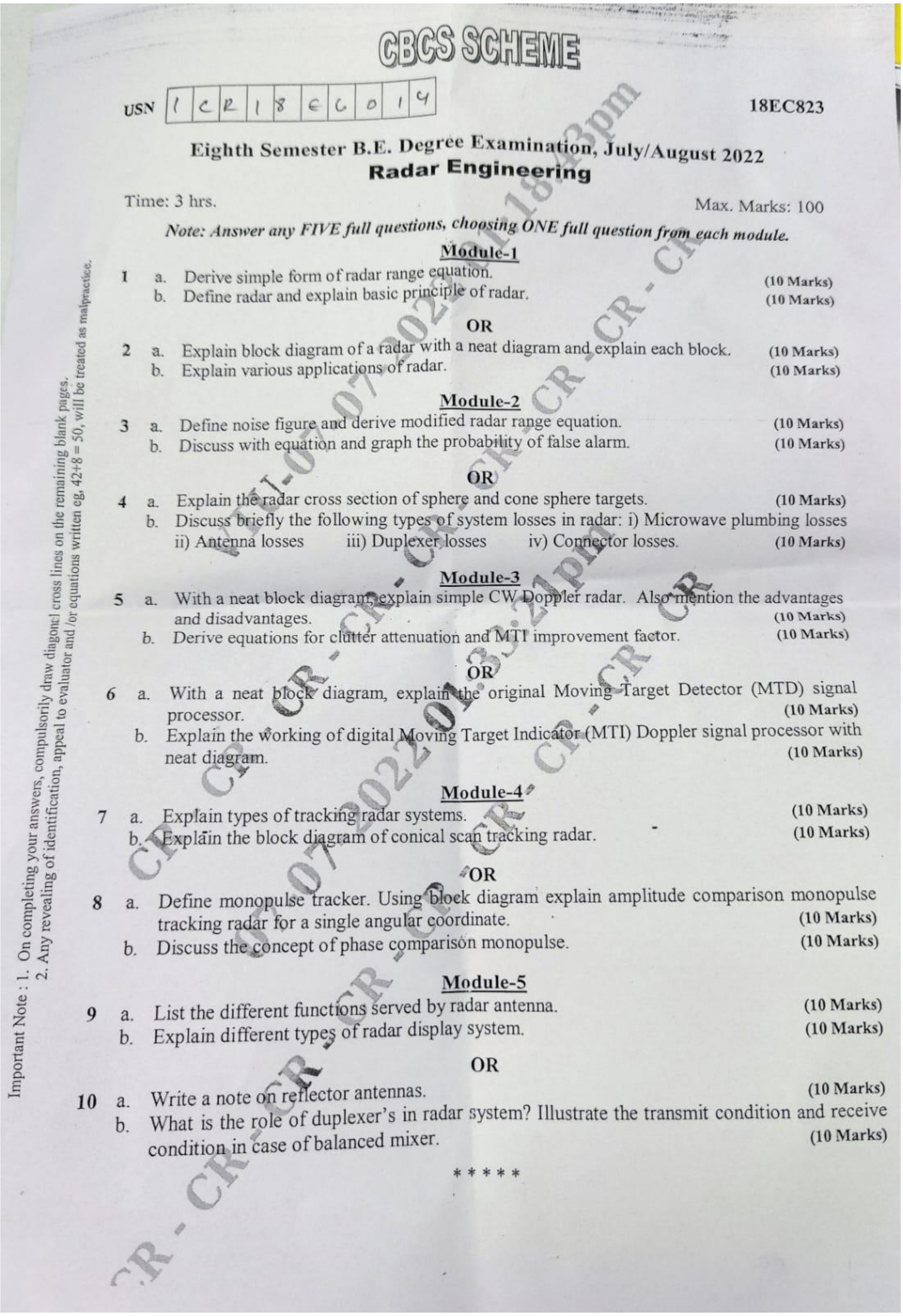


CBCS SCHEME

USN 1CR18EC014 18EC823

Eighth Semester B.E. Degree Examination, July/August 2022
Radar Engineering

Time: 3 hrs. Max. Marks: 100

Note: Answer any FIVE full questions, choosing ONE full question from each module.

Important Note : 1. On completing your answers, compulsorily draw diagonal cross lines on the remaining blank pages.
2. Any revealing of identification, appeal to evaluator and /or equations written eg, 42+8 = 50, will be treated as malpractice.

Module-1

1 a. Derive simple form of radar range equation. (10 Marks)
b. Define radar and explain basic principle of radar. (10 Marks)

OR

2 a. Explain block diagram of a radar with a neat diagram and explain each block. (10 Marks)
b. Explain various applications of radar. (10 Marks)

Module-2

3 a. Define noise figure and derive modified radar range equation. (10 Marks)
b. Discuss with equation and graph the probability of false alarm. (10 Marks)

OR

4 a. Explain the radar cross section of sphere and cone sphere targets. (10 Marks)
b. Discuss briefly the following types of system losses in radar: i) Microwave plumbing losses ii) Antenna losses iii) Duplexer losses iv) Connector losses. (10 Marks)

Module-3

5 a. With a neat block diagram, explain simple CW Doppler radar. Also mention the advantages and disadvantages. (10 Marks)
b. Derive equations for clutter attenuation and MTI improvement factor. (10 Marks)

OR

6 a. With a neat block diagram, explain the original Moving Target Detector (MTD) signal processor. (10 Marks)
b. Explain the working of digital Moving Target Indicator (MTI) Doppler signal processor with neat diagram. (10 Marks)

Module-4

7 a. Explain types of tracking radar systems. (10 Marks)
b. Explain the block diagram of conical scan tracking radar. (10 Marks)

OR

8 a. Define monopulse tracker. Using block diagram explain amplitude comparison monopulse tracking radar for a single angular coordinate. (10 Marks)
b. Discuss the concept of phase comparison monopulse. (10 Marks)

Module-5

9 a. List the different functions served by radar antenna. (10 Marks)
b. Explain different types of radar display system. (10 Marks)

OR

10 a. Write a note on reflector antennas. (10 Marks)
b. What is the role of duplexer's in radar system? Illustrate the transmit condition and receive condition in case of balanced mixer. (10 Marks)

* * * * *

SOLUTION

1 (a) Radar Equation Derivation

Radar Equation Derivation:

The radar equation relates the range of the radar to the characteristics of transmitter, receiver, target and environment. It is useful for determining the maximum range at which radar can detect a target. If the transmitting antenna used is isotropic in nature, the power density is given by,
Power density at a range, R from an isotropic antenna is

$P_{is} = P_t/4\pi R^2$ ----------------- (1)

If a directive antenna of gain, G is used, the power density is given by,

Power density at a range, R from a directive antenna is

$P_{dic} = P_t G/4\pi R^2$ ----------------- (2)

The radiated back power density is given by,

$P_{rerad} = P_t G/4\pi R^2 . \sigma/4\pi R^2$

Where σ – radar cross section

The received signal power, Pr = radiated poor density x effected area

ie, $Pr = P_t G \sigma A_e/(4\pi)^2 R^4$.

The maximum range of radar, R_{max} is the distance beyond which the target cannot be detected. It occur when the received signal power, Pr = minimum detectable signal, S_{min}.

Therefore, $S_{min} = P_t G \sigma A_e/(4\pi)^2 R_{max}^4$.

$R_{max} = [P_t G \sigma A_e/(4\pi)^2 \; S_{min}]^{1/4}$

This is the fundamental form of radar range equation.

If the same antenna is used for transmitting and receiving the relation between gain and effective area is

$G = 4\pi A_e/\lambda^2$
$A_e = \rho a A$

Where, ρa – aperture

Therefore, $R_{max} = [P_t 4\pi A_e \sigma A_e/ \lambda 2 (4\pi)^2 \; S_{min}]^{1/4}$

$$\boxed{\mathbf{R_{max} = [P_t \sigma A_e^2/ 4\pi \, \lambda 2 \; S_{min}]^{1/4}}}$$

1(b)
Radar (radio detection and ranging) is a detection system that uses radio waves to determine the distance (ranging), angle, and radial velocity of objects

Radar Principle

The electronic principle on which radar operates is very similar to the principle of sound-wave reflection. If you shout in the direction of a sound-reflecting object (like a rocky canyon or cave), you will hear an echo. If you know the speed of sound in air, you can then estimate the distance and general direction of the object. The time required for an echo to return can be roughly converted to distance if the speed of sound is known.

Radar uses electromagnetic energy pulses in much the same way, as shown in Figure 1. The radio-frequency (rf) energy is transmitted to and reflected from the reflecting object. A small portion of the reflected energy returns to the radar set. This returned energy is called an ECHO, just as it is in sound terminology. Radar sets use the echo to determine the direction and distance of the reflecting object.

The term RADAR is an acronym made up of the words:

RAdio (Aim) **D**etecting **A**nd **R**anging

The term “RADAR” was officially coined as an acronym by U.S. Navy Lieutenant Commander Samuel M. Tucker and F. R. Furth in November 1940. The acronym was by agreement adopted in 1943 by the Allied powers of World War II and thereafter received general international acceptance. [1]

It refers to electronic equipment that detects the presence of objects by using reflected electromagnetic energy. Under some conditions, radar system can measure the direction, height, distance, course, and speed of these objects. The frequency of electromagnetic energy used for radar is unaffected by darkness and also penetrates fog and clouds. This permits radar systems to determine the position of airplanes, ships, or other obstacles that are invisible to the naked eye because of distance, darkness, or weather.

Modern radar can extract widely more information from a target's echo signal than its range. But the calculating of the range by measuring the delay time is one of its most important functions.

Basic design of radar system

The following figure shows the operating principle of a primary radar set. The radar antenna illuminates the target with a microwave signal, which is then reflected and picked up by a receiving device. The electrical signal picked up by the receiving antenna is called echo or return. The radar signal is generated by a powerful transmitter and received by a highly sensitive receiver.

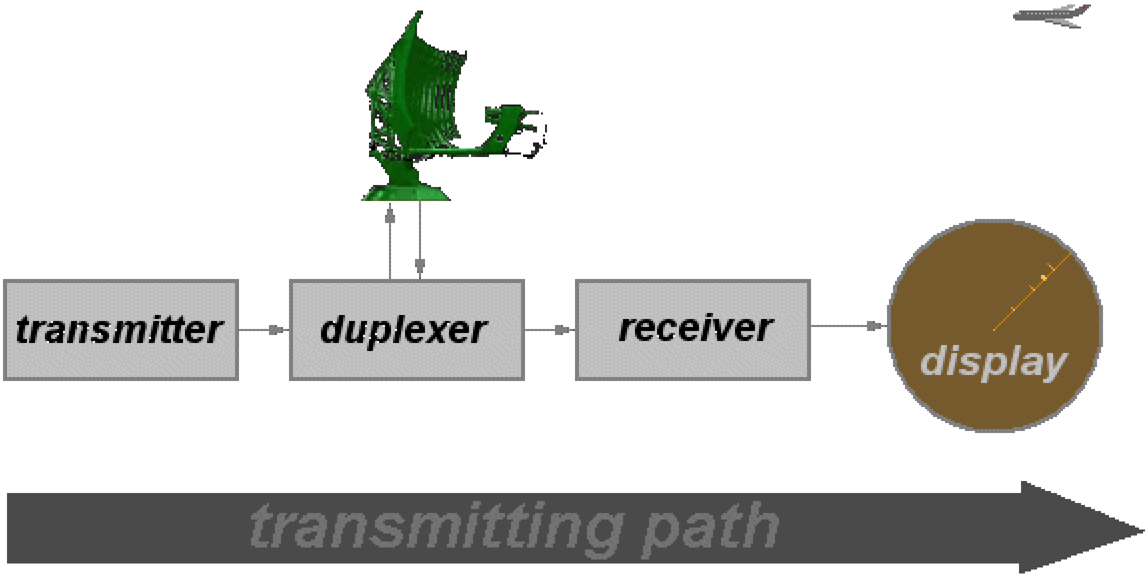


Figure 2: Block diagram of a primary radar (interactive picture)

All targets produce a diffuse reflection i.e. it is reflected in a wide number of directions. The reflected signal is also-called scattering. **Backscatter** is the term given to reflections in the opposite direction to the incident rays.

Radar signals can be displayed on the traditional plan position indicator (PPI) or other more advanced radar display systems. A PPI has a rotating vector with the radar at the origin, which indicates the pointing direction of the antenna and hence the bearing of targets.

- **Transmitter**
  The radar transmitter produces the short duration high-power rf pulses of energy that are into space by the antenna.
- **Duplexer**
  The duplexer alternately switches the antenna between the transmitter and receiver so that only one antenna need be used. This switching is necessary because the high-power pulses of the transmitter would destroy the receiver if energy were allowed to enter the receiver.
- **Receiver**
  The receivers amplify and demodulate the received RF-signals. The receiver provides video signals on the output.
- **Radar Antenna**
  The Antenna transfers the transmitter energy to signals in space with the required distribution and efficiency. This process is applied in an identical way on reception.
- **Indicator**
  The indicator should present to the observer a continuous, easily understandable, graphic picture of the relative position of radar targets.
  The radar screen (in this case a PPI-scope) displays the produced from the echo signals bright blibs. The longer the pulses were delayed by the runtime, the further away from the center of this radar scope they are displayed. The direction of the deflection on this screen is that in which the antenna is currently pointing.

2(a) **Definition**: **RADAR** is an abbreviation for **RA**dio **D**etection **A**nd **R**anging. A system used for detecting and locating the presence of objects like ships, vehicles, aircraft etc. by radiating electromagnetic signal in space is known as the **Radar system**.

Basically, radar is used to collect the information related to the object or target like its range and location by radiating electromagnetic energy and examining the echo received from the distant object.

Content: Radar System

History

Radar was invented for military purpose before **world war II** in order to secretly detect the presence of unknown objects. Initially, the transmitting tubes were not that much powerful thus worked at a very low frequency of about **60 MHz**.

But further development in the field and use of magnetrons has extended the frequency range to a higher level.

Radar system

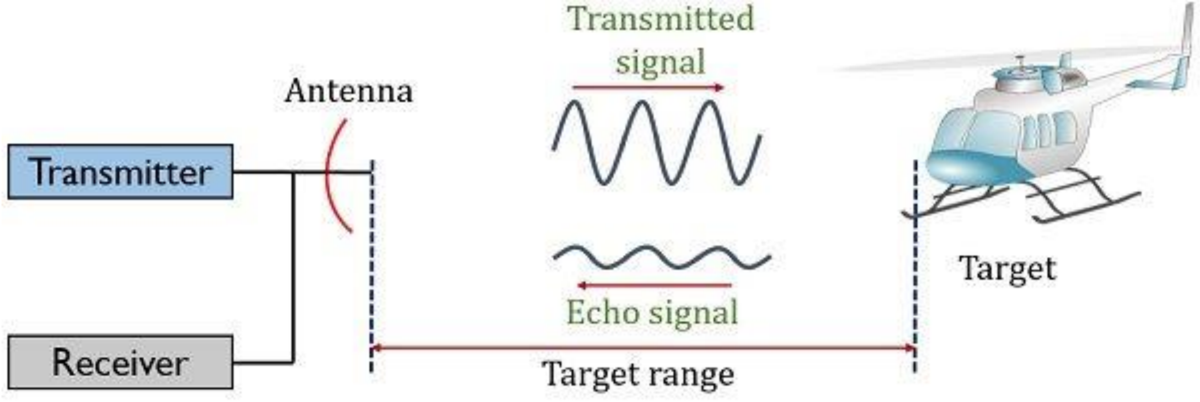
According to the operation performed by the radar, it is very important to have a system that can accurately detect the presence of the target. So for this purpose, narrow beam antennas with short-wavelength are used that correspond to upper UHF and microwave frequencies.

Thus the US army developed microwave radar system and such a system can determine the position of the object to within **0.1°** and **25** **meters**.

Principle

A radar system operates in a way that it radiates electromagnetic energy into space and detects various aspects related to objects by analysing the echo generated when the radiated energy gets re-radiated by the object.

The figure below shows the basic principle of radar:



Basic Principle of Radar

Electronics Desk

The electromagnetic signal is produced by the transmitter unit and is radiated in space by the radar antenna. While the receiver performs extraction of information from the signal received by the radar antenna.

We know whenever an electromagnetic wave is transmitted by the system then it reflects or re-radiates some of its parts on experiencing a variation in the conductivity of the medium. This variation in conductivity arises due to the presence of an object either stationary or moving. Thereby producing an echo.

The radar system receives the echo by the help of an antenna in order to analyse it and have the location of the object.

Now the question arises **how the reception of an echo can determine the range and location of the target**?

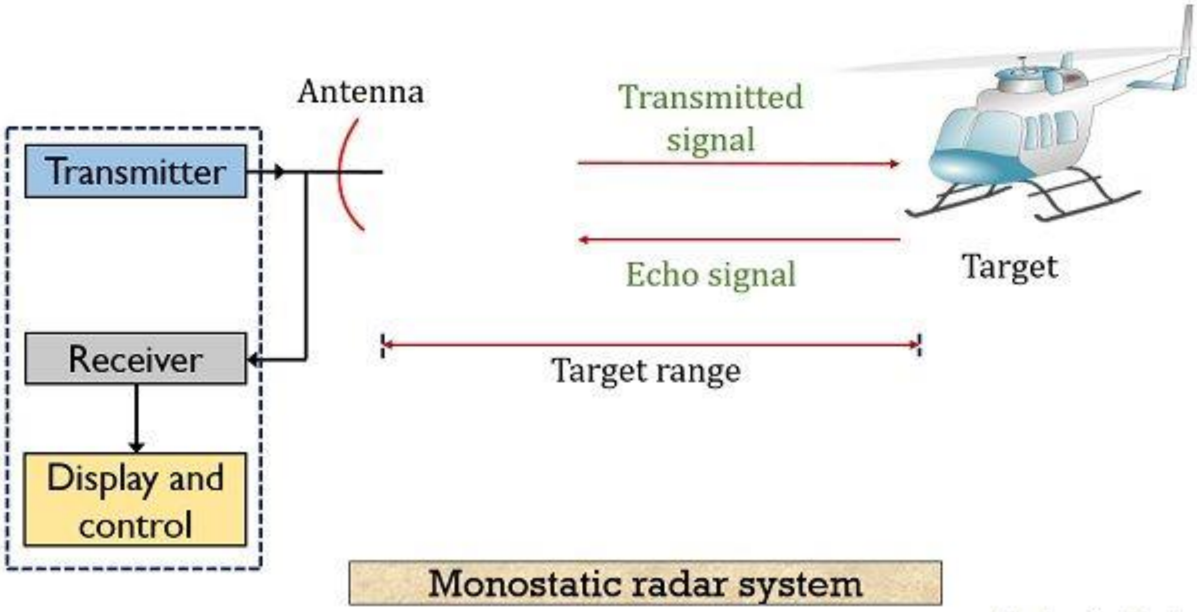
Range specifies the distance between the target and the radar system.

The range to an object is determined by the measurement of the time taken by the radiated signal to reach the object and come back to the radar. And the location of the stationary object in the space is determined from the angle pointed by the antenna when the echo received is of maximum amplitude.

For a moving object because of the Doppler effect, there exists a shift in the frequency of the re-radiated signal. And the frequency shift shows proportionality with the radial velocity of the object.

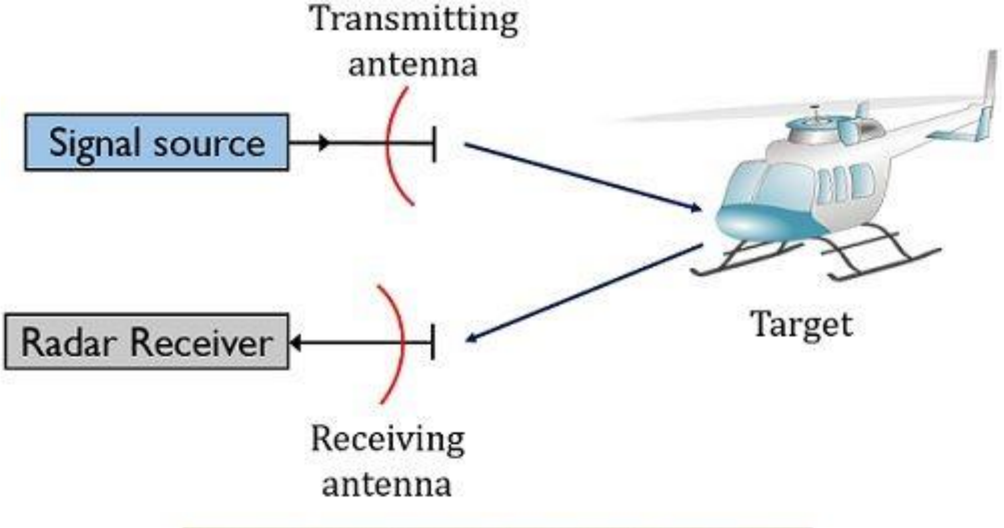
Basically, there exist two major radar systems:

Monostatic Radar System: A monostatic radar system uses a single antenna for transmission as well as reception purpose.



Monostatic radar system

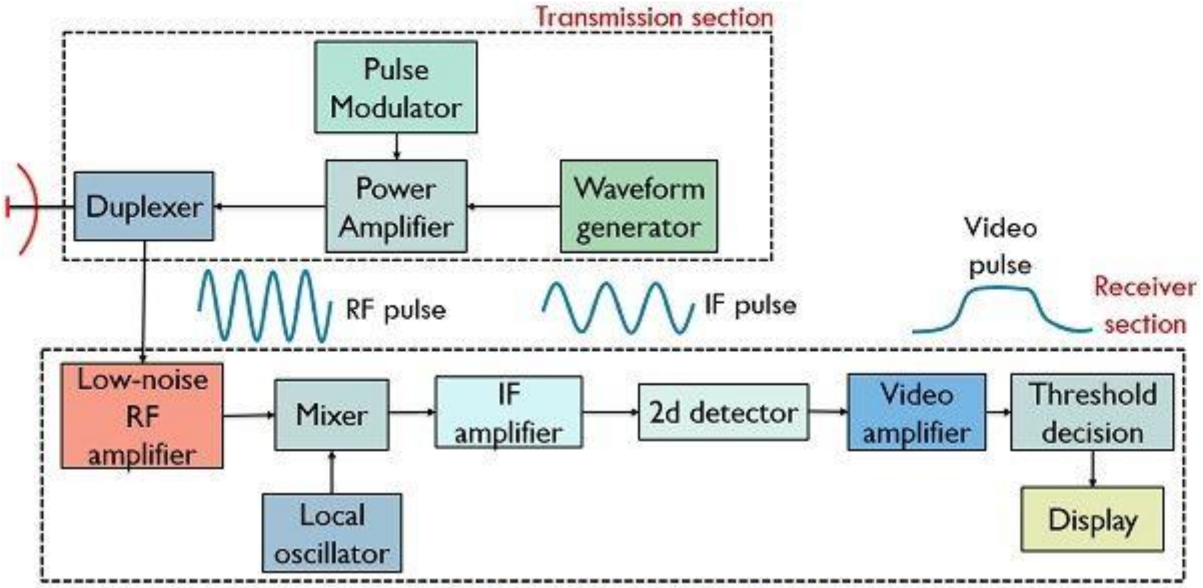
Bistatic Radar System: A bistatic radar system utilizes independent antennas for transmission and reception of the signal.



Bistatic radar system

Block Diagram of Radar System

The figure below shows the block diagram representation of radar:



Block Diagram of Radar system

Electronics Desk

We know that a radar system has a transmitting and receiving section. And both the sections perform their respective operation.

Let us now discuss how radar operates:

Transmitter Section: The transmitter section is composed of the following units:

1. Waveform Generator: The waveform generator (usually a magnetron) generates a radar signal at low power which is to be transmitted into space.

2. Transmitter: The signal generated by the waveform generator is fed to the transmitter. The transmitter section can be a magnetron, travelling wave tube or a transistor amplifier. In the case of pulse radar, magnetrons are widely used as transmitters but whenever there exists a need for high average power then amplifiers are used.

3. Pulse modulator: A pulse modulator is used to build synchronization between the waveform generator and transmitter.

The pulse modulator causes the turning on and off of the power amplifier according to the input pulses generated by the waveform generator.

4. Duplexer: A duplexer is basically used to form isolation between transmitter and receiver section. A duplexer allows the use of a single antenna for both transmission and reception purpose. However, both the sections operate at different power level, therefore, a duplexer is used to isolate the two section.

Thus the signal from the transmitter is provided to the antenna through the duplexer. As the duplexer short circuits the input of the receiver section.

Also, the re-radiated signal received by the common antenna is fed to the receiver section using duplexer.

Receiver Section: The following components are present inside the receiver section:

5. Low noise RF amplifier: The receiver must be superheterodyne. The unit acts as the input stage for the receiver section. The RF amplifier generates an RF pulse which is proportional to the echo of the transmitted signal.

6. Mixer and Local Oscillator: The RF pulse received from the low noise RF amplifier is converted into an IF pulse. Usually, the RF amplifier acts at the input stage of the receiver section but sometimes the mixer acts at the input stage by eliminating the RF amplifier. But this leads to a less sensitive receiving section due to the high noise figure of the mixer.

7. IF amplifier: The IF pulse generated by the mixer circuit is amplified by the IF amplifier. It acts as a matched filter and increases the SNR of the received signal. Also, it enhances the echo detecting ability of the receiver section by reducing the effects of unwanted signals. The receiver's bandwidth is associated with the bandwidth of the IF stage.

8. 2nd Detector or Demodulator: This unit is nothing but a crystal diode that performs demodulation of the signal by separating the transmitted signal from the carrier.

9. Video Amplifier: This unit amplifies the received signal to a level that can be displayed on the screen.

10. Threshold decision: This unit makes the decision about the existence of the target in space. Basically, it has some threshold limit set which is compared with the magnitude of the received signal.
If the threshold value is surpassed by the output signal, then this shows that presence of the target. Otherwise, it is assumed that only the noise component is present in the space.

11. Display: The display unit shows the final output of the receiver section. **PPI** i.e., plan position indication is typically used as the radar display unit.
It presents the range and location of the object by mapping it in polar coordinates. PPI is implemented with CRT.
The output signal modulates the electron beam of the cathode ray tube in order to permit the electron beam to sweep from the centre in the outward direction of the tube. And this sweep shows rotation in synchronization with the pointing of the antenna.

Applications of Radar

Radar systems find its applications in a wide variety of fields like military, air traffic control, in weather forecasting, remote sensing, astronomy, mapping etc.

1. **Military**: It is the major application of radar and is one of the most important parts of the air defence system. Radar is used for the purpose of navigation and surveillance in the military for secure operations.
2. **Air traffic controlling**: Radar is used to control the air traffic in the air routes and airports. High-resolution radars are used for analysing the aircraft and ground vehicular traffic at the airports.
3. **Ship safety**: Radars are used to provide safety measures to the ships in bad visibility conditions by giving alerts about the existence of other ships in the route.
4. **Remote sensing**: Radar is a remote sensor by nature as they can sense the geophysical objects. And these are used forecasting of weather conditions along with agricultural conditions and environmental pollution.

2(b) **Applications And Uses of RADAR**

Applications and uses of Radar are given below:

- Military
- Law enforcement
- Space
- Remote sensing of environment
- Aircraft navigation
- Ship Navigation
- Air Traffic Controller

RADARs Used In Military

RADARs have a wide range of usage in military operations. They are used in Naval, Ground as well as Air defence purposes. They are used for detection, tracking and surveillance purposes also. Weapon control and missile guidance often use various types of RADARs.

RADARs Used In Law Enforcement

Law enforcement, especially highway police, has extensive use of RADARs during a pursuit to measure the speed of a vehicle. Due to bad weather conditions, when the satellite cannot get a clear image of traffic and barricades, RADARs are used to get the desired results.

RADARs Used In Space

RADARs in satellites are used for remote sensing. RADARs are used to track and detect satellites and spacecraft. They are also used for safely landing and docking spacecraft.

RADARs Used For Remote Sensing of Environment

Just like various types of waves are received by an antenna, this technology is also used to detect weather conditions of the atmosphere. It is also used for tracking the motions of planets, asteroids and other celestial bodies in the solar system.

RADARs Used In Aircraft Navigation’

Ground mapping and weather avoidance RADARs are used in aircraft to navigate them properly. This technology enables an aircraft to ensure the location of obstacles that can threaten the flight plan.

RADARs Used In Navigating Ships

Ships are guided through high resolution RADARs situated on the shores. Because of poor visibility in bad weather conditions, RADARs provide safety by warning threats. These ships often use this technology to measure the proximity of other ships and their speed on the water.

RADARs Used In in Air Traffic Controller

RADARs are used to safely control air traffic. It is used to guide aircraft for proper landing and take-off during bad weather conditions. These RADARs also detect the proximity and the altitude of the aircraft.
These were some applications and uses of RADAR. If you wish to know more, download BYJU’S – The Learning App.

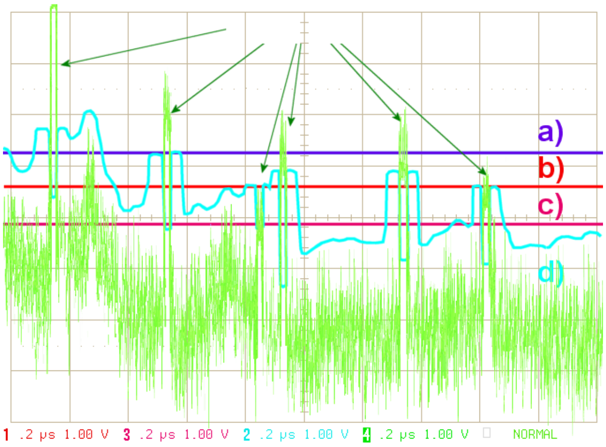
3(a) **Monostatic radar equation:**
(20.1)σPr=PtG2λ2σ(4π)3R4L
Noise spectral density at the optimum receiver output:
(20.2)b=kT0F
Signal-to-noise ratio on output from the coherent processing:
(20.3)(S/N0)=Erb=PmrTcb=PkrTNFFTb
Signal-to-noise ratio (SNR) at the noncoherent output processing (including processing gain and sampling losses):
(20.4)S/N=(S/N)0Gt
Approximate value of non-coherent post-detection integration gain of N pulses:
(20.5)Gt=2N−1
Signal-to-noise required for the detection of a Rayleigh fluctuating target (Swerling I or Swerling II with no post detection integration):
(20.6)S/N=log(Pfa)log(PD)−1
Antenna gain in the main beam axis:
(20.7)G=η4π Sλ2
Radar range:
(20.8)σσR=[PmTcG2λ2σ(4π)3(S/N0)kT0FLh]14=[PkTG2λ2(σ)NFFT(4π)3(S/N0)kT0FLh]14
where

- P_r is the received power at the receiver input (P_{cr} peak value, P_{mr} mean value)

- P_t is the transmitted power at the transmitter output (P_k peak value, P_m mean value)
- σ is the radar cross section (RCS)
- R is the radar-target range
- L_h is the microwave losses (internal, radome, propagation)
- k is the Boltzmann's constant
- T_0 is the operating temperature (≈300 K)
- F is the receiver noise figure
- E_r is the energy received during coherent processing
- T_c is the coherent processing duration
- T is the transmitted pulse width
- N_{FFT} is the number of integrated interpulse periods during T_c (coherent burst)
- S is the antenna geometrical area
- η is the illumination efficiency

3(b) False Alarm Rate

A false alarm is “an erroneous radar target detection decision caused by noise or other interfering signals exceeding the detection threshold”. In general, it is an indication of the presence of radar target when there is no valid aim. The **False Alarm Rate** (FAR) is calculated using the following formula:



real aims

Figure 1: Different threshold levels

$$FAR = \frac{false\ targets\ per\ PRT}{Number\ of\ rangecells} \quad (1)$$

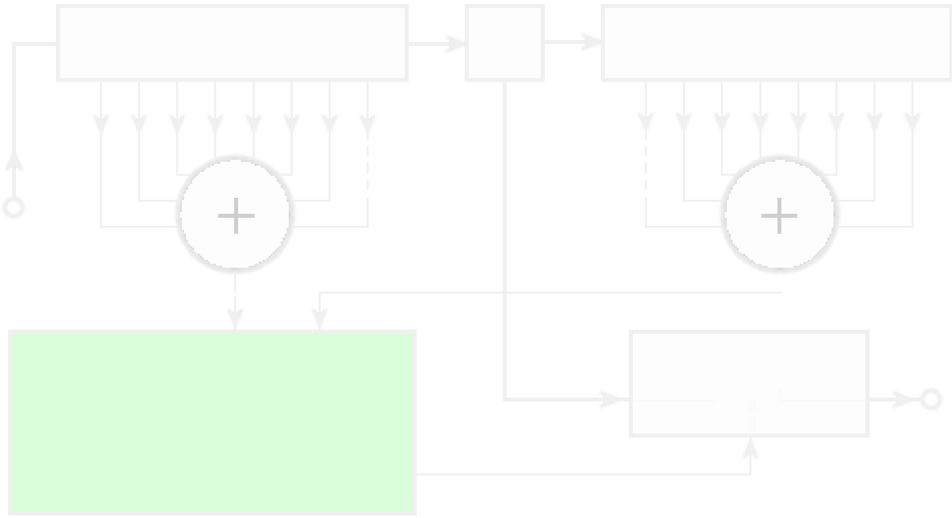
False alarms are generated when thermal noise exceeds a pre-set threshold level, by the presence of spurious signals (either internal to the radar receiver or from sources external to the radar), or by equipment malfunction. A false alarm may be manifested as a momentary blip on a cathode ray tube (CRT) display, a digital signal processor output, an audio signal, or by all of these means. If the detection threshold is set too high, there will be very few false alarms but the signal-to-noise ratio required will inhibit detection of valid targets. If the threshold is set too low, the large number of false alarms will mask detection of valid targets.

1. threshold is set too high: Probability of Detection = 66%
2. threshold is set optimal: Probability of Detection = 83%
   But one false alarm arises!
   False alarm rate = 1 / 666 = 1,5 $\cdot 10^{-3}$
3. threshold is set too low: a large number of false alarms arises!
4. threshold is set variabel: constant false-alarm rate

The false alarm rate depends on the level of all interferences, like noise, clutter or jamming. Near the radar site the influence of the fixed clutter is higher than the noise level. At large distances the influence of the noise level is higher. This has the effect, that the false alarm rate depends on the range. But the equation doesn't give any range dependences. To achieve a higher probability of detection in large distances by using a lower threshold level, the false alarm rate rises at close range.

Constant False-Alarm Rate (CFAR)

range cell under



test
Tapped digital delay line
Tapped digital delay line
RUT
Threshold
sampled
video input
CFAR
output
arithmetic logic unit
a) Cell Average: CA-CFAR, or
b) Greatest Of: CAGO-CFAR
c) Smallest Of: CASO-CFAR

Figure 2: Principle of a “Cell-averaging CFAR”- wiring.

The principle of a circuit for a constant false alarm rate was first described in 1968 by H. M. Finn and R. S. Johnson.[1]

Solutions to the false-alarm problem involve implementation of **constant false-alarm rate (CFAR)** schemes that vary the detection threshold as a function of the sensed environment. Whilst there are a large number of types of CFAR circuit, they are usually based around the ‘background averager’ (sometimes referred to as cell averaging CFAR). A simplified block diagram is shown in Figure 2.

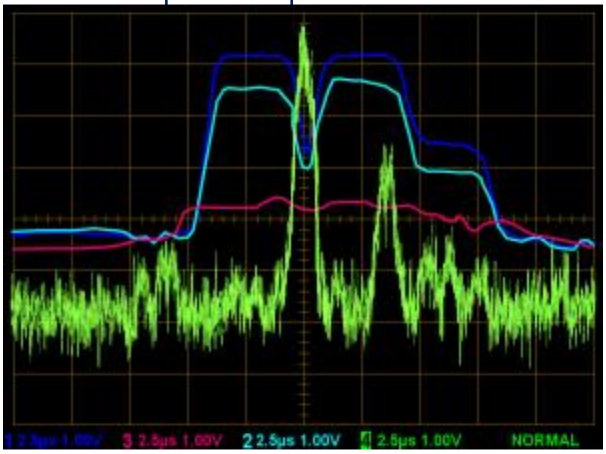
This circuit estimates the level of interference (noise or clutter) in radar range cells on either side of a range cell and uses this estimate to decide if there is a target in the cell of interest in the center. The process steps out one cell in range and is repeated until all range cells have been investigated.

The basis of the circuit is that when noise is present, the cells around the cell of interest will contain a good estimate of the noise in the tested cell, i.e. it assumes that the noise or interference is spatially or temporarily homogeneous. Theoretically the circuit will produce a constant false alarm rate, which is independent of the noise or clutter level so long as the noise has a Rayleigh distribution in all range cells investigated by the circuitry.

Cell-Averaging Constant False Alarm Rate (CA-CFAR)

In Figure 1 the graph d) denotes a customized profile of the threshold to the level of the noise floor. The interference at the beginning of the deflection, which would cause for the threshold a) a false alarm, also reaches a critical level here. However, the third echo signal, which is so weak that it would be lost even under the optimal threshold b), will be detected in the CFAR.

The circuit in Figure 2 shows a very simplified schematic. The sum-signs stand for the function as per the equation:



CAGO-CFAR
OS-CFAR
CA-CFAR

Figure 3: Comparing the thresholds of various CFAR method for the situation of two adjacent targets: the weaker target is hidden by the stronger one at the cell-averaging methods.[2]

$$Z = \frac{1}{N}\sum_{i=1}^{N} X_i \qquad (2)$$

In the CA-CFAR method this averaging is carried out in the device "arithmetic logic unit" too. The CA-CFAR graph in Figure 3 shows strong values left and right of the target but at the target itself it has got a relatively low value. This can be quite easily explained by the schematic diagram. Shortly before and shortly after the *range cell under test* (RUT, sometimes called *cell under test*, CUT), the strong amplitude of the echo signal has an impact on the average. Therefore this one raises to its maximum. During the target itself, the average is made without the amplitude of the target. The threshold will be relatively low. The

CFAR thus makes for strong targets a contrast enhancement. In a noise environment, very weak echo signals may be lost rather than in the case of a fixed threshold. One way to reduce these losses is, the both close to the RUT located cells not to include in the evaluation (in the circuit in Figure 2 indicated as dashed lines). These unused cells are then called *guard cells*. The remaining cells are called *reference window cells*.

CAGO-CFAR

In the case of *Cell-Averaging Greatest Of*-CFAR (CAGO-CFAR) the average power of clutter Z is estimated differently where both sides of the sliding window are analyzed separately. The threshold value is then defined by maximum selection between these two results. The value of Z for CAGO-CFAR is estimated as:

$$Z = \max\left(\frac{2}{N} \sum_{i=1}^{N/2} X_i \; ; \; \frac{2}{N} \sum_{i=(N/2)+1}^{N} X_i \right) \tag{3}$$

Advantages of CAGO CFAR are the small required computing power and relatively low target losses. Compared to the CA-CFAR the treatment of non-homogeneous clutter environment is improved.

Disadvantages are: the overall still low effectiveness and the possibility (typical for all CA-CFAR variants) that two adjacent targets can cover each other (see Figure 3). There are also problems during an abrupt change in the disturbance signals (for example, on the edges of fixed clutter areas).

CASO-CFAR

The *Cell-Averaging Smallest Of*-CFAR (CASO-CFAR) uses the same circuit as the CAGO-CFAR. The one and only difference is that instead of the higher value of the output signal of both delay lines now the smaller one is used. The big level of the adjacent echo signal is thus usually not used for the threshold value calculation. The possibility that two adjacent target sign can cover each other, is therefore slightly reduced.

CAOS-CFAR or OS-CFAR

Since the previous methods cannot treat equally both extremes of the interference environment (homogeneous and non-homogeneous interference environment), the method of *Ordered Statistic*-CFAR (OS-CFAR) have been developed.[2] In the block diagram in Figure 2, the two logic symbols with the plus sign are replaced by a statistical method. The amplitude values taken from the reference windows are first rank-ordered according to decreasing magnitude. A certain number of the highest values will be excluded from further processing. It can be formed an average of the remaining values again (CAOS-CFAR), and/or additional weights are made, for example, depending on the average noise level (OS-CFAR).

Here can be done also a separate division in preceding and subsequent reference window cells. Their individual results can be selected again as *Greatest Of* (OSGO-CFAR) or *Smallest Of* (OSSO-CFAR) before further processing.[3]

Advantage of the OS-CFAR is the much better effectiveness of the preparation of the threshold. Adjacent echo signals can no longer cover each other. The major disadvantage of the OS-CFAR is the high processing power required for performing the sorting algorithm. This processing power must be provided during the real-time part of radar signal processing, since the threshold calculation is still ahead of target recognition.

CASH-CFAR

The so-called CASH CFAR (*Cell Averaging Statistic Hofele*) is also a statistical method which was developed by *Franz Xaver Hofele*, an employee of the former DASA (today Cassidian electronics).[4] It is based on a series of summating elements associated with each range cell and a specific maximum-minimum detector.[5] The advantage of the CASH-CFAR algorithm is that it avoids alternate covering and aggregation of objects. Their time sidelobes resulting from the pulse compression are thereby reliably hidden by the threshold. The required processing power of the CASH-CFAR algorithm is also significantly less than that of the OS- and CAOS-CFAR algorithms with their rank-selection methods.

MAMIS-CFAR

The MAMIS-CFAR (*MAximum MInimum Statistic*) is essentially the same as the CASH-CFAR, except that a special maximum-minimum circuit replaces the adders of the CASH-CFAR (for example, as an FPGA chip). The characteristics of the MAMIS-CFAR are quite similar to those of the CASH-CFAR for the handling of block interference and of point- and extended targets.

Inverse False Alarm Rate

The false alarm rate can be converted into an inverse false alarm rate (IFAR) trivially by taking the inverse. It can be calculated as in equation (1), and then inverted. Another possibility of the calculation is over the time relation:

$$IFAR = \frac{1}{FAR} = \frac{T}{\Lambda} = T\cdot B_{tx} \qquad (4)$$

width:

FAR = False Alarm Rate
T = Average interval between two transmit pulses
Λ = Duration of the false alarm
B_{tx} = Transmitters pulse bandwidth

In the case of a simple keyed on/off modulated pulse radar, the duration of a false alarm Λ is equal to the length of the transmitted pulse τ. In the case of radar with intrapulse modulation, the duration of a false alarm can only be measured after the pulse compression. For this reason, there are also calculations into which the bandwidth B_{tx} of the transmitters pulse is used as a measure for the pulse compression rate as well as for the possible range resolution.

4(a) Radar Cross-Section

The **Radar Cross Section** σ (RCS) is an aircraft-specific quantity that depends on many factors. The computational determination of the RCS is only possible for simple bodies. The RCS of simple geometric bodies depends on the ratio of the structural dimensions of the body to the wavelength.

Practically, the RCS of a target depends on:

- the physical geometry and exterior features of the target,
- the direction of the illuminating radar,
- the radar transmitters frequency,
- the electrical properties of the target's surface.

Whereas in the design of passenger airplanes more attention is paid to effectiveness and safety, in the case of an aircraft used for military purposes, care is taken to ensure that this reflective surface is as small as possible. Measures to achieve this are referred to as *stealth technology*.

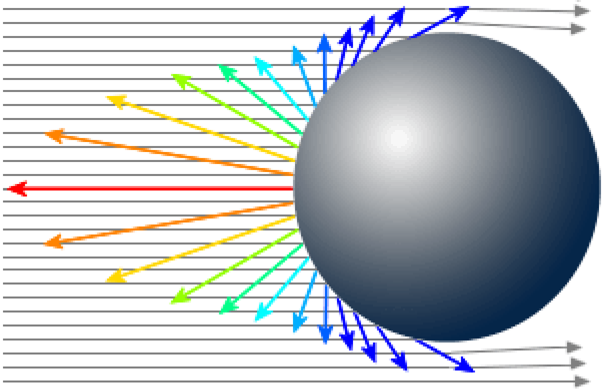


Figure 2: The reference for the radar cross section: a metallic sphere, which in the view offers a (projected) circle with an area of 1 m²

What does RCS mean for radar?

The RCS of any reflector can be seen as a ratio to an idealized reference reflector. The projected area of an equivalent isotropic reflector (that is: reflecting equally in all directions) has an RCS of exactly one square meter. Reflecting equally in all directions means: in practice, this is only performed by a spherical reflector with an ideally conducting surface. From a large distance, you cannot see the spherical shape, you can only see a circular area: the so-called projection, both with the same diameter. The diameter of this sphere must be approximately 1.128 m to be the size of one square meter. Such an equivalent isotropic reflector delivers the same power per unit measure of solid angle back to the radar, regardless of the aspect angle (i.e., regardless of the direction of the radar). Isotropic reflective does not mean that this sphere would distribute the power arriving from one direction equally in all directions. The shape and size of the distribution are different, but always the same relative to the aspect angle of the illuminating radar, regardless of the angle from which the radar illuminates this sphere. However, the reference reflector can re-radiate only the power it has received:

$$\frac{\sigma S_t}{4\pi} = S_r \cdot r^2$$

with

S_t – power density of the transmitter at the radar target in [W/m²]

S_r – scattered power density at the receiving site in [W/m²]

σS_t – is the power received and re-radiated by the radar target (in watts)

$\sigma S_t/4\pi$ – is this power per solid angle, i.e. divided by 4π steradian (in watts per steradian) *(1)*

r – radius of the sphere

This equation (1) expresses only a power balance: only the power that arrives at this reflecting object can be reflected, and this power is radiated in many directions. From this power, however, the radar can only receive a small part again. This part depends on the effective antenna area, the antenna aperture.

Since the power density generated by the radar transmitter and arriving at the reflection point is put into a ratio with the reflected power density arriving at the radar, all other influences, such as free space attenuation and distance to the radar, are eliminated. It is assumed that for a monostatic radar, the propagation conditions are the same on the outbound and return paths.

Let S_r be the power density at the receiving point of the radar, which we now see from the perspective of the reflecting object. This power density has the unit of measurement watts per unit area: W/m^2. The receiving antenna of the radar has only one effective antenna aperture A_r (this is an area and a part of the surface of a sphere). The received power of the radar antenna is then $S_r \cdot A_r$, which is the power density at the antenna multiplied by its effective aperture.

However, this antenna can receive only a very small portion of the power reflected from the object in all directions, because it occupies only a small part of the surface of the sphere. This area is proportional to the solid angle Ω occupied by the total reflected power distributed on a spherical surface:

$$\boldsymbol{\Omega = A_r / r^2} \quad (2)$$

Thus, a power density (power per solid angle) of $S_r \cdot A_r / \Omega$ arrives at the receiving antenna. The solid angle can be replaced with the expression from equation (2) and leads to

$$\boldsymbol{S_r \cdot A_r / \Omega = S_r \cdot A_r / (A_r / r^2) = S_r \cdot r^2} \quad (3)$$

The expression $S_r \cdot r^2$ thus stands for the received power per unit solid angle (in watts per steradian) and corresponds to equation (1) above. This can then be rearranged to the equation (4) used below.

Non-isotropic reference reflector

In contrast to the isotropic radiator mentioned in the antenna technology, such an isotropic reference reflector can very well be constructed in reality. It would only be very unwieldy because of its dimensions. Since the direction to the radar is known in a measurement setup, a calibrated corner reflector can also be used. As usual in antenna technology, this has a gain G compared to the isotropic reflector, which, however, can be calculated out of the measurement result later.

Computational determination of the reflective area

In the following formula, the radar cross section indicates an effective area that captures the incoming wave and re-radiates it into space. Thus, only a power density caused by the surface of the sphere $(4\pi r^2)$ arrives at the receiving antenna of the radar. The radar cross section σ is defined as:

$$\boldsymbol{\sigma = 4\pi r^2 \cdot \frac{S_r}{S_t}} \quad (4)$$

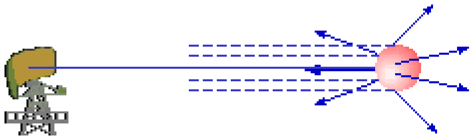
where

σ: apparent area in [m²], measure of the backscattering ability.

S_t: power density of the transmitter at the radar target in [W/m²]

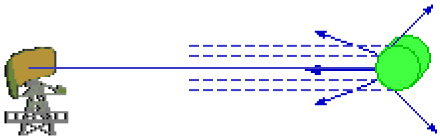
S_r: scattered power density at the receiving location in [W/m²]

The following formulas for calculation of the radar cross section are valid under the condition of optical, i.e., frequency-independent reflection at bodies that are much further away from the radar than the wavelength and which are much larger than the used wavelength of the radar.



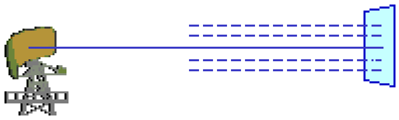
Reflection from a sphere

$$\sigma = \pi r^2 \qquad (5)$$



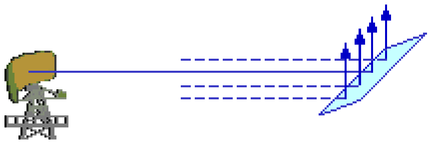
Reflection at a cylinder

$$\sigma_{max} = \frac{2\pi r h^2}{\lambda} \qquad (6)$$



Reflection at a flat plate

$$\sigma_{max} = \frac{4\pi b^2 h^2}{\lambda^2} \qquad (7)$$



Reflection at an inclined plate

…actually like the previous example, if the projection of the plate to the radar is used as the surface. Only: the reflected energy is reflected in a different direction. So the scanning radar cannot receive this energy. That is why there are bistatic radars, where the emitter and the receivers are spatially separated.

Table 1: Reflection from geometric bodies

Radar cross sections for point-like targets

Targets	**RCS** [m²]	**RCS** [dB]
bird	0.01	-20
man	1	0
cabin cruiser	10	10
automobile	100	20
truck	200	23
corner reflector	20379	43.1

Table 2: RCS for Point-Like Targets

In radar technology, point-like targets are targets whose geometric dimensions are smaller than the pulse volume of the radar set. In contrast to volumetric targets (occurring mainly in weather radar), they do not completely fill the pulse volume. In radar signal processing they occupy one resolution cell (maximum two if they are exactly on the boundary).

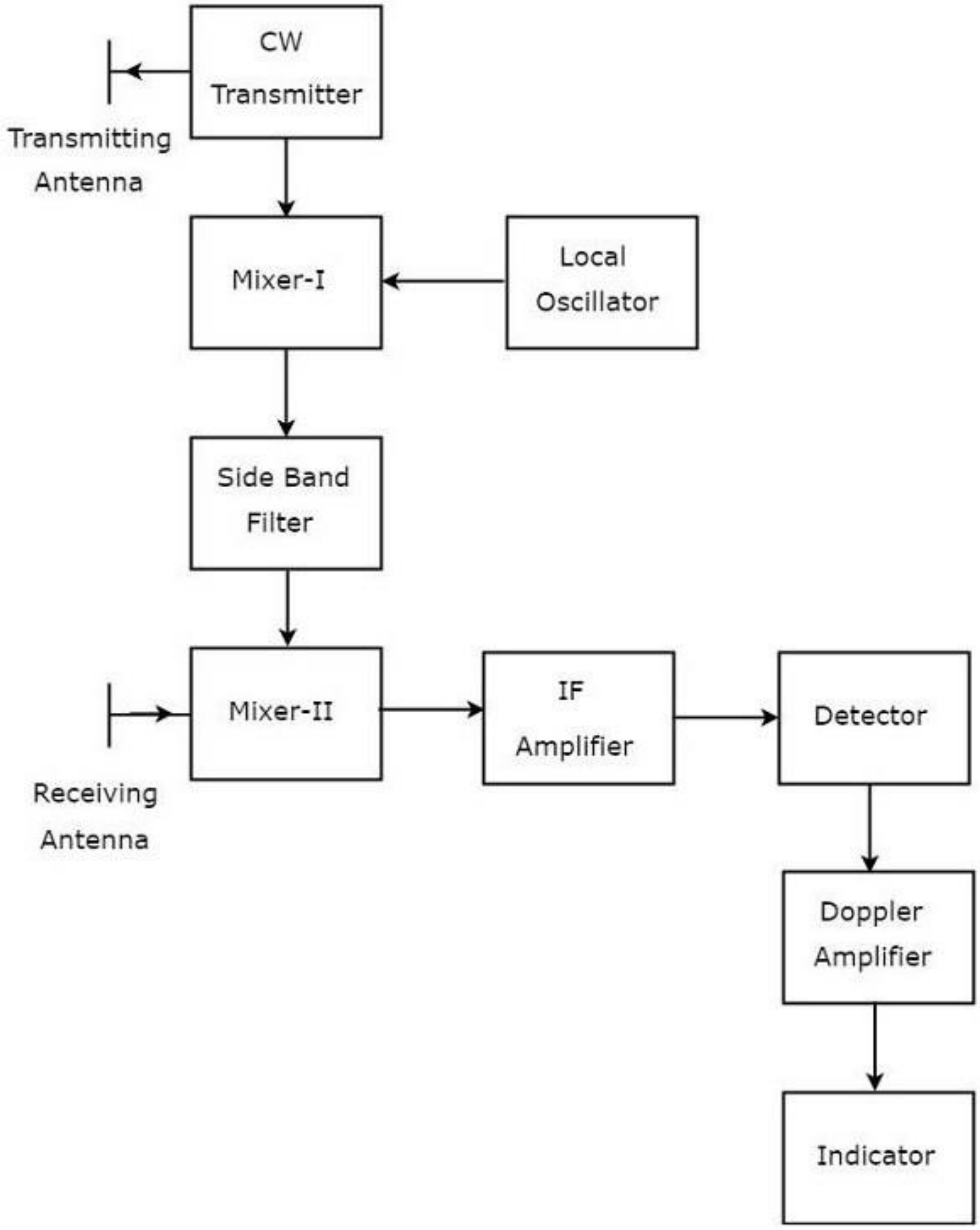
In reality, the radar cross section is composed of the sum of many small partial powers, which are located at different points of the reflecting object. Depending on the angle from which this object is illuminated, these partial areas have more or less influence, they may be obscured or their distance to the radar may differ by several multiples of half the wavelength so that they overlap partly constructively and partly destructively (see interference). The RCS is thus strongly dependent on the aspect angle and can no longer be easily calculated geometrically. It is usually a result of extensive practical measurements either on the original or with a model scaled down to the wavelength currently used in the measurement.

Some targets mentioned as examples have according to their geometrical extension a very large amount of the RCS and reflect therefore a rather large amount of the transmitted energy. The table on the right gives some examples of reflective surfaces in the X-band.

5 (a) The Radar, which operates with continuous signal (wave) for detecting non-stationary targets, is called Continuous Wave Radar or simply **CW Radar**. This Radar requires two Antennas. Among which, one Antenna is used for transmitting the signal and the other Antenna is used for receiving the signal.

Block Diagram of CW Radar

We know that CW Doppler Radar contains two Antennas − transmitting Antenna and receiving Antenna. Following figure shows the **block diagram** of CW Radar −



The block diagram of CW Doppler Radar contains a set of blocks and the **function** of each block is mentioned below.

- **CW Transmitter** − It produces an analog signal having a frequency of fofo. The output of CW Transmitter is connected to both transmitting Antenna and Mixer-I.
- **Local Oscillator** − It produces a signal having a frequency of flfl. The output of Local Oscillator is connected to Mixer-I.
- **Mixer-I** − Mixer can produce both sum and difference of the frequencies that are applied to it. The signals having frequencies of fofo and flfl are applied to Mixer-I. So, the Mixer-I will produce the output having frequencies fo+flfo+fl or fo−flfo−fl.
- **Side Band Filter** − As the name suggests, side band filter allows a particular side band frequencies − either upper side band frequencies or lower side band frequencies. The

side band filter shown in the above figure produces only upper side band frequency, i.e., fo+flfo+fl.

- **Mixer-II** − Mixer can produce both sum and difference of the frequencies that are applied to it. The signals having frequencies of fo+flfo+fl and fo±fdfo±fd are applied to Mixer-II. So, the Mixer-II will produce the output having frequencies of 2fo+fl±fdfo+fl±fd or fl±fdfl±fd.
- **IF Amplifier** − IF amplifier amplifies the Intermediate Frequency (IF) signal. The IF amplifier shown in the figure allows only the Intermediate Frequency, fl±fdfl±fd and amplifies it.
- **Detector** − It detects the signal, which is having Doppler frequency, fdfd.
- **Doppler Amplifier** − As the name suggests, Doppler amplifier amplifies the signal, which is having Doppler frequency, fdfd.
- **Indicator** − It indicates the information related relative velocity and whether the target is inbound or outbound.

CW Doppler Radars give accurate measurement of **relative velocities**. Hence, these are used mostly, where the information of velocity is more important than the actual range.

5(b) If the Radar is used for detecting the movable target, then the Radar should receive only the echo signal due to that movable target. This echo signal is the desired one. However, in practical applications, Radar receives the echo signals due to stationary objects in addition to the echo signal due to that movable target.

The echo signals due to stationary objects (places) such as land and sea are called **clutters** because these are unwanted signals. Therefore, we have to choose the Radar in such a way that it considers only the echo signal due to movable target but not the clutters.

For this purpose, Radar uses the principle of Doppler Effect for distinguishing the non-stationary targets from stationary objects. This type of Radar is called Moving Target Indicator Radar or simply, **MTI Radar**.

According to **Doppler effect**, the frequency of the received signal will increase if the target is moving towards the direction of Radar. Similarly, the frequency of the received signal will decrease if the target is moving away from the Radar.

Types of MTI Radars

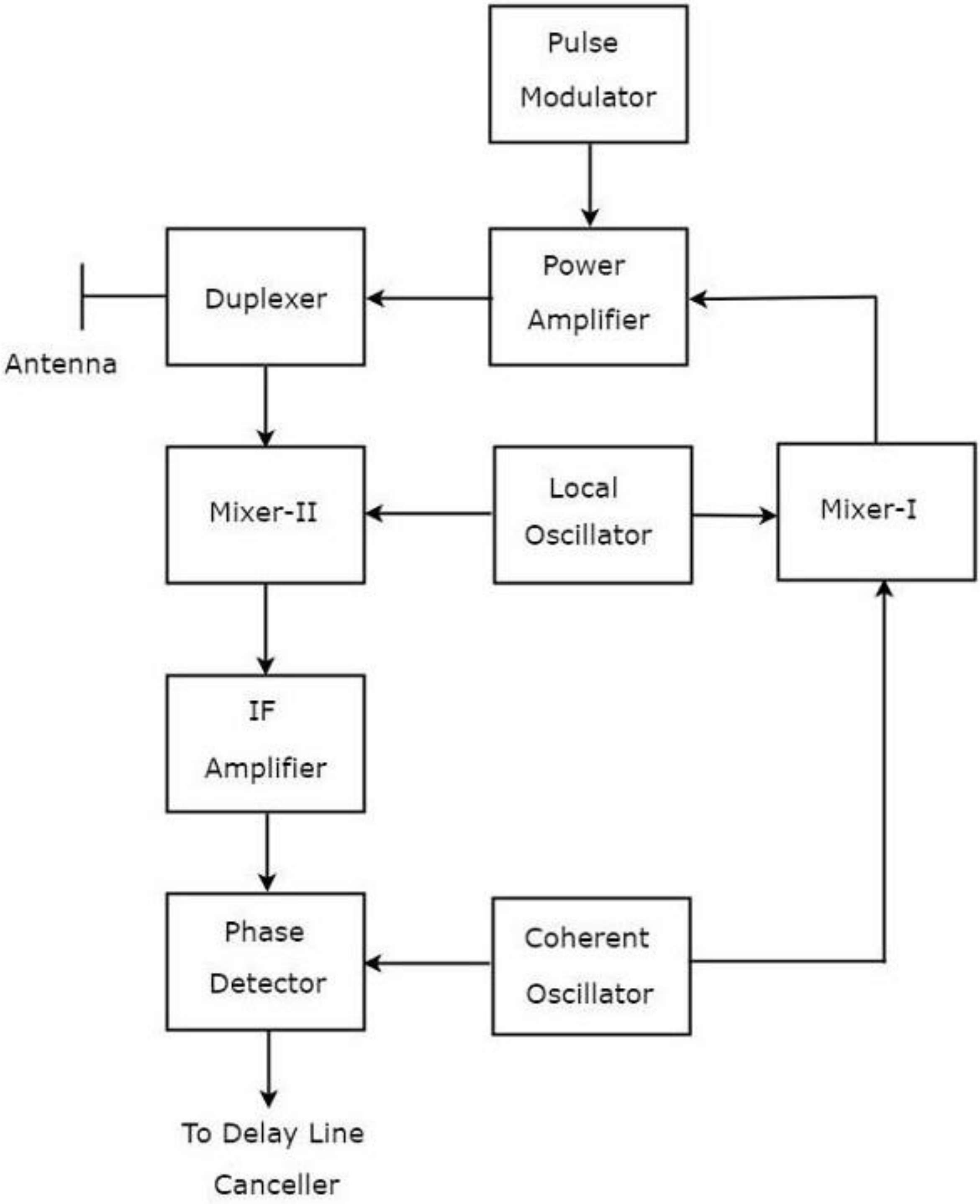
We can classify the MTI Radars into the following **two types** based on the type of transmitter that has been used.

- MTI Radar with Power Amplifier Transmitter
- MTI Radar with Power Oscillator Transmitter

Now, let us discuss about these two MTI Radars one by one.

MTI Radar with Power Amplifier Transmitter

MTI Radar uses single Antenna for both transmission and reception of signals with the help of Duplexer. The **block diagram** of MTI Radar with power amplifier transmitter is shown in the following figure.



The **function** of each block of MTI Radar with power amplifier transmitter is mentioned below.

- **Pulse Modulator** − It produces a pulse modulated signal and it is applied to Power Amplifier.
- **Power Amplifier** − It amplifies the power levels of the pulse modulated signal.
- **Local Oscillator** − It produces a signal having stable frequency $f_l$fl. Hence, it is also called stable Local Oscillator. The output of Local Oscillator is applied to both Mixer-I and Mixer-II.
- **Coherent Oscillator** − It produces a signal having an Intermediate Frequency, $f_c$fc. This signal is used as the reference signal. The output of Coherent Oscillator is applied to both Mixer-I and Phase Detector.

- **Mixer-I** − Mixer can produce either sum or difference of the frequencies that are applied to it. The signals having frequencies of flfl and fcfc are applied to Mixer-I. Here, the Mixer-I is used for producing the output, which is having the frequency fl+fcfl+fc.
- **Duplexer** − It is a microwave switch, which connects the Antenna to either the transmitter section or the receiver section based on the requirement. Antenna transmits the signal having frequency fl+fcfl+fc when the duplexer connects the Antenna to power amplifier. Similarly, Antenna receives the signal having frequency of fl+fc±fdfl+fc±fd when the duplexer connects the Antenna to Mixer-II.
- **Mixer-II** − Mixer can produce either sum or difference of the frequencies that are applied to it. The signals having frequencies fl+fc±fdfl+fc±fd and flfl are applied to Mixer-II. Here, the Mixer-II is used for producing the output, which is having the frequency fc±fdfc±fd.
- **IF Amplifier** − IF amplifier amplifies the Intermediate Frequency (IF) signal. The IF amplifier shown in the figure amplifies the signal having frequency fc+fdfc+fd. This amplified signal is applied as an input to Phase detector.

Phase Detector − It is used to produce the output signal having frequency fdfd from the applied two input signals, which are having the frequencies of fc+fdfc+fd and fcfc. The output of phase detector can be connected to Delay line canceller.

MTI Radar with Power Oscillator Transmitter

The block diagram of MTI Radar with power oscillator transmitter looks similar to the block diagram of MTI Radar with power amplifier transmitter. The blocks corresponding to the receiver section will be same in both the block diagrams. Whereas, the blocks corresponding to the transmitter section may differ in both the block diagrams.

The **block diagram** of MTI Radar with power oscillator transmitter is shown in the following figure.

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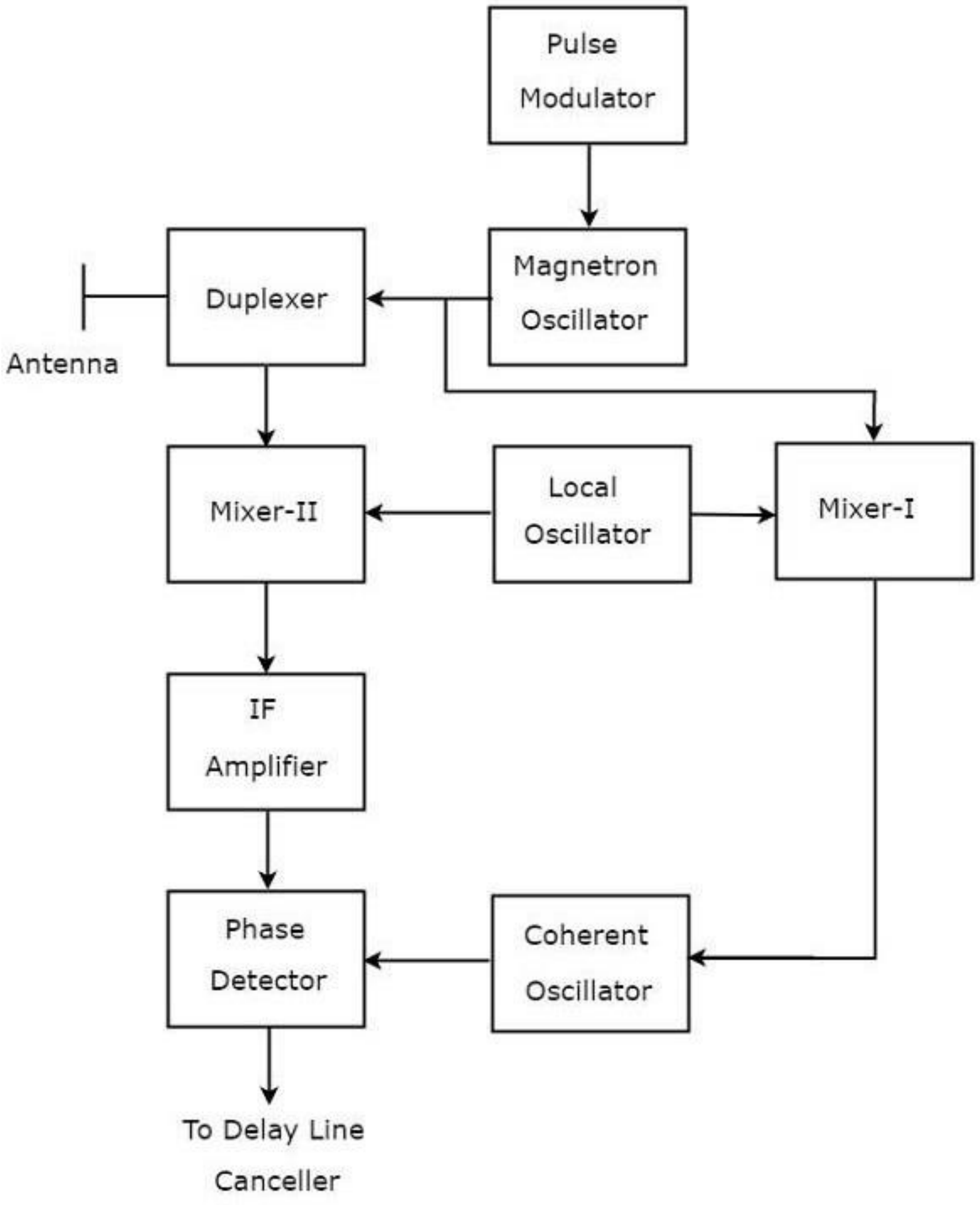

As shown in the figure, MTI Radar uses the single Antenna for both transmission and reception of signals with the help of Duplexer. The **operation** of MTI Radar with power oscillator transmitter is mentioned below.

- The output of Magnetron Oscillator and the output of Local Oscillator are applied to Mixer-I. This will further produce an **IF signal**, the phase of which is directly related to the phase of the transmitted signal.
- The output of Mixer-I is applied to the Coherent Oscillator. Therefore, the phase of Coherent Oscillator output will be **locked** to the phase of IF signal. This means, the phase of Coherent Oscillator output will also directly relate to the phase of the transmitted signal.

- So, the output of Coherent Oscillator can be used as reference signal for comparing the received echo signal with the corresponding transmitted signal using **phase detector**.

The above tasks will be repeated for every newly transmitted signal.

6(a) Basic MTI with Post-Processing

The block diagram of the used simple MTD as deployed in SkyRadar's FreeScopes ATC I module is shown in Figure 5.

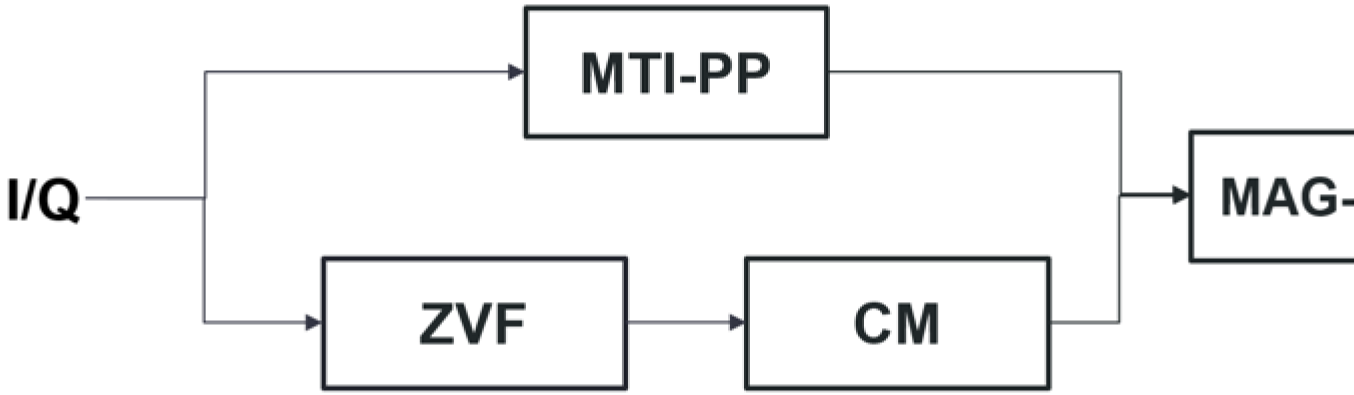

Figure 5 Moving Target Detector

In this configuration MTD consist of four sub-blocks:

1.
- MTI – PP Moving Target Indication Post-Process
- ZVF – Zero Velocity Filter
- CM – Clutter Map
- MAG-APX Magnitude Approximator

In the FreeScopes ATC II module, advanced students and trainees can compose and vary their specifc MTD by assembling it from scratch with subcomponents (MTI-PP, Zero Velocity Filter, Clutter Map, Magnitude Approximator, ...) .

Zero Velocity Filter

As the upper path of this block diagram was already discussed on the MTI article, the next block to be introduced here would be the ZVF.

The zero-velocity filter represents a filter which filters out all the doppler-targets and passes only the standing targets, doppler of which equals to zero. This filter on the lower path of MTD block diagram serves also as the real time estimator of the mean clutter power because this information will then update on real time the stored clutter map. The principle of the ZVF here is the inverse MTI.

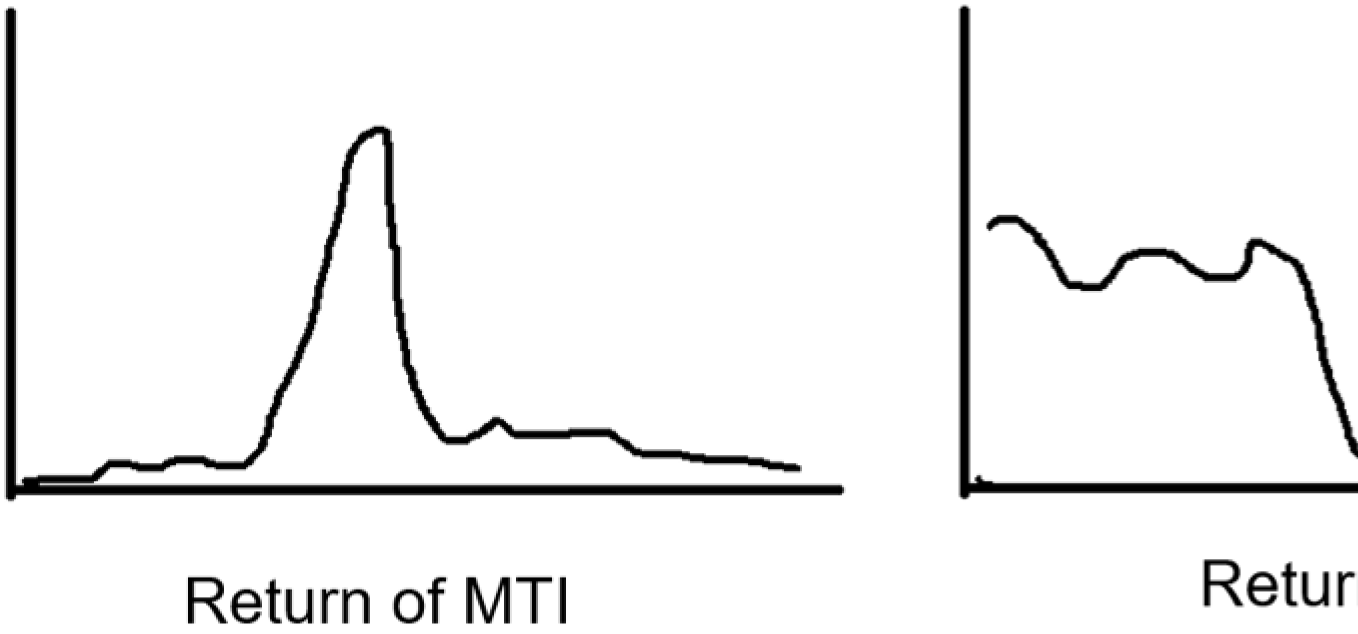

Figure 6 The difference between the MTI and inverse MTI (ZVF)

Since MTI does detect the moving targets, an inverse MTI would detect the zero-Doppler targets, in our case called the ZVF. In Figure 6., you can see the difference between these two filters and how the ZVF does estimate relevant clutter information used later as input for CM.

Clutter Map

The CM – Clutter Map is an innovation employed in MTD, for controlling the false alarm rates against spatially nonstationary clutters.

The clutter map can be understood also as a big matrix which stores the reflected clutter power for a whole radar sweep (360°) from the stationary background. After one whole radar sweep, the operation of MTD begins, and in this way also the clutter map is synchronized with the angle position of the radar, and in this way, it will be updated on real time basis from the output signal coming from ZVF.

The output signal of ZVF is coherently integrated with the with the stored signal in clutter map for the respective compass position (angular position). The updated information on the clutter map then will be forwarded to the MAG-APX for comparison with the signal coming from the MTI PP.

Magnitude Approximator

With the next block, the MAG-APX Magnitude Approximator is introduced, like the MIT Lincoln Lab, who developed the MTD for air traffic control, also we in Sky Radar team use this algorithm for comparing, detecting, and estimating clearer Doppler-target tracks on the PPI scope.

The main aim of the MAG-APX is to compare the peaks or main power targets from MTI PP and CM, and from here decide if the radar did detect a Doppler- or a stationary-object. As it can be seen in Figure 7., the output signals of the MTD algorithm represent clear tracks of moving objects on PPI scope.

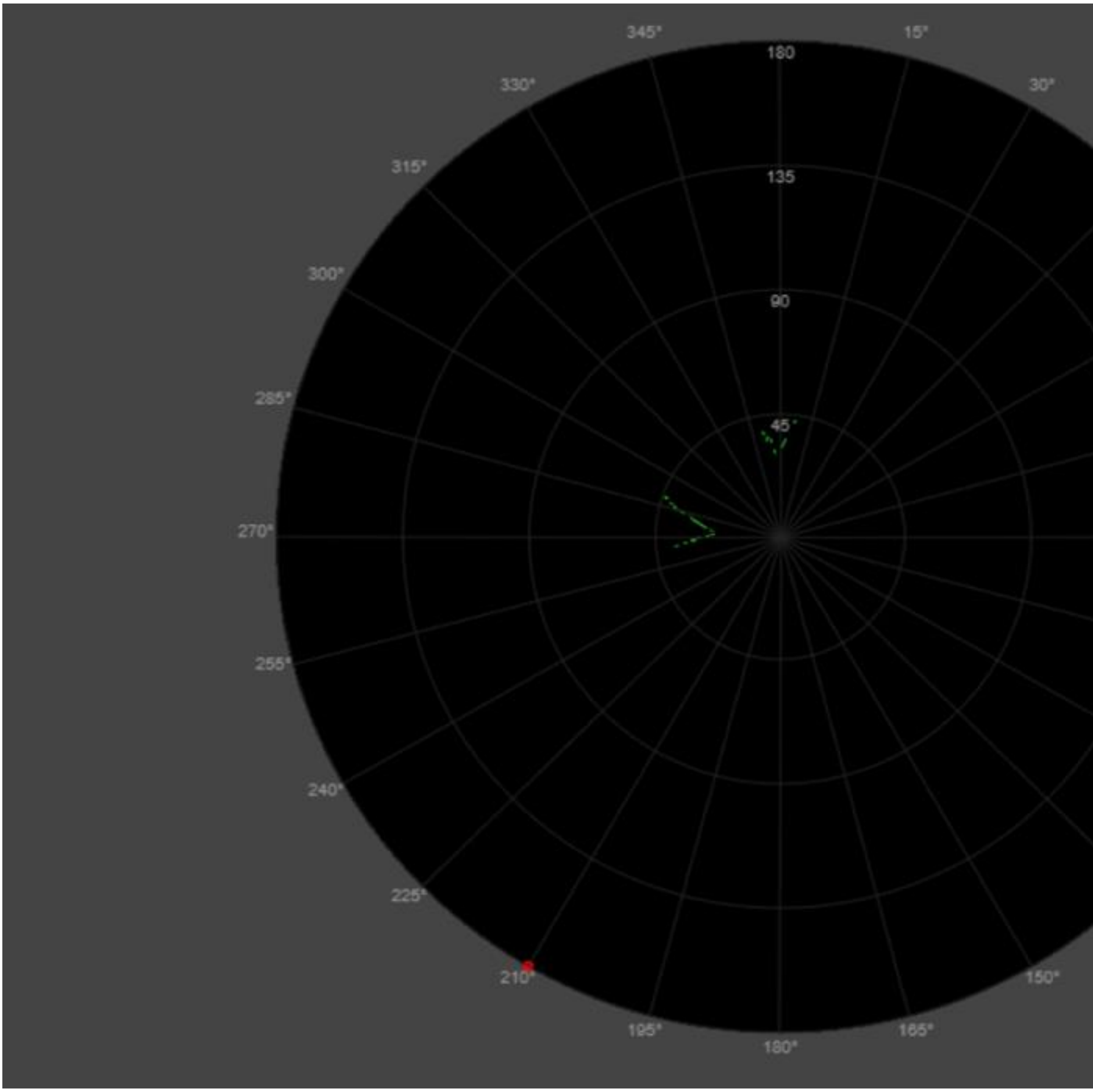

Figure 7 The output of the MTD shown in PPI scope

MTD with Doppler Filter

In the following chapter we introduce an advanced/extended version of the MTD algorithm. The MTD-DF Moving Target Detector Doppler Filter incorporates an additional filter or detector as it can be seen in Figure 8.

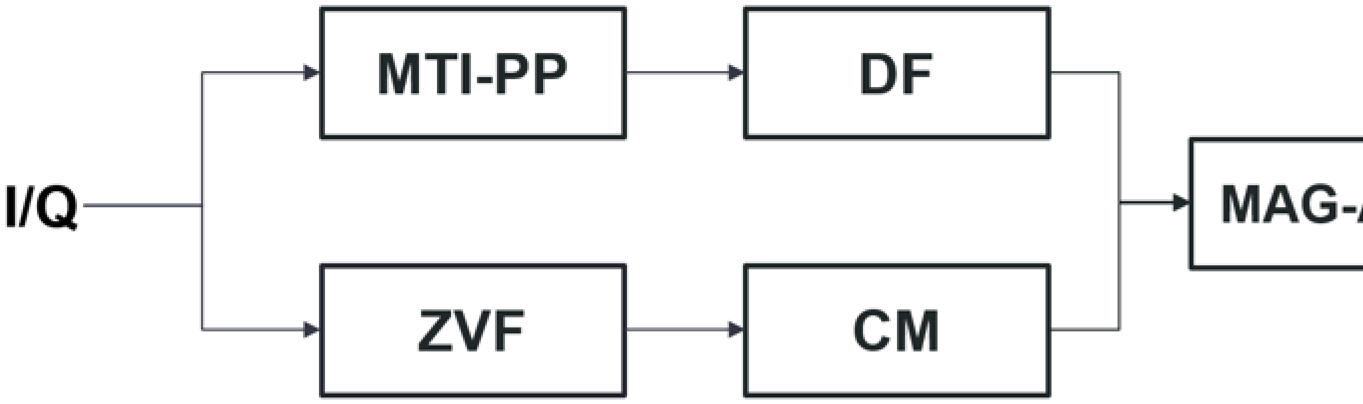

Figure 8 Moving Target Detector Doppler Filter

The difference between the MTD and MTD-DF is the additional Doppler Filter method.

The DF technique is developed as a phase detector in order to make the upper path more robust form possible complex background clutter environments. The main aim of this block is to detect the phase shifts from two consecutive pulses. These phase shifts are then compared with each other and in this case the filter serves as a plausibility method of the output signals from the MTI-PP. Two consecutive pulses which have a Doppler-frequency will not have a regular/expected phase shift in comparison with two consecutive pulses of stationary targets.

The idea of these phase shifting concept is shown in the following sketch, in Figure 9.

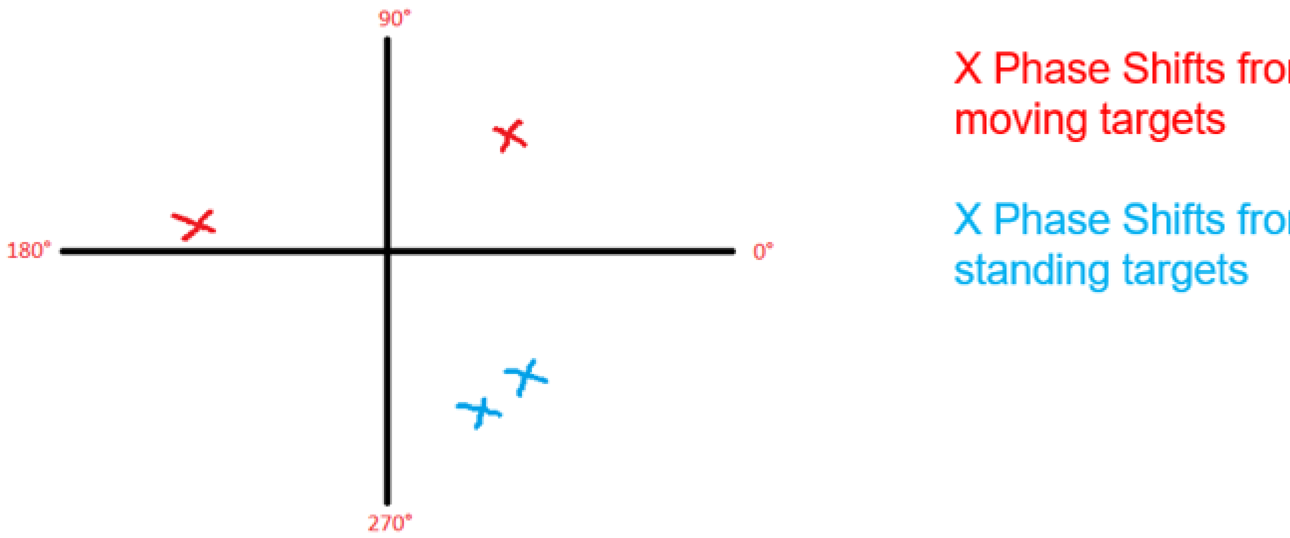

Figure 9 Phase shift detector

The additional Doppler filter algorithm makes the MTD-DF even more reliable and highly accurate for detecting Doppler-targets, in comparison with the pure MTD method. However, the simple MTD can also be deployed in more basic radar sources which do not have a Doppler feature included.

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Types of MTI Radars

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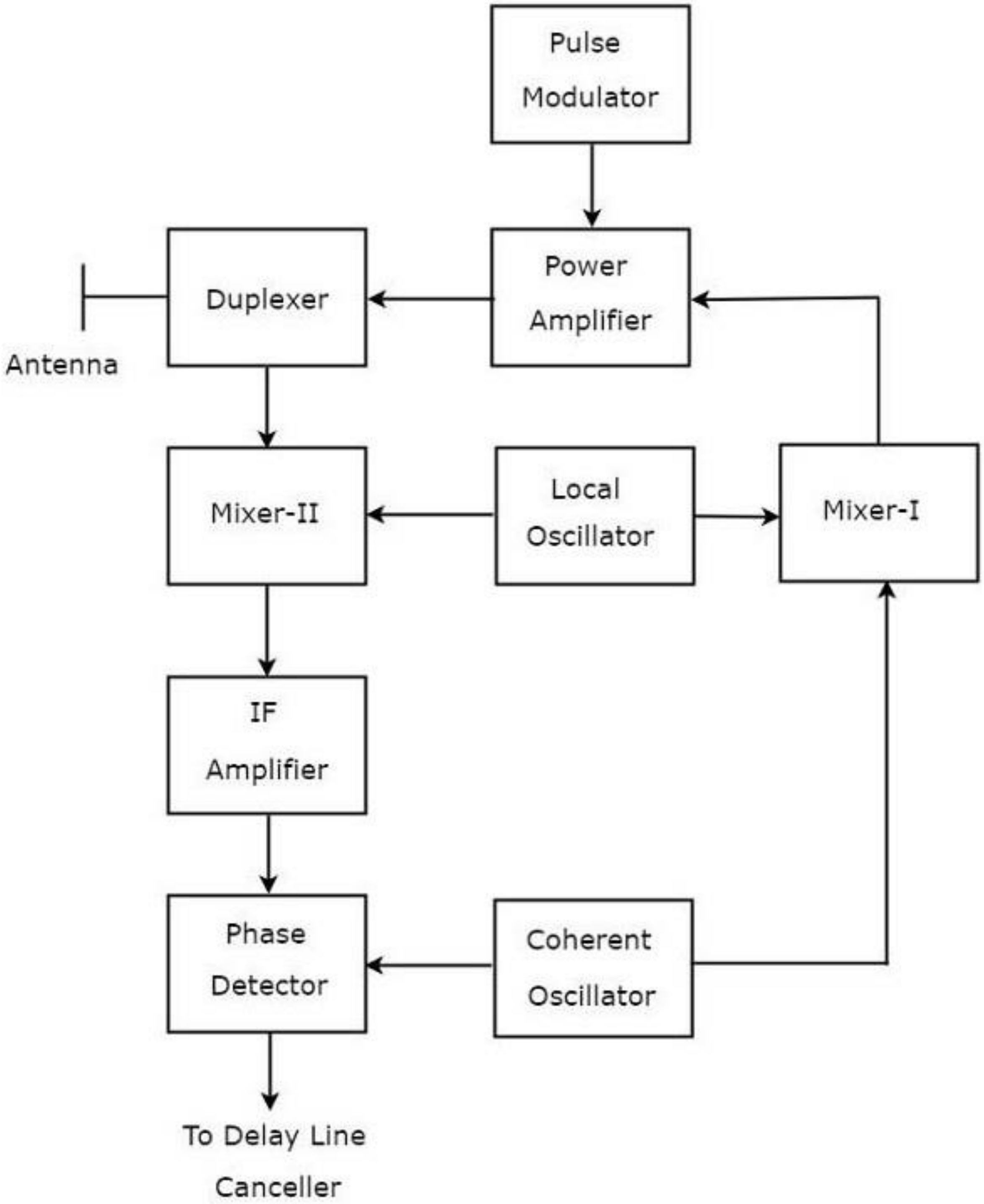

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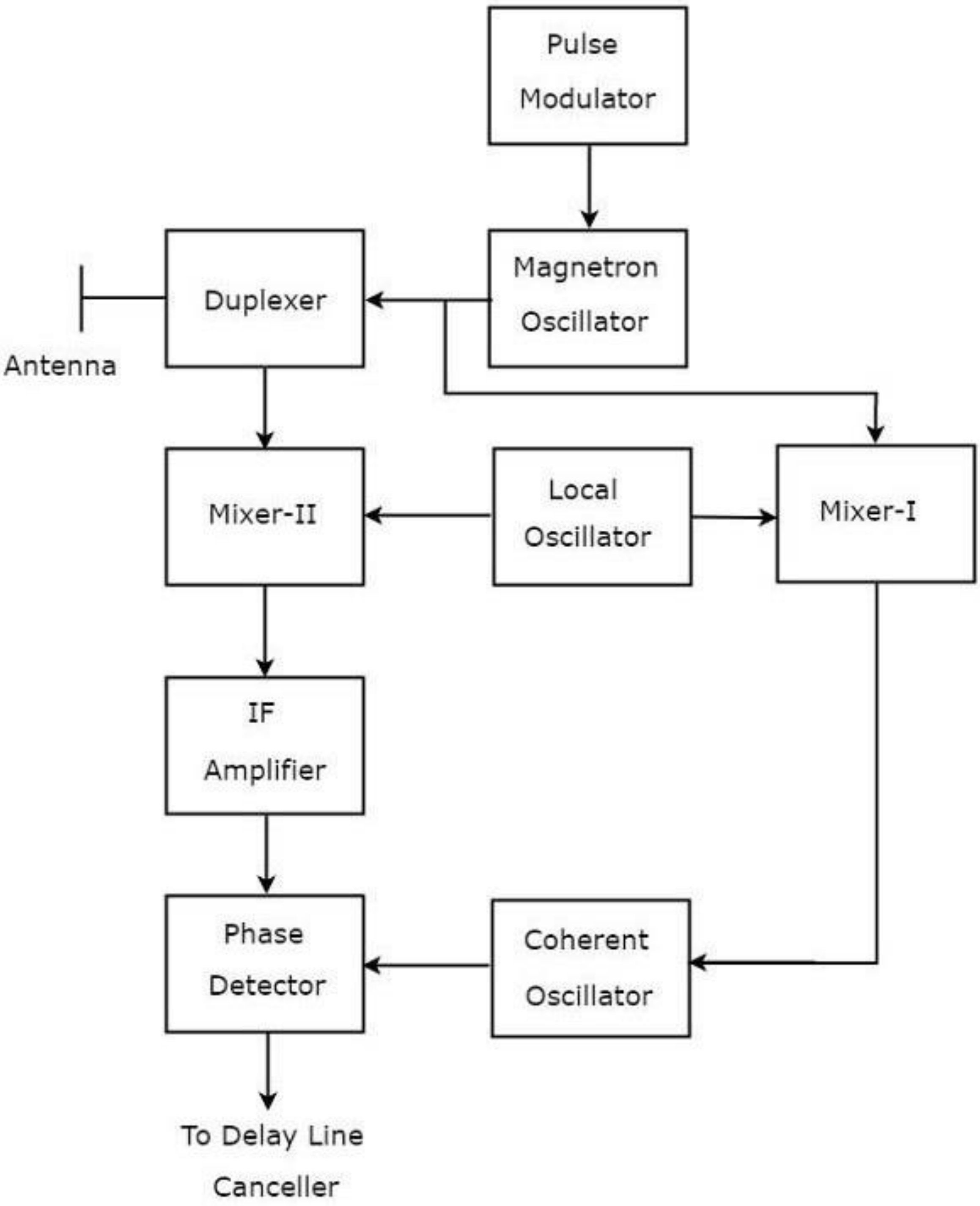

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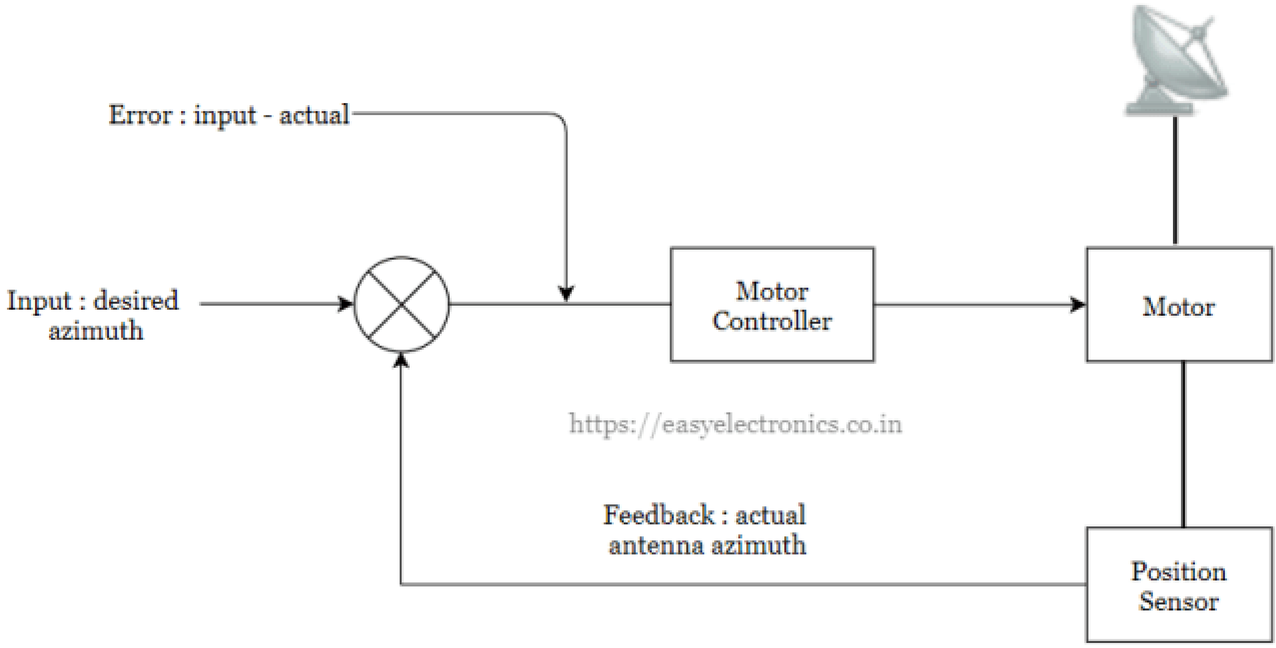
- So, the output of Coherent Oscillator can be used as reference signal for comparing the received echo signal with the corresponding transmitted signal using **phase detector**.

7(a)+7(b) A Tracking Radar system measures the different coordinates of a target such as range, elevation angle, azimuth angle, and doppler shift frequency to determine the target path and to predict its future position.
In general, it is the method by which angle tracking accomplished may be called the tracking radar.
One of the most useful features of radar is the ability of a radar set to continuously predict the next location of the target from the information received from the target and to align itself to continuously point at the predicted location. When this is occurring, the radar is said to be **tracking radar**.

Servo Mechanism of Tracking Radar
One of the most basic tracking systems is the servo tracking system, as shown in the figure below.



Servo Mechanism

Here, the radar antenna is initially trained on the target after which it automatically remains pointed at the target as it follows its motion. Furthermore, the system provides continuous position information to the operator and possibly to a fire control system. The antenna is rotated by a motor which provides a negative position feedback signal to a controller. This system is known as a **servo mechanism**.
Sometimes single antenna is not favorable for both search and tracking the target at the same time. So in this condition, a separate search radar is employed to provide the information related to the position of the target to the tracking system. When a separate search radar is employed for giving the information of the target to the tracking radar system is called **acquisition radar**.

Types of Tracking Radar

There are many types of tracking radar, which is being used to track the targets. They are as follows:

1. Single Target Tracker (STT)
2. Track While Scan (TWS)
3. Automatic Detection And Track (ADT)
4. Phased Array Tracking

1. Single Target Tracker (STT)

A single target tracker is used where continuous tracking of a single target with a higher data rate is required. Generally, this type of tracking is used in controlling the missile movements as it is carried out by a missile guidance radar.

In this type of tracker, a closed-loop servomechanism is used to keep the angle coordinates error very small. If the errors are less then there will be more accurate.

2.Track While Scan (TWS)

TWS radar scans their beam over relatively large areas. It rapidly scans in the angular sector to keep track of the targets, maybe move one target at a time. The radar computer still measures returned power as a function of beam location to provide tracking but the large scanning area enables the radar to still see the target even if the track has beam broken or lost. However, this large scan makes the TWS highly vulnerable to ECM jamming.

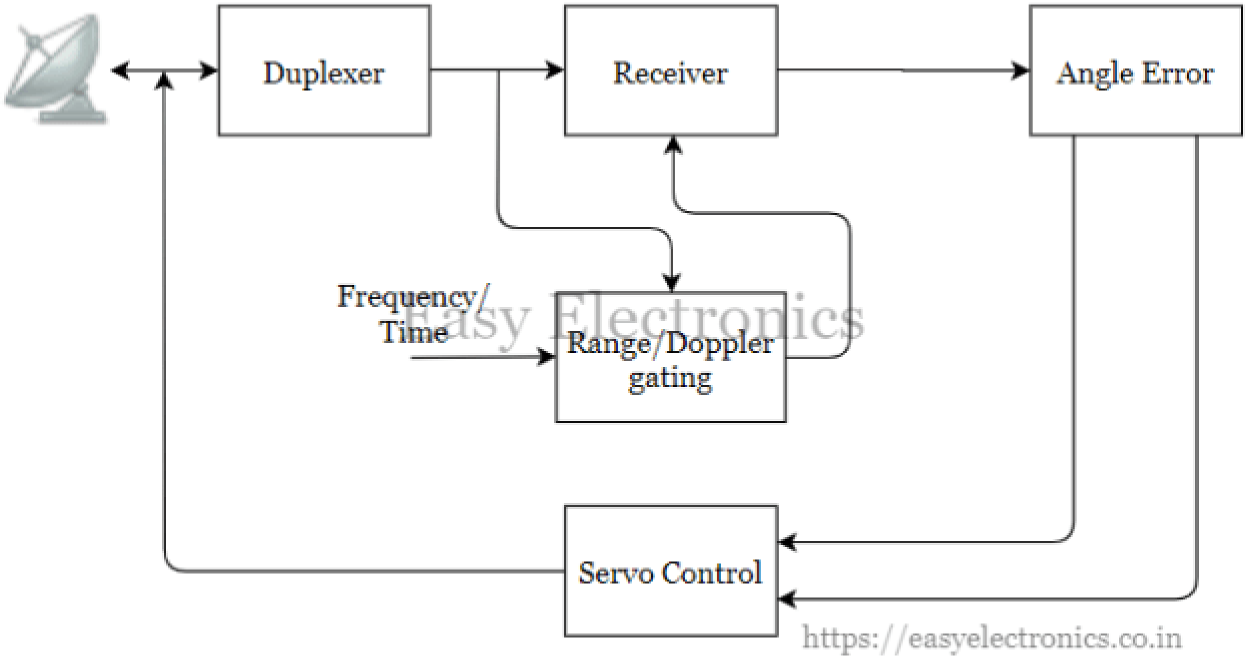
3.Automatic Detection and Track

This type of technique is used in air traffic control radar. This technique is employed with the air surveillance radar, which has 7.5 to 15 RPM. It does provide updating data according to the rotation of the antenna. It can track an enormous number of targets simultaneously may be few hundred. This antenna position is not controlled by closed-loop, it works in the open-loop system.

4.Phased Array Radar Tracking

In this technique, multiple targets are tracked on a time-sharing basis by the computer. Large numbers of tracks can be scanned rapidly in this technique because of electronically steered phased array method is used here. the antenna beam is scanned electronically make to switch in from one angular direction to another in a small-time such as a few microseconds.

Block Diagram of Tracking Radar



Block Diagram of Tracking Radar

Most tracking radars use angular information as the basis for tracking operations. For better accuracy, it is important that radar concentrates on one target at a time. Range gating/Doppler filtering can be used for that purpose. Time and frequency control for range and doppler gating is done in range and doppler trackers respectively. The angular error signal for the desired target to be tracked is developed in the error demodulator block which is also controlled by range/doppler gate generation block and then fed back to the steerable antenna in a closed-loop for tracking.

Sequential Lobbing

What is Sequential Lobbing?
A single beam is switched between two angular positions to obtain an angle measurement. This is called sequential Lobbing, lobe switching, or sequential switching.
Here, the direction of the antenna beam is rapidly switched between two positions. The echo signal from the target will fluctuate at the switching rates unless the target reaches exactly between two directions. The error signal obtained from a target not located on the switching axis is shown in the figure. The difference between the amplitude of these two echo signals is given the error signal.
The error signal may be defined as the angular displacement of the target from the switching axis. These tracking error signals are applied to the servomechanism unit, which attempts to position the antenna beam on the target.
When the target is located at the reference’s direction then the angular error is zero. Thus sequential lobbing with a two-position beam is used for tracking the target in only one place. The sign of the difference determines the direction of the antenna to move in order to align the switching axis with the direction of the target.
Four switching positions are required to obtain angle measurement in the orthogonal coordinate. Thus a two-dimensional sequentially lobbing radar consists of a cluster of four fed horns illuminating a single reflector antenna, arranged so that the right-left, up-down sectors

are covered by successive antenna positions. A cluster of five feed horns might also be used, with a control feed used for transmission and four outer feeds used for reception on a sequential basis.

Conical Scanning

In the conical scanning, the squinted beam is scanned rapidly and continuously on a circular path around the axis. The angle between the axis of rotation and the axis of the antenna beam s called the **squint angle**. If a target is present within a squint angle then the echo signal from the target will be amplitude modulated at a frequency equal to the rotation frequency of the beam also called conical scan frequency.

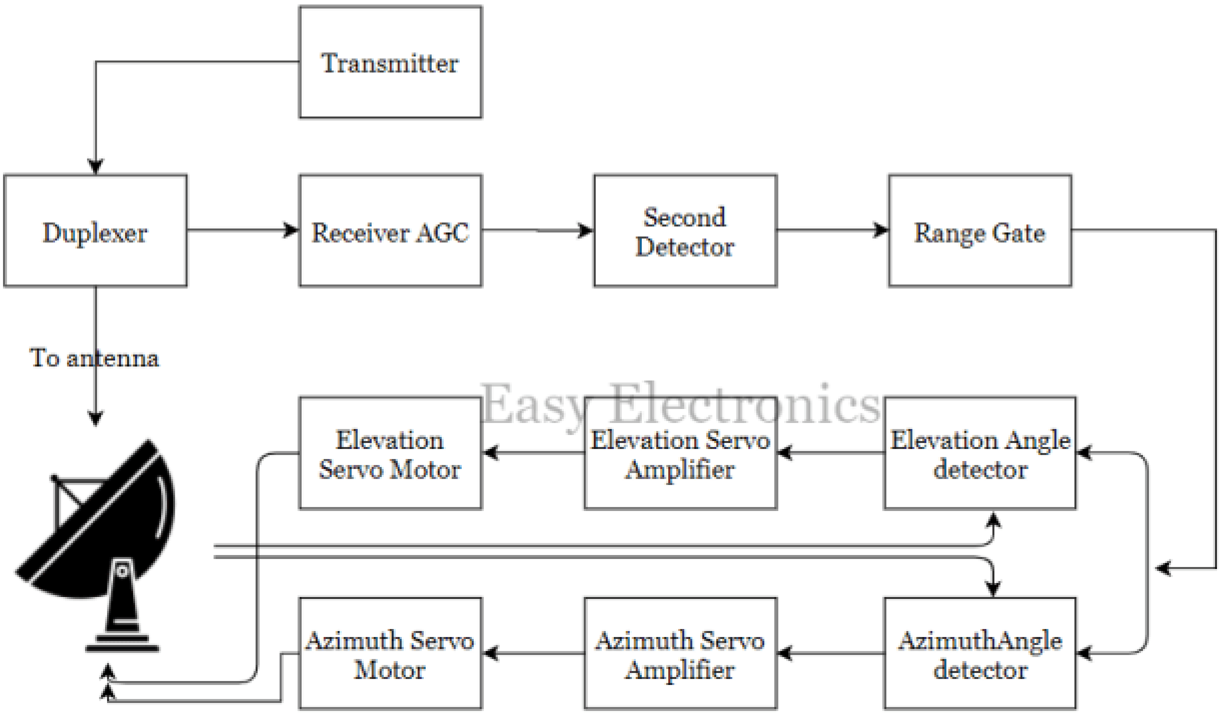
The amplitude of the modulation depends on the angular distance between the target direction and the rotation axis. The location of the target in two angles coordinates determines the phase of the conical scan modulation is extracted from the echo signal and applied to a servo control system which positions the antenna on the target both azimuth and elevation.

Two servo motors are required one for azimuth and another one for elevation. The conical scan modulation becomes zero and thus the target is tracked accurately by conical scanning, both azimuth, and elevation.

The antenna beam s squinted and scanned either mechanically by offsetting the feed and rotating it or electronically with the help of phase shifters. Electronic scans are very fast than mechanical scans. Typical scan rates are 30 to 40 scans/sec.

Block Diagram of Conical Scanning

A block diagram of a conical scan tracking radar system is shown in the figure below. The antenna is mounted such that it can be positioned both in elevation with the help of respective motors. The scan antenna beam generates two signals, the azimuth detector and the other for the elevation detector, which is 90 degrees out of phase.



Block Diagram of Conical Sacanning https://easyelectronics.co.in

The receiver is a conventional superheterodyne except for features related to the conical scan tracking radar. The error signal is extracted in the video after the second detector. The error signal is compared with the elevation and azimuth references signal, in the angle detectors, which are phase-sensitive detection.

The phase-sensitive detector is a non-linear device in which the input signal is mixed with a reference signal. This angle detection produces a DC voltage, which is proportional to the error, and the sign is an indication of the direction of the error.

The angle error detector output is amplified and drives the antenna elevation and azimuth servomotors. The angular position of the target may be determined from the elevation and azimuth of the antenna axis.

Conical scan systems require a minimum amount of hardware and therefore are commonly used on inexpensive, mobile systems such as AAA or mobile SAM sites.

They suffer the serious disadvantage of not being able to see a target outside their narrow scan patterns. This means that not only is a second radar is required to help it find that target but also the tracked aircraft can easily escape it is successful in breaking track since the conical san radar cannot see the target except in the track mode.

Mono Pulse Tracking

There are two disadvantages connected with the use of sequential lobbing and conical scanning which is as follows:

1. The motion of the antenna is more complex in lobe switching and conical scanning.
2. In conical scanning, a minimum of four pulses is required. the difficulty here is that if the cross-section of the target, the tracking accuracy may be degraded.

The effect of the fluctuating echo can be sufficiently serious is some application severely limits the accuracy of those tracking radar which requires many pulses to be processed in extracting the error signal.

The above problems can be overcome by using single-pulse only. There are several methods by which angle error information might be obtained with a single pulse.

The tracking techniques which derive angle error information on the basis of a single pulse is known as mono pulse tracking or simultaneous lobbing more than one antenna beam is used simultaneously in their method whereas in conical scanning or sequential lobbing, which uses one antenna beam on a time-shared basis.

There are several methods by which a mono pulse angle measurement can be made. The most popular method is the amplitude-comparison mono pulse, which compares the amplitude of the signals simultaneously received in multiple squinted beams to determine the angle.

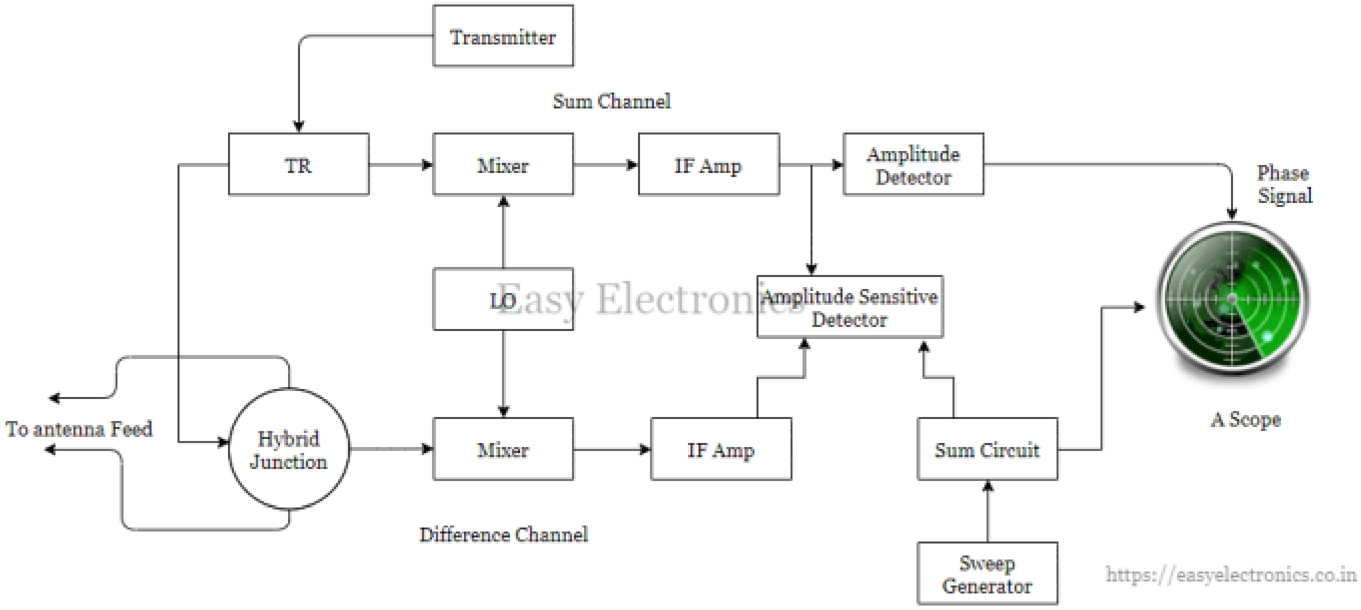
Amplitude comparison Mono Pulse tracking Radar

In an amplitude mono pulse system, four feeds are used with one paraboloid reflector. There are four horn antennas displaced about the central focus of the reflector. The transmitter feeds the horns simultaneously so that a sum signal is transmitted. The echo signal is received by a receiver duplexer using a hybrid ring to provide the following three signals:

1. Sum signals (A + B + C + D)
2. Azimuth error signal = (A+ C) – (B + D)
3. Elevation error signal = (A + B) – (C + D)

Block Diagram of Amplitude comparison Mono Pulse tracking Radar

A block diagram of the amplitude comparison mono pulse tracking radar for a single angular coordinate is as shown in the figure below.



Block Diagram of Amplitude Comparison Mono Pulse Tracking Radar

The receiver has three input channels consisting of three mixers, a common local oscillator, three IF amplifiers, and three detectors. The elevation and azimuth error signals are used to drive a servo amplifier and a motor in order to position the antenna in the direction of the target.

The o/p of sum channel is used to provide the data generally obtained from a radar receiver so that it can be used for applications like automatic control of the firing weapon.

The advantage of this technique is that it obtains with one pulse (online 4 pulses in conical scanning) all the information regarding the target and is able to locate the target in less time compared to other methods. Also, the mono pulse technique is not subject to error due to the variation in the target cross-section.

The disadvantage is that it requires two extra Rx channels and more complex duplexer feeding arrangements, which makes the system bulky and more expensive.

Phase comparison Mono Pulse tracking Radar

The angular error may also be determined by comparing the difference in the phase between the signals received from the two separate antennas. The antennas used in phase comparison mono pulse tracking are not offset from the axis as used in amplitude comparison trackers. It is essential that the amplitude of the target echo signal is the same from each antenna, but the phases are different.

Tracking radar, which operates with phase information, might be called simultaneous phase comparison radar, or phase comparison mono pulse radar. The measurement of the angle of arrival by comparison of the phase relationship in the signals from the separated antenna of radio interferon meer has been widely used by radio astronomers for precise measurement of the position of stars.

Tracking radar which operates with phase information is similar to an active interferometer. An additional antenna and receiving channel are necessary in order to track two orthogonal coordinates. In the phase comparison radar, four antennas are required, one of these antennae for transmitter only, while the other three for the receiver.

This technique has not been as widely used as the other techniques. There are two main drawbacks to why this might be so:

1. The side lobes levels, which result higher than the single antenna

2. The phase comparison radar does not usually make efficient use of the total available antenna patterns.

8 (a) We can classify the Radar Antennas into the following **two types** based on the physical structure.

- Parabolic Reflector Antennas
- Lens Antennas

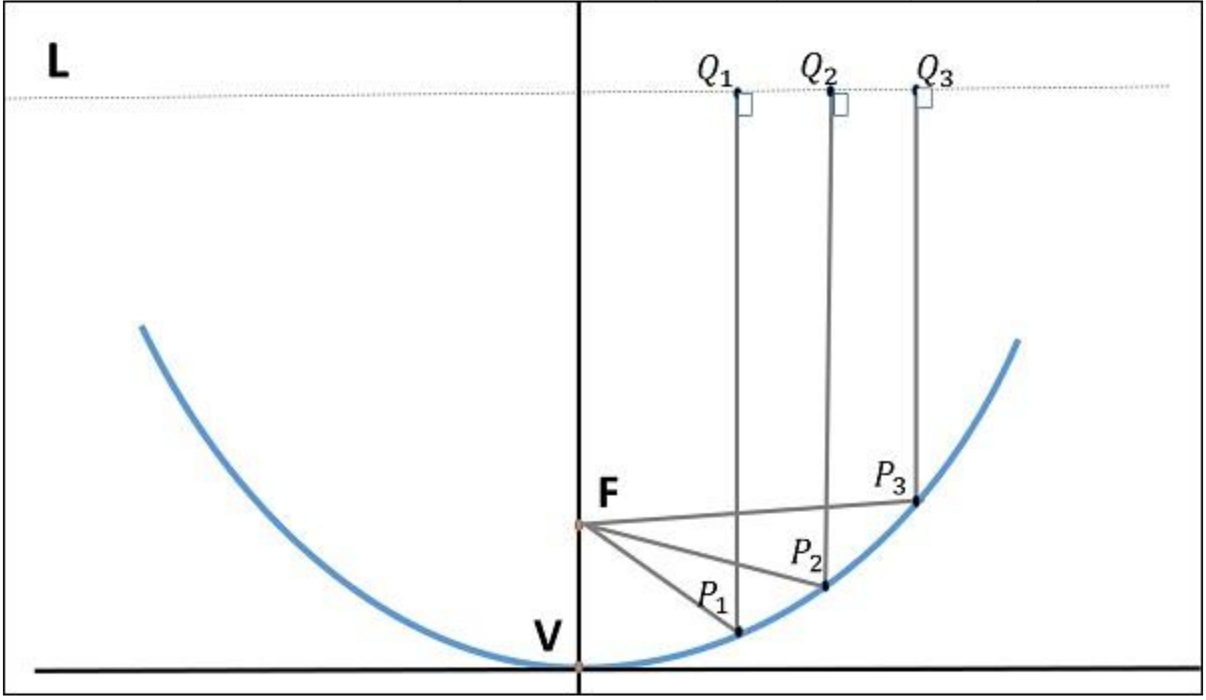
In our subsequent sections, we will discuss the two types of Antennas in detail.

Parabolic Reflector Antennas

Parabolic Reflector Antennas are the Microwave Antennas. A knowledge of parabolic reflector is essential to understand about working of antennas in depth.

Principle of Operation

Parabola is nothing but the Locus of points, which move in such a way that its distance from the fixed point (called focus) plus its distance from a straight line (called directrix) is constant. The following figure shows the **geometry of parabolic reflector**. The points F and V are the focus (feed is given) and the vertex respectively. The line joining F and V is the axis of symmetry. P1Q1,P2Q2P1Q1,P2Q2 and P3Q3P3Q3 are the reflected rays. The line L represents the directrix on which the reflected points lie (to say that they are being collinear).



As shown in the figure, the distance between F and L lie constant with respect to the waves being focussed. The reflected wave forms a collimated wave front, out of the parabolic shape. The ratio of focal length to aperture size (i.e., f/Df/D) is known as **“f over D ratio”**. It is an important parameter of parabolic reflector and its value varies from **0.25 to 0.50**.

The **law of reflection** states that the angle of incidence and the angle of reflection are equal. This law when used along with a parabola helps the beam focus. The shape of the parabola when used for the purpose of reflection of waves, exhibits some properties of the parabola, which are helpful for building an Antenna, using the waves reflected.

Properties of Parabola

Following are the different properties of Parabola −

- All the waves originating from focus reflect back to the parabolic axis. Hence, all the waves reaching the aperture are in phase.

- As the waves are in phase, the beam of radiation along the parabolic axis will be strong and concentrated.

Following these points, the parabolic reflectors help in producing high directivity with narrower beam width.

Construction & Working of a Parabolic Reflector

If a Parabolic Reflector Antenna is used for **transmitting a signal**, the signal from the feed comes out of a dipole Antenna or horn Antenna, to focus the wave on to the parabola. It means that, the waves come out of the focal point and strike the paraboloid reflector. This wave now gets reflected as collimated wave front, as discussed previously, to get transmitted.

The same Antenna is used as a **receiver**. When the electromagnetic wave hits the shape of the parabola, the wave gets reflected onto the feed point. The dipole Antenna or the horn Antenna, which acts as the receiver Antenna at its feed receives this signal, to convert it into electric signal and forwards it to the receiver circuitry.

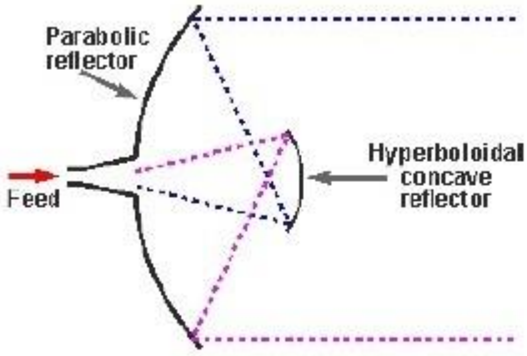
The gain of the paraboloid is a function of aperture ratio D/λD/λ. The Effective Radiated Power **(ERP)** of an Antenna is the multiplication of the input power fed to the Antenna and its power gain.

Usually a wave guide horn Antenna is used as a feed radiator for the paraboloid reflector Antenna. Along with this technique, we have the following two types of feeds given to the paraboloid reflector Antenna.

- Cassegrain Feed
- Gregorian Feed

Cassegrain Feed

In this type, the feed is located at the vertex of the paraboloid, unlike in the parabolic reflector. A convex shaped reflector, which acts as a hyperboloid is placed opposite to the feed of the Antenna. It is also known as **secondary hyperboloid reflector** or sub-reflector. It is placed in such a way that one of its foci coincides with the focus of the paraboloid. Thus, the wave gets reflected twice.



The above figure shows the working model of the cassegrain feed.

Gregorian Feed

The type of feed where a pair of certain configurations are there and where the feed beam width is progressively increased while Antenna dimensions are held fixed is known as **Gregorian feed**. Here, the convex shaped hyperboloid of Cassegrain is replaced with a concave shaped paraboloid reflector, which is of course, smaller in size.

These Gregorian feed type reflectors can be used in the following four ways −

- Gregorian systems using reflector ellipsoidal sub-reflector at foci F1.
- Gregorian systems using reflector ellipsoidal sub-reflector at foci F2.
- Cassegrain systems using hyperboloid sub-reflector (convex).
- Cassegrain systems using hyperboloid sub-reflector (concave but the feed being very near to it).

Among the different types of reflector Antennas, the simple parabolic reflectors and the Cassegrain feed parabolic reflectors are the most commonly used ones.

Lens Antennas

Lens Antennas use the curved surface for both transmission and reception of signals. These antennas are made up of glass, where the converging and diverging properties of lens are followed. The **frequency range** of usage of Lens Antenna starts at **1 GHz** but its use is greater at **3 GHz and above**.

A knowledge of Lens is required to understand the working of Lens Antenna in depth. Recall that a normal glass Lens works on the **principle of refraction**.

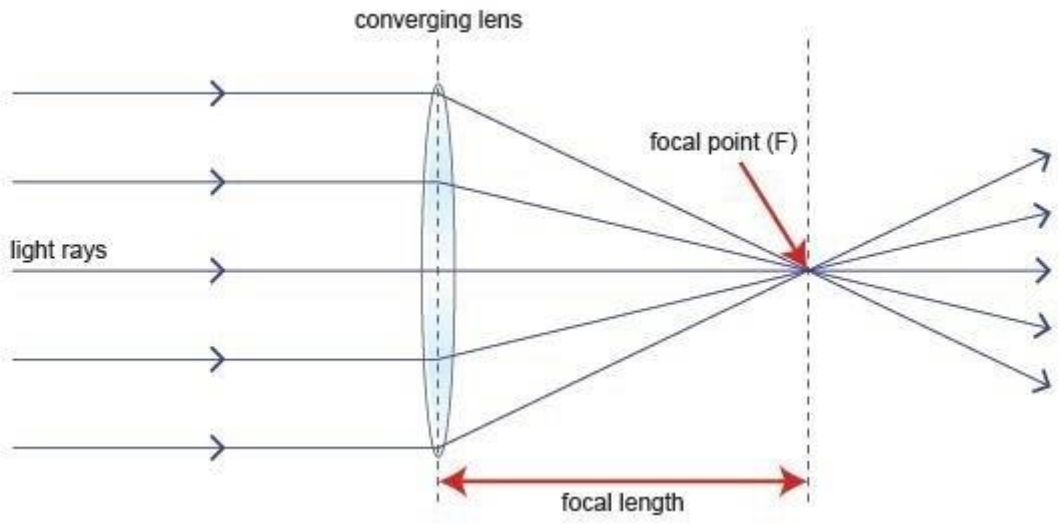
Construction & Working of Lens Antenna

If a light source is assumed to be present at a focal point of a lens, which is at a focal distance from the Lens, then the rays get through the Lens as collimated or **parallel rays** on the plane wave front.

There are two phenomena that happens when rays fall from different sides of a lens. They are given here −

- The rays that pass through the centre of the Lens are less refracted than the rays that pass through the edges of the Lens. All of the rays are sent in parallel to the plane wave front. This phenomenon of Lens is called as **Divergence**.
- The same procedure gets reversed if a light beam is sent from the right side to the left side of the same Lens. Then the beam gets refracted and meets at a point called the focal point, at a focal distance from the Lens. This phenomenon is called **Convergence**.

The following diagram will help us understand the phenomenon better.



The **ray diagram** represents the focal point and the focal length from the source to the Lens. The parallel rays obtained are also called collimated rays.

In the above figure, the source at the focal point, at a focal distance from the Lens is collimated in the plane wave front. This phenomenon can be reversed which means the light if sent from the left side, is converged at the right side of the Lens.

It is because of this **reciprocity**, the Lens can be used as an Antenna, as the same phenomenon helps in utilizing the same Antenna for both transmission and reception.

To achieve the focusing properties at higher frequencies, the refractive index should be less than unity. Whatever may be the refractive index, the purpose of Lens is to straighten the waveform. Based on this, the E-plane and H-plane Lens are developed, which also delay or speed up the wavefront.

8(b) An electronic instrument, which is used for displaying the data visually is known as display. So, the electronic instrument which displays the information about Radar's target visually is known as **Radar display**. It shows the echo signal information visually on the screen.

Types of Radar Displays

In this section, we will learn about the different types of Radar Displays. The Radar Displays can be classified into the following types.

A-Scope

It is a two dimensional Radar display. The horizontal and vertical coordinates represent the range and echo amplitude of the target respectively. In A-Scope, the deflection modulation takes place. It is more suitable for **manually tracking Radar**.

B-Scope

It is a two dimensional Radar display. The horizontal and vertical coordinates represent the azimuth angle and the range of the target respectively. In B-Scope, intensity modulation takes place. It is more suitable for **military Radars**.

C-Scope

It is a two-dimensional Radar display. The horizontal and vertical coordinates represent the azimuth angle and elevation angle respectively. In C-Scope, intensity modulation takes place.

D-Scope

If the electron beam is deflected or the intensity-modulated spot appears on the Radar display due to the presence of target, then it is known as blip. C-Scope becomes D-Scope, when the blips extend vertically in order to provide the distance.

E-Scope

It is a two-dimensional Radar display. The horizontal and vertical coordinates represent the distance and elevation angle respectively. In E-Scope, intensity modulation takes place.

F-Scope

If the Radar Antenna is aimed at the target, then F-Scope displays the target as a centralized blip. So, the horizontal and vertical displacements of the blip represent the horizontal and vertical aiming errors respectively.

G-Scope

If the Radar Antenna is aimed at the target, then G-Scope displays the target as laterally centralized blip. The horizontal and vertical displacements of the blip represent the horizontal and vertical aiming errors respectively.

H-Scope

It is the modified version of B-Scope in order to provide the information about elevation angle of the target. It displays the target as two blips, which are closely spaced. This can be approximated to a short bright line and the slope of this line will be proportional to the sine of the elevation angle.

I-Scope

If the Radar Antenna is aimed at the target, then I-Scope displays the target as a **circle**. The radius of this circle will be proportional to the distance of the target. If the Radar Antenna is aimed at the target incorrectly, then I-Scope displays the target as a segment instead of circle. The arc length of that segment will be inversely proportional to the magnitude of pointing error.

J-Scope

It is the modified version of A-Scope. It displays the target as radial deflection from time base.

K-Scope

It is the modified version of A-Scope. If the Radar Antenna is aimed at the target, then K-Scope displays the target as a pair of vertical deflections, which are having equal height. If the

Radar Antenna is aimed at the target incorrectly, then there will be pointing error. So, the magnitude and the direction of the pointing error depends on the difference between the two vertical deflections.

L-Scope

If the Radar Antenna is aimed at the target, then L-Scope displays the target as two horizontal blips having equal amplitude. One horizontal blip lies to the right of central vertical time base and the other one lies to the left of central vertical time base.

M-Scope

It is the modified version of A-Scope. An adjustable pedestal signal has to be moved along the baseline till it coincides the signal deflections, which are coming from the horizontal position of the target. In this way, the target's distance can be determined.

N-Scope

It is the modified version of K-Scope. An adjustable pedestal signal is used for measuring distance.

O-Scope

It is the modified version of A-Scope. We will get O-Scope, by including an adjustable notch to A-Scope for measuring distance.

P-Scope

It is a Radar display, which uses intensity modulation. It displays the information of echo signal as plan view. Range and azimuth angle are displayed in polar coordinates. Hence, it is called the **Plan Position Indicator** or the **PPI display**.

R-Scope

It is a Radar display, which uses intensity modulation. The horizontal and vertical coordinates represent the range and height of the target respectively. Hence, it is called **Range-Height Indicator** or **RHI display**.

10 (b) In two-way communication, if we are supposed to use the same Antenna for both transmission and reception of the signals, then we require Duplexer. **Duplexer** is a microwave switch, which connects the Antenna to the transmitter section for transmission of the signal. Therefore, the Radar cannot receive the signal during transmission time.

Similarly, it connects the Antenna to the receiver section for the reception of the signal. The Radar cannot transmit the signal during reception time. In this way, Duplexer isolates both transmitter and receiver sections.

Types of Duplexers

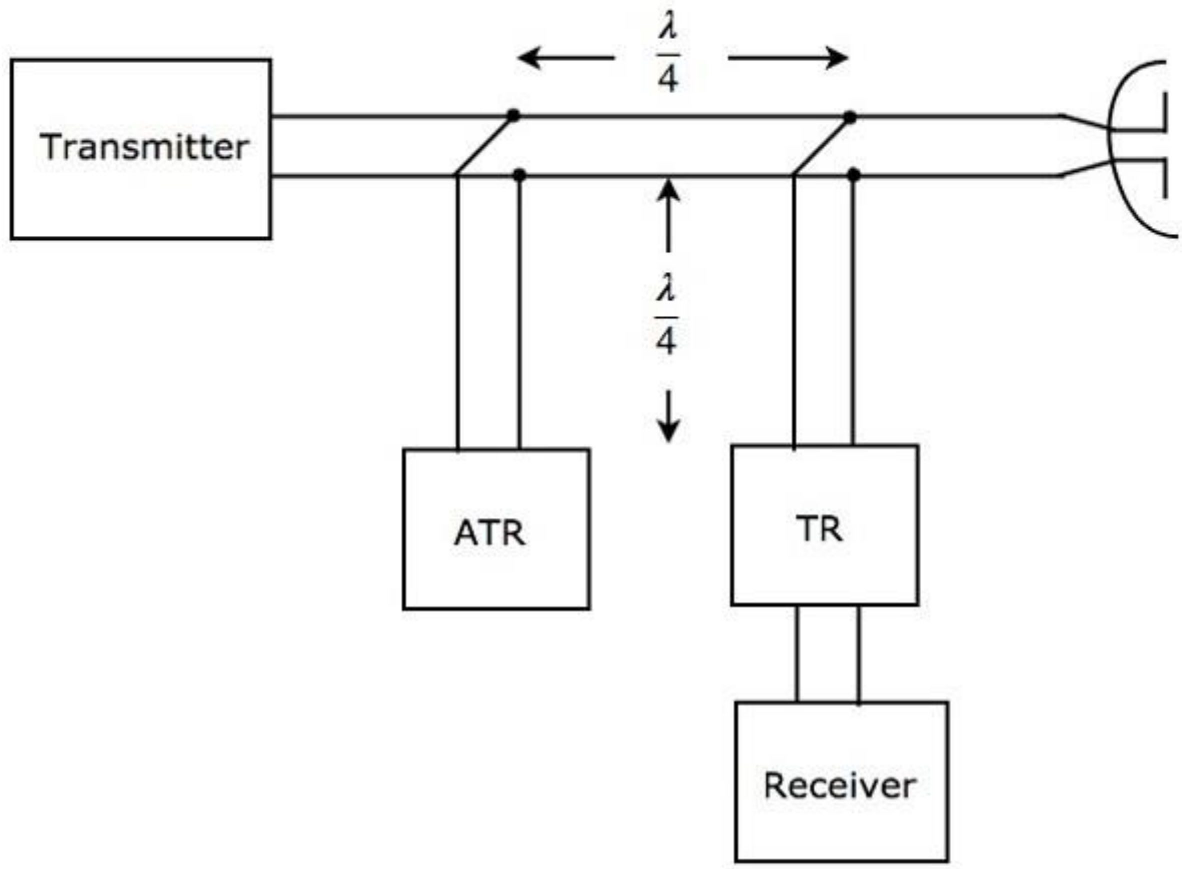
In this section, we will learn about the different types of duplexers. We can classify the Duplexers into the following **three types**.

- Branch-type Duplexer
- Balanced Duplexer
- Circulator as Duplexer

In our subsequent sections, we will discuss the types of Duplexers in detail.

Branch-type Duplexer

Branch-type Duplexer consists of two switches — Transmit-Receive (TR) switch and Anti Transmit-Receive (ATR) switch. The following figure shows the **block diagram** of Branch-type Duplexer −



As shown in the figure, the two switches, TR & ATR are placed at a distance of λ/4λ/4 from the transmission line and both the switches are separated by a distance of λ/4λ/4. The **working** of Branch-type Duplexer is mentioned below.

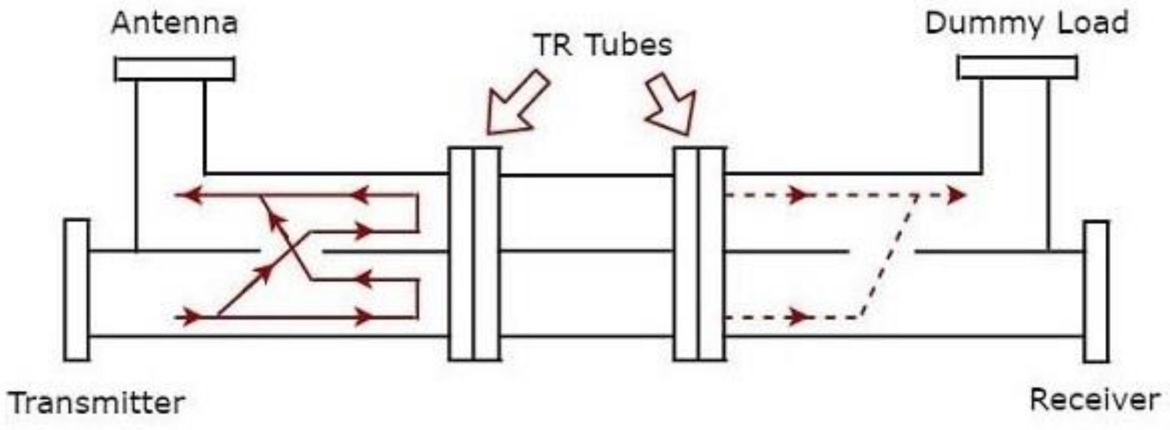
- During **transmission**, both TR & ATR will look like an open circuit from the transmission line. Therefore, the Antenna will be connected to the transmitter through transmission line.
- During **reception**, ATR will look like a short circuit across the transmission line. Hence, Antenna will be connected to the receiver through transmission line.

The Branch-type Duplexer is suitable only for low cost Radars, since it is having less power handling capability.

Balanced Duplexer

We know that a **two-hole Directional Coupler** is a 4-port waveguide junction consisting of a primary waveguide and a secondary waveguide. There are two small holes, which will be common to those two waveguides.

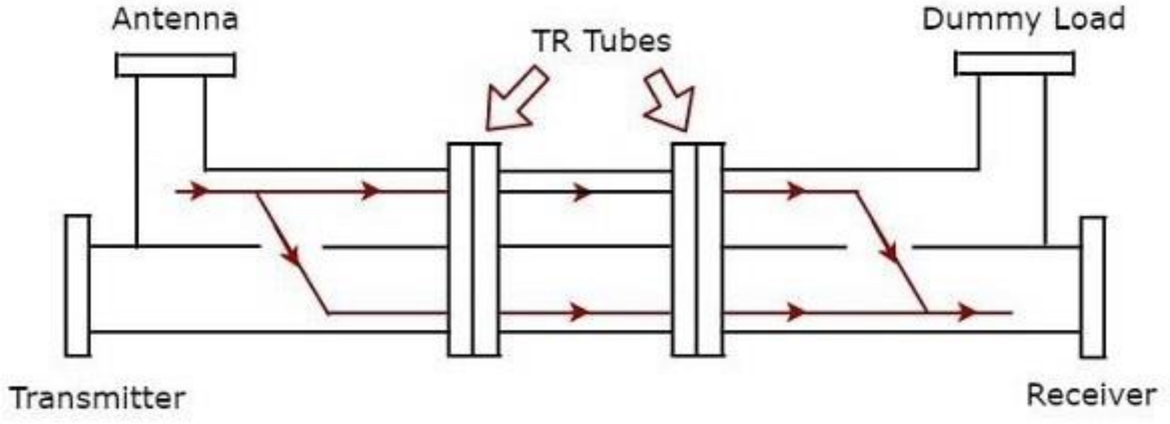
The Balanced Duplexer consists of two TR tubes. The configuration of Balanced Duplexer for **transmission** purpose is shown in the following figure.



The signal, which is produced by the transmitter has to reach the Antenna for the Antenna to transmit that signal during transmission time. The **solid lines with arrow marks** shown in the above figure represent how the signal reaches Antenna from transmitter.

The dotted lines with arrow marks shown in the above figure represent the signal, which is leaked from the Dual TR tubes; this will reach only the matched load. So, no signal has been reached to the receiver.

The configuration of Balanced Duplexer for **reception** purpose is shown in figure given below.



We know that Antenna receives the signal during reception time. The signal which is received by the Antenna has to reach the receiver. The **solid lines with arrow marks** shown in the above figure represent how the signal is reaching the receiver from Antenna. In this case, Dual TR tubes pass the signal from the first section of waveguide to the next section of waveguide.

The Balanced Duplexer has high power handling capability and high bandwidth when compared to Branch-type Duplexer.

Circulator as Duplexer

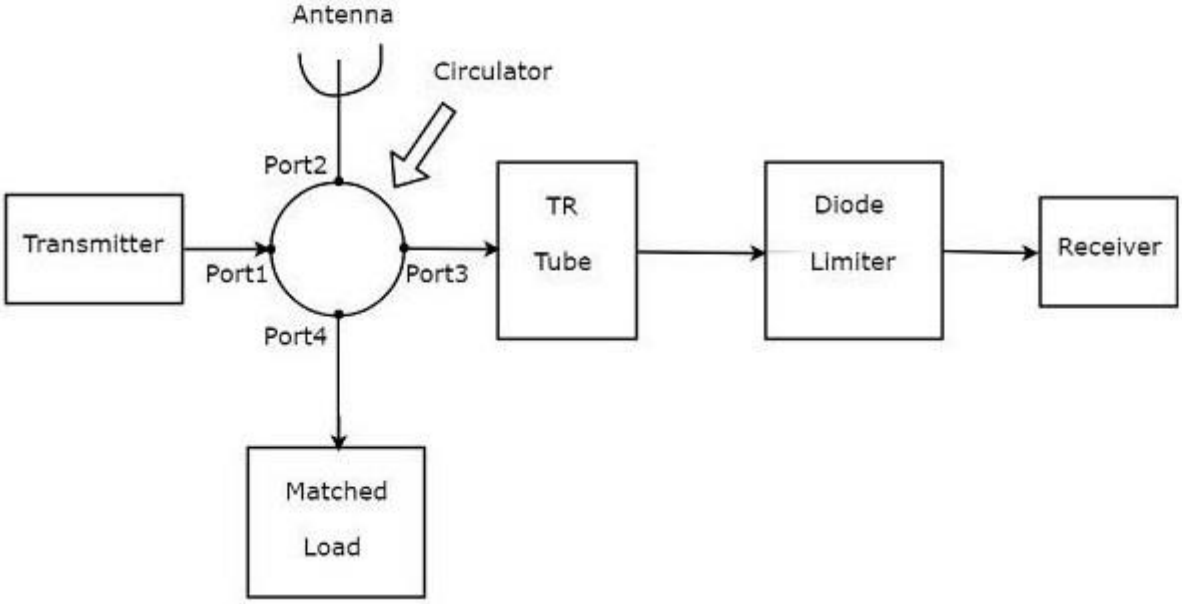
We know that the **functionality** of the circulator is that if we apply an input to a port, then it will be produced at the port, which is adjacent to it in the clockwise direction. There is no output at the remaining ports of the circulator.

So, consider a 4-port circulator and connect the transmitter, Antenna, receiver and matched load to port1, port2, port3 and port4 respectively. Now, let us understand how the **4-port circulator** works as Duplexer.

The signal, which is produced by the transmitter has to reach the Antenna for the Antenna will transmit that signal during **transmission** time. This purpose will be achieved when the transmitter generates a signal at port1.

The signal, which is received by the Antenna has to reach the receiver during **reception** time. This purpose will be achieved when the Antenna present at port2 receives an external signal.

The following figure shows the **block diagram** of circulator as Duplexer −



The above figure consists of a 4-port circulator — Transmitter, Antenna and the matched load is connected to port1, port2 and port4 of circulator respectively as discussed in the beginning of the section.

The receiver is not directly connected to port3. Instead, the blocks corresponding to the passive TR limiter are placed between port3 of circulator and receiver. The blocks, TR tube & Diode limiter are the blocks corresponding to passive TR limiter.

Actually, the circulator itself acts as Duplexer. It does not require any additional blocks. However, it will not give any kind of protection to the receiver. Hence, the blocks corresponding to passive TR limiter are used in order to provide the **protection to the receiver**.