAR system which can produce high-resolution on two- and three-dimensional images.
- An ISAR system consists of a stationary radar antenna and a target scene that is undergoing some motion.
- ISAR is theoretically equivalent to SAR in that high-azimuth resolution is achieved via relative motion between the sensor and object, yet the ISAR moving target scene is usually made up of non cooperative objects.
- Algorithms with more complex schemes for motion error correction are needed for ISAR imaging than those needed in SAR.
- ISAR technology uses the movement of the target rather than the emitter to make the synthetic aperture.

- ISAR radars are commonly used on vessels or aircraft and can provide a radar image of sufficient quality for target recognition.
- The ISAR image is often adequate to discriminate between various missiles, military aircraft, and civilian aircraft.

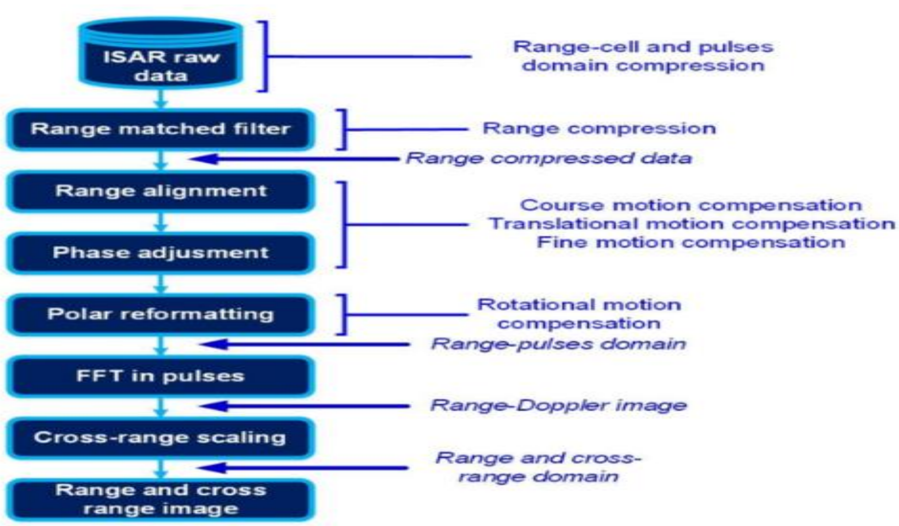
➢ **<u>Disadvantages of ISAR</u>**

1. The ISAR imaging cannot obtain the real azimuth of the target.
2. There sometimes exists a reverse image. For example, the image formed of a boat when it rolls forwards and backwards in the ocean.

➢ The ISAR image is the 2-D projection image of the target on the Range-Doppler plane which is perpendicular to the rotating axis. When the Range-Doppler plane and the coordinate plane are different, the ISAR image can not reflect the real shape of the target.

➢ Thus, the ISAR imaging can not obtain the real shape information of the target in most situations.

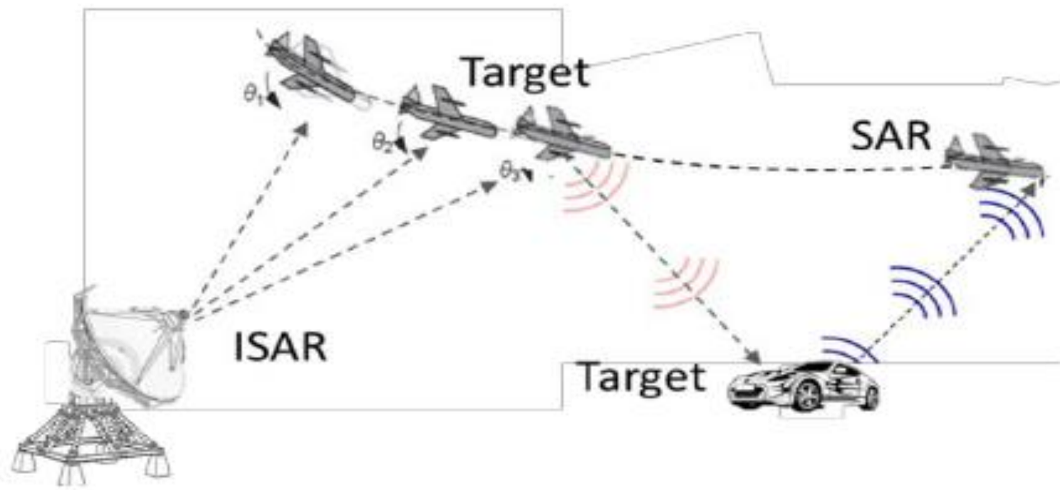
4. Rolling is side to side. Pitching is forward and backwards, yawing is turning left or right.



<u>ISAR SYSTEM ALGORITHM</u>

- Difference between SAR and ISAR imaging

	SAR	ISAR
RADAR	Moving	Stationary
OBJECT	Stationary	Moving



PROBABILITY OF FALSE ALARM AND DETECTION

❖ Receiver Noise:

- Noise is the unwanted electromagnetic energy that interferes with the ability of the receiver to detect the wanted signal.
- It may enter the receiver through the antenna along with the desired signal or it may be generated within the receiver.
- As discussed earlier, noise is generated by the thermal motion of the conduction electrons in the ohmic portions of the receiver input stages. This is known as ***Thermal or Johnson Noise***.

$$P_N = kT_o\beta \qquad \text{Watt,}$$

where: k – Boltzmann's Constant (1.38×10^{-23} J/K),
T_o – System Temperature (usually 290K),
β – Receiver Noise Bandwidth (Hz).

Noise power P_N is expressed in terms of the temperature to of a matched resistor at the input of the receiver.

The total noise at the output of the receiver, N, can be equal to the ***noise power output*** from an ideal receiver multiplied by a factor called the ***Noise Figure, F_n***.

$$N = P_N F_N = kT_o\beta.F_n \text{ Watt.}$$

❖ Noise Probability Density Functions (N PDF)

- ➢ Consider a typical radar front-end that consists of an antenna followed by a wide band amplifier, a mixer that down converts the signal to an intermediate frequency (IF) where it is further amplified and filtered (bandwidth β_{IF}).
- ➢ This is followed by an envelope detector and further filtering (bandwidth $\beta_V = \beta_{IF}/2$).
- ➢ The noise entering the IF filter is assumed to be Gaussian (as it is thermal in nature) with a probability density function (PDF) given by.

$$P_N = kT_o\beta \qquad \text{Watt,}$$

where: k – Boltzmann's Constant (1.38×10^{-23} J/K),
T_o – System Temperature (usually 290K),
β – Receiver Noise Bandwidth (Hz).

- **If Gaussian noise is passed through a narrow band filter (one whose bandwidth is small compared to the centre frequency), then the PDF of the envelope of the noise voltage output can be shown to be**

$$p(R) = \frac{R}{\psi_o}\exp\frac{-R^2}{2\psi_o},$$

where R is the amplitude of the envelope of the filter output.

This has the form of the Rayleigh probability density function

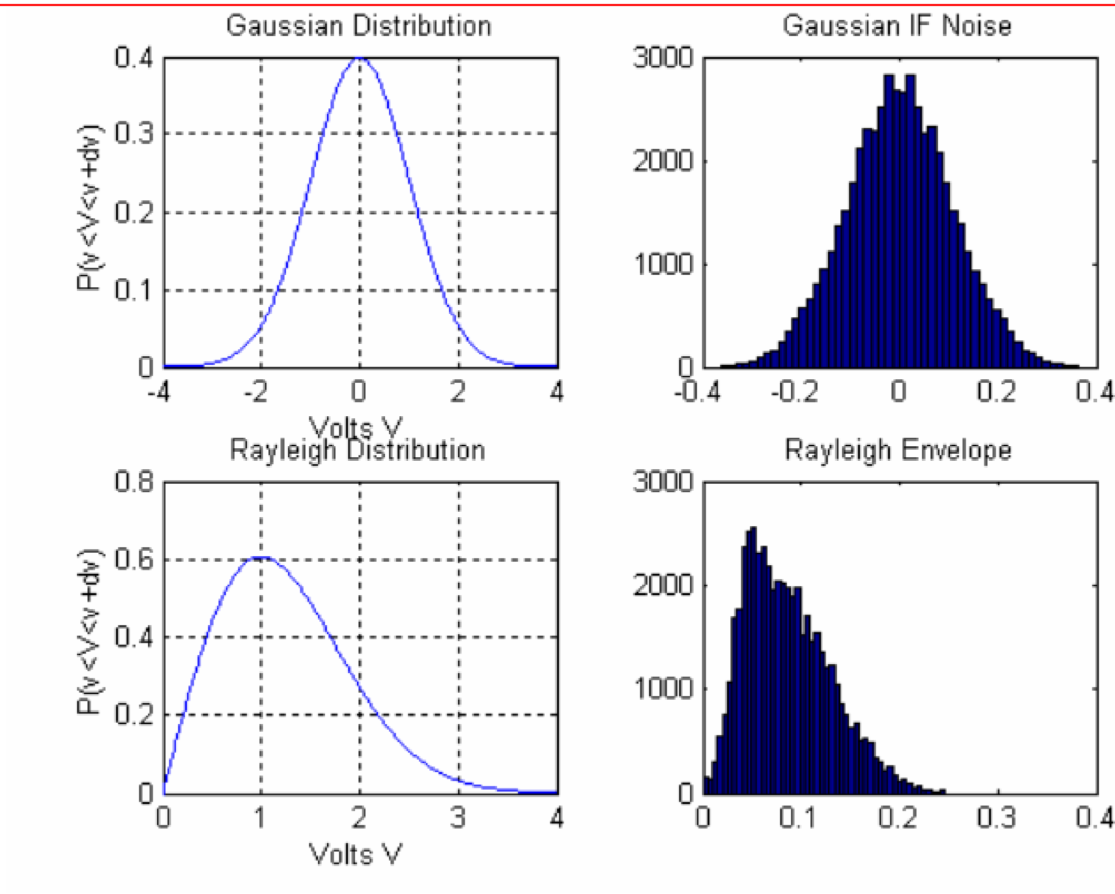


Figure 11.1: Amplitude Distributions of Noise

➢ PROBABILITY OF FALSE ALARM

- A false alarm occurs whenever this noise voltage exceeds a defined threshold voltage V_t.
- The probability of this occurring is determined by integrating the PDF as shown

$$\Pr ob(V_t < R < \infty) = \int_{V_t}^{\infty} \frac{R}{\psi_o} \exp\frac{-R^2}{2\psi_o} dR = \exp\frac{-V_t^2}{2\psi_o} = P_{fa} .$$

- The average time interval between crossings of the threshold is called the **false alarm time T_{fa}**

$$T_{fa} = \lim_{N\to\infty} \frac{1}{N} \sum_{k=1}^{N} T_k ,$$

where T_k – Time between crossings of the threshold V_t by the noise envelope (when the slope of the crossing is positive).

- **The false alarm probability** could also have been defined as the ratio of the time that the envelope is above the threshold to the total time as shown graphically in the figure below.

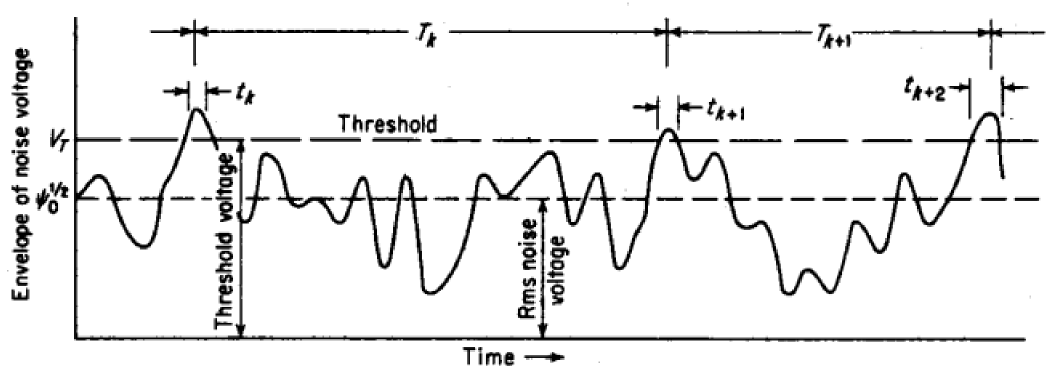


Figure 11.2: Receiver Output Voltage Illustrating False Alarms due to Noise

$$P_{fa} = \frac{\sum_{k=1}^{N} t_k}{\sum_{k=1}^{N} T_k} = \frac{\langle t_k \rangle_{ave}}{\langle T_k \rangle_{ave}} = \frac{1}{T_{fa}\beta},$$

where t_k and T_k are defined in the figure, and the average duration of a noise pulse is the reciprocal of the bandwidth B.

- For a bandwidth $\beta = \beta_{IF}$, the false alarm time is just

$$T_{fa} = \frac{1}{\beta_{IF}} \exp \frac{V_t^2}{2\psi_o}.$$

- The false alarm times of practical radars must be very large, so the probability of false alarm must be very small, typically $P_{fa} < 10^{-6}$.
- **PROBABILITY OF DETECTION**
- Consider that a sine wave with amplitude, A, is present along with the noise at the input to the IF filter.
- The frequency of the sine wave is equal to the centre frequency of the IF filter It is shown by Rice that the signal at the output of the envelope detector will have the following PDF (known as a Rician distribution)

$$p_s(R) = \frac{R}{\psi_o} \exp\left(-\frac{R^2 + A^2}{2\psi_o}\right) I_o\left(\frac{RA}{\psi_o}\right).$$

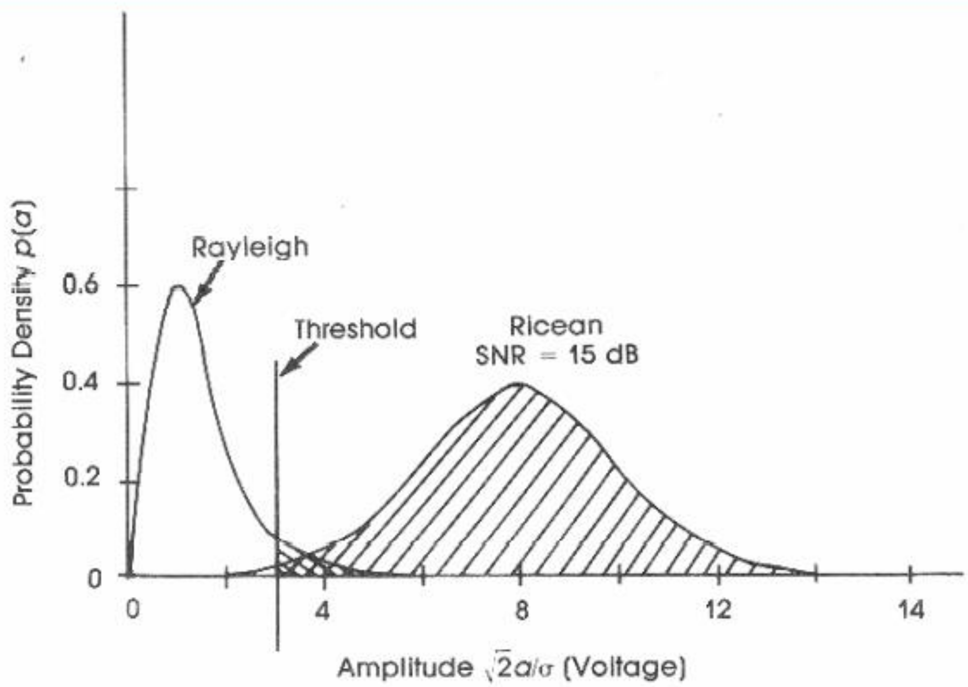
- $I_o(Z)$ modified Bessel function of order zero and argument Z.
- It can be shown that for large Z, an asymptotic expansion for Io(Z) is

$$I_o(Z) \approx \frac{e^Z}{\sqrt{2\pi Z}}\left(1 + \frac{1}{8Z} + \dots\right).$$

- The probability that the signal will be detected is the same as the probability that the envelope R will exceed the threshold V_t.

$$p_d = \int_{V_t}^{\infty} p_s(R)dR = \int_{V_t}^{\infty} \frac{R}{\psi_o} \exp\left(-\frac{R^2 + A^2}{2\psi_o}\right) I_o\left(\frac{RA}{\psi_o}\right) dR.$$

- Unfortunately, this cannot be evaluated in a closed form and so numerical techniques or a series approximation must be used.
- However, this has already been done, and tables and a series of curves have been produced.
- In terms of the PDFs, the detection and false alarm process is shown graphically in the figure below.



Probability density functions of noise and signal-plus-noise with threshold shown for $P_{FA} = 10^{-2}$.

- A typical radar system will operate with a detection probability of 0.9 and a probability of false alarm of 10^{-6}.
- The required signal to noise ratio can be read directly off the graph as 13.2dB.

- Note that this is for a single pulse of a steady sinusoidal signal in Gaussian noise with no detection losses.

- **MODIFIED RADAR RANGE EQUATION WITH SWERLING MODELS::**

- The use of Swerling target models is to describe the fluctuations in radar cross-section.
- **Fluctuation loss** is an effect seen in radar systems as the target object moves or changes its orientation relative to the radar system.
- SWERLING MODELS CASES
    a. Case(0) – Non fluctuating model
    b. Case (1), Case(2), Case(3) ,Case(4) - Fluctuating models
- ✓ **In Case(1) & Case(3) Fluctuating loss can determined by scan to scan basis.**
- ✓ **In Case(2) & Case(4) Fluctuating loss can determined by pulse to pulse basis.**
- In general fluctuating targets requires large SNR than the Non-fluctuating targets.
- Thus if the radar had been designed on the basis of a constant cross section equal to σ_{avg} .But in reality the cross section flucated according the models there would be reduction of range.
- **Case(1) & Case(3)** puts more demand than do tht for other cases indicates that for Probability of detection is greater ,a greater SNR is required when fluctuations independent scan to scan **Case(1) & Case(3)** than fluctuations independent pulse to pulse **Case(2) & Case(4)** .
- The pulse to pulse fluctuations **Case(2) & Case(4)** tend to average to that of the constant cross section case **Case(0)** as the number of independent pulses integrated increases.
- The statistical theory of detection can be applied to find for each Swerling case the SNR per pulse required for a given
    a. Probability of detection
    b. Probability of false alarm

c. Number of pulses integrated

- The required SNR $(S/N)_1$ for Swerling **Case(1) & Case(3)** when n=1

Signal pulse detection = Additional SNR for one pulse (L_f)
+
SNR of Non- fluctuating of single pulse

- Barton calls the ordinate the fluctuation loss (L_f) with scan to scan target fluctuations
- **The integration improvement factor $nE_i(n)$ is the same for the constant (Non- fluctuating) cross section**
- Where the integration improvement factor

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

- But in fluctuating target in the radar range Equation when the target is Swerling **Case(1) & Case(3)** $(S/N)_1$ is replaced with $(S/N)_1 * L_f$
- Then Radar range equation is modified as

$$\boxed{R_{max}^4 = \frac{P_t * G * A_e * \sigma * n * E_i(n)}{(4\pi)^2 * k * B * T_o * F_n (S/N)_1 * L_f}}$$

- Modified radar range equation using Swerling cases cand be obtained by Partial correlation of Coefficient
- (A partial correlation coefficient is **a measure of the linear dependence of a pair of random variables from a collection of random variables in the case where the influence of the remaining variables is eliminated)**

➢ **According to partial correlation coefficient of target cross section**

The Swerling cases assume the pulses received as the antenna scans by the target are either completely correlated or completely uncorrelated pulse to pulse

- ✓ Completely correlated coefficient(ρ=1)
- ✓ Completely uncorrelated coefficient(ρ=0)

- When the correlation of the pulses is some value of ρ other than '0' or '1', barton provides empirical relationship for required SNR.
- Barton States that the fluctuations loss when n_e independent samples are integrated is approximately.

$$\boxed{L_f(n_e) = (L_f)^{1/n_e}}$$

Where,

L_f – fluctuation loss as was given for detection with a single pulse either case(1) or case(3)

n_e – The number of independent samples received from target

- **Radar Equation for Swerling cases::**

The radar equation for partially correlated Swerling cases can be written

$$\boxed{R_{max}^4 = \frac{P_t * G * A_e * \sigma * n * E_i(n)}{(4\pi)^2 * k * B * T_o * F_n(S/N)_1 * (L_f)^{1/n_e}}}$$