Displays:

The purpose of the display is to visually present the information contained in the radar echo signal in a form suitable for operator interpretation and action.

The cathode-ray tube (CRT) has been almost universally used as the radar display. There are two basic cathode-ray tube displays. One is the ***deflection-modulated CRT,*** such as the A-scope, in which a target is indicated by the deflection of the electron beam. The other is the ***Intensity modulated CRT*** such as the **PPI**, in which a target is indicated by intensifying the electron beam and presenting a luminous spot on the face of the CRT.

The deflection of the beam or the appearance of an intensity-modulated spot on a radar display caused by the presence of a target is commonly referred to as a ***blip.***

With the advent of technology in the display systems being used in other applications like computer monitors and TVs , the modern Radars now a days use the state of the art LCD and LED displays along with digital storage techniques overcoming many of the limitations of CRT displays used earlier.

Types of display presentations:

The various types of displays which were used forsurveillance and tracking radars are defined as follows:
A-scope*: A*deflection-modulated display in which the vertical deflection is proportional to target echostrength and the horizontal coordinate is proportional to range.
B-scope: An intensity-modulated rectangular display with azimuth angle indicated by the horizontalcoordinate and range by the vertical coordinate.
C-scope:An intensity-modulated rectangular display with azimuth angle indicated by the horizontalcoordinate and elevation angle by the vertical coordinate.
D-scope:A C-scope in which the blips extend vertically to give a rough estimate of distance.
E-scope:An intensity-modulated rectangular display with distance indicated by the horizontal coordinateand elevation angle by the vertical coordinate. Similar to the **RHi**in which target height or altitude isthe vertical coordinate.
F –Scope: A rectangular display in which a target appears as a centralized blip when the radar antenna isaimed at it. Horizontal and vertical aiming errors are respectively indicated by the horizontal andvertical displacement of the blip.
PPI, or ***Plan Position Indicator*** (also called ***P-scope):***An intensity-modulated circular display on whichecho signals produced from reflecting objects are shown in plan position with range and azimuthangle displayed in polar (rho-theta) coordinates, forming a map-like display. An ***offset,*** or ***off centerPPI***has the zero position of the time base at a position other than at the center of the display toprovide the equivalent of a larger display for a selected portion of the service area. A ***delayed PPI*** is one in which the initiation of the time base isdelayed.
R-scope: An **A-s**cope with a segment of the time base expanded near the blip for greater accuracy in distance measurement.
RHI or ***Range-Height Indicator:***An intensity modulated display with height (altitude) as the vertical axisand range as the horizontal axis.

The above definitions are taken from the IEEE Standard definition with somemodifications. The terms **A-scope** and **A-display, B-scope** and **B-display**, etc., are used interchangeably. These letter descriptions of radar displays date back to World War 2. All of them are not in current usage. However; the **PPI, A-scope, B-scope,** and**RHI**are among the moreusual displays employed in radar.

Duplexers:

Introduction:

Duplexer is the device that allows a single antenna to serve both the transmitter and thereceiver. During transmission it protects the receiver from burnout or damage, and onreception it channels the echo signal to the receiver. Duplexers, especially for high-powerapplications, sometimes employ a form of gas-discharge device. Solid-state devices are also utilized.

There are two basic methods employed that allow the use of a common antenna for both transmitting and receiving. The older method is represented by the branch-type duplexer and the balanced duplexer which utilize gas TR-tubes for accomplishing the necessary switching actions. The other method uses a ferrite circulator to separate the transmitterand receiver, and a receiver protector consisting of a gas TR-tube and diode limiter.

Branch-type duplexers:

The branch-type duplexer, shown in **Fig. 4** is one of the earliest duplexer configurations. It consists of a TR (transmit-receive) switch and anATR (anti-transmit receive) switch, both of which are gas-discharge tubes.
When the transmitteris turned on, **both the TR and the ATR** tubes ionize.i.e.they break down, or fire. The **TR** in the fired condition acts as a short circuit to prevent transmitter power from entering the receiver. Since the **TR** is located a quarter wavelength from the main transmission line, it appears as a short circuit at the receiver but as an open circuit at the transmission line so that it does not impede the flow of transmitter power. Since the **ATR** is displaced a quarter wavelength from the main transmission line, the short circuit it produces during the fired condition appears as an open circuit on the transmission line and thus has no effect on transmission.
During reception, the transmitter is **OFF** and neither the **TR** nor the **ATR** is fired. The open circuit of the **ATR**, being a quarter wave from the transmission line, appears as a short circuit across the line. Since this short circuit is located a quarter wave from the receiver branch-line, the transmitter is effectively disconnected from the line and the echo signal power is directed to the receiver. The diagram of **Fig. 4** is a parallel configuration. Series or series-parallel configurations are possible.
The branch-type duplexer is of limited bandwidth and power-handling capability, and hasgenerally been replaced by the balanced duplexer and other protection devices. It is used, inspite of these limitations, in some low-cost radars.

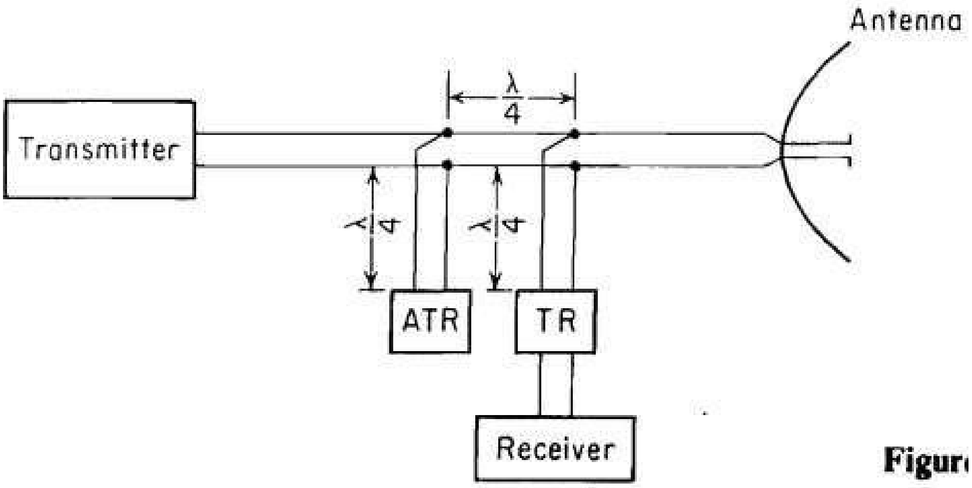

Figure 4: Principle of branch-type duplexer.

Balanced duplexers:

Thebalanced duplexer, Fig. **5**, is based on the short-slot hybrid junctionwhich consists of two sections of waveguides joined along one of their narrow walls with a slotcut in the common narrow wall to provide coupling between the two .The short-slot hybrid may be considered as a broadband directionalcoupler with a coupling ratio of 3 dB.

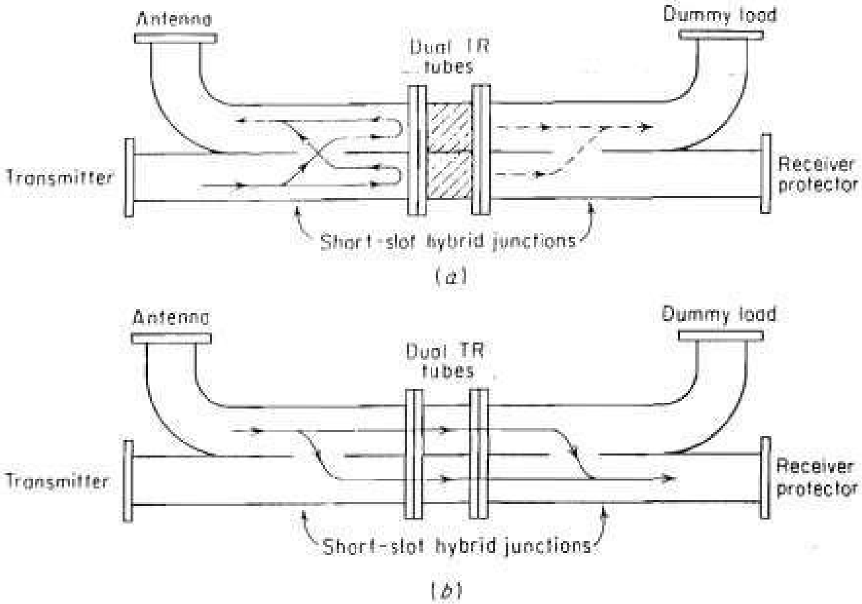

Figure 5: Balanced duplexer using dual TR tubes and two short-slot hybrid junctions. (a) Transmit Condition (b) Receive condition.

In the transmit condition (Figure 5 a) power is divided equally into eachwaveguideby the first short slothybrid junction. Both TR tubes break down and reflect the incident power out the antennaarm as shown. ***The short-slot hybrid has the property that each time the energy passes throughthe slot in either direction, its phase is advanced 90^0***. Therefore, the energy travels asindicated by the solid lines. Any energy which leaks through the TR tubes (shown by thedashed lines) is directed to the arm with the matched dummy load and not to the receiver. Inaddition to the attenuation provided by the TR tubes, the hybrid junctions provide an additional 20 to 30 dB of isolation.

On reception the TR tubes are unfired and the echo signals pass through the duplexer and into the receiver as shown in Fig.5b. The power splits equally at the first junction andbecause of the **90^0**phase advance on passing through the slot, the energy recombines in thereceiving arm and not in the dummy-load arm.

The power-handling capability of the balanced duplexer is inherently greater than that ofthe branch-type duplexer and it has wide bandwidth, over ten percent with proper design. ***A receiver protector,*** is usually inserted between the duplexer and the receiver for added protection.

Circulator and receiver protector: The ferrite circulator is a three- or four-port device thatcan in principle, offer separation of the transmitter and receiver without the need for theconventional duplexer configurations explained earlier. The circulator does not provide sufficient protection by itself and requires a receiver protector as in **Fig.6**. The isolation between the transmitter and receiver ports of a circulator is seldom sufficient to protect the receiver from damage. However, it is not the isolation between transmitter and receiver ports that usually determines the amount of transmitter power at the receiver, but the impedance mismatch at the antenna which reflects transmitter power back into the receiver.

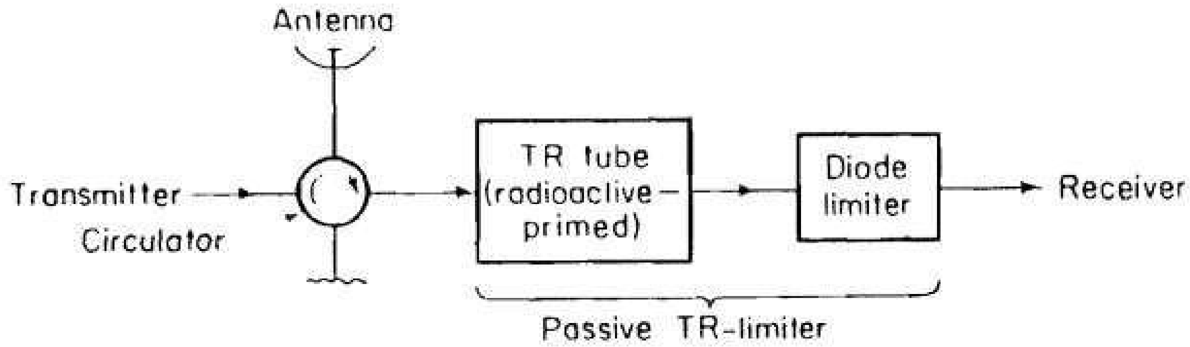

Figure 6: Circulator and receiver protector. A four-port circulator is shown with the fourth port terminatedin a matched load to provide greater isolation between the transmitter and the receiver thanprovidedhy a three-port circulator.

The VSWR is a measure of the amount of power reflected by the antenna. For example, a **VSWR of 1.5** means that about **4 percent** of the transmitter power will be reflected by the antenna mismatchin the direction of the receiver, which corresponds to an isolation of only **14** dB. About **11** percent of the power is reflected when the **VSWR is 2.0**, corresponding to less than **10** dB ofisolation. Thus, a receiver protector is almost always required. It also reduces to safe level radiations from nearby transmitters.

Introduction to phased array antennas:

- The phased array is a directive antenna made up of individual radiating antennas, or elements, which generate a radiation pattern whose shape and direction is determined by the relative phases and amplitudes of the currents at the individual elements.
- By properly varying the relative phases it is possible to steer the direction of the radiation.
- The radiating elements might be dipoles, open-ended waveguides, slots cut in waveguide, or any other type of antenna.
- It has the flexibility of steering the beam by means of electronic control rather than by physical movement of the antenna.
- It has been considered in those radar applications where it is necessary to shift the beam rapidly from one position in space to another, or where it is required to obtain information about many targets at a flexible, rapid data rate.
- Initially during World War 2 the radar with fixed phased-array antennas was used in which the beam was scanned by mechanically actuated phase shifters.
- A major advance in phased array technology was made in the early 1950s with the replacement of mechanically actuated phase shifters by electronic phase shifters.
- Frequency scanning in one angular coordinate was the first successful electronic scanning technique to be applied.
- The introduction of digitally switched phase shifters employing either ferrites or diodes in the early 1960s made a significant improvement in the practicality of phased arrays that could be electronically steered in two orthogonal angular coordinates.

Basic concepts:

- Two common geometrical forms of array antennas used in radar are the linear array and the planar array. **A** linear array consists of elements arranged in a straight line in one dimension. A planar array is a two dimensional configuration of elements arranged to lie in a plane. The planar array may be thought of as a linear array of linear arrays.
- The two-dimensional planar array is the most commonly used in radar applications since it is fundamentally the most versatile of all radar antennas. A rectangular aperture can produce a fan shaped beam. A square or a circular aperture produces a pencil beam. The array can be made to simultaneously generate many search and/or tracking beams with the same aperture.
- An array in which the relative phase shift between elements is controlled by electronic devices is called an *electronically scanned array.* In an electronically scanned array the antenna elements, the transmitters, the receivers, and the data-processing portions of the radar are often designed as a unit.

Radiation pattern:

Consider a linear array made up of N elements equally spaced a distance ***d apart*** shown ***in Fig*. 7**.. The elements are assumed to be isotropic point sources radiating uniformly in all directions with equal amplitude and phase. Although isotropic elements are not realizable in practice, they are a useful concept in array theory, especially for the computation of radiation patterns. The array is shown as a receiving antenna for convenience, but because of the reciprocity principle, the results obtained apply equally well to a transmitting antenna. The outputs of all the elements are summed via lines of equal length to give a sum output voltage E_a. Element **1** will be taken as the reference signal with zero phase. The difference in the phase of the signals in adjacent elements is $\Psi = 2\pi\,(d/\lambda)\sin\theta$, where **θ** is the direction of the incoming radiation. It is further assumed that the amplitudes and phases of the signals at each element are weighted uniformly. Therefore the amplitudes of the voltages in each element are the same and, for convenience, will be taken to be unity. The sum of all the voltages from the individual elements, when the phase difference between adjacent elements is **Ψ**, can be written as

$$E_a = \sin\omega t + \sin(\omega t + \psi) + \sin(\omega t + 2\psi) + \cdots + \sin[\omega t + (N-1)\psi] \qquad \text{..... (1)}$$

where ω is the angular frequency of the signal. The sum can be written

$$E_a = \sin\left[\omega t + (N-1)\frac{\psi}{2}\right]\frac{\sin(N\psi/2)}{\sin(\psi/2)} \qquad \text{..... (2)}$$

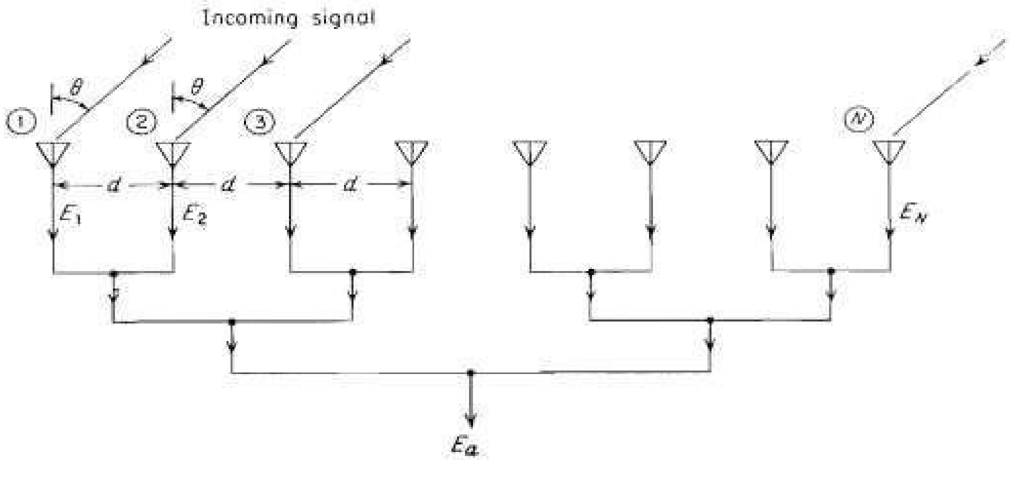

Figure 7: N-element linear array.

The first factor is a sine wave of frequency ω with a phase shift **(N - 1) ψ/2.** The second term represents the amplitude factor of the form **sin (Nψ/2)/sin (ψ/2).** The field intensity pattern is the magnitude of the equation **2** , or

$$|E_a(\theta)| = \left|\frac{\sin[N\pi(d/\lambda)\sin\theta]}{\sin[\pi(d/\lambda)\sin\theta]}\right| \qquad \text{.... (3)}$$

The pattern has nulls when the numerator is zero.

For discrete aperture antennas (such as phased arrays) in which the element spacing is greater than a half wavelength, the spatial aliasing effect causes some sidelobes to become substantially larger in amplitude, and approaching the level of the main lobe; these are called ***grating lobe****s, and they are identical, or nearly identical to the main beams.*

The radiation pattern is equal to the normalized square of the amplitude, or

$$G_a(\theta) = \frac{|E_a|^2}{N^2} = \frac{\sin^2[N\pi(d/\lambda)\sin\theta]}{N^2 \sin^2[\pi(d/\lambda)\sin\theta]} \quad \text{........ [4]}$$

When directive elements are used, the resultant array antenna radiation pattern is

$$G(\theta) = G_e(\theta)\frac{\sin^2[N\pi(d/\lambda)\sin\theta]}{N^2 \sin^2[\pi(d/\lambda)\sin\theta]} = G_e(\theta)G_a(\theta) \quad \text{...... [5]}$$

where **$G_e(\theta)$** is the radiation pattern of an individual element. The resultant radiation pattern is the product of the ***element factor $G_e(\theta)$*** and the ***array factor $G_a(\theta)$,*** the latter being the pattern of an array composed of isotropic elements.

In a two-dimensional, rectangular planar array, the radiation pattern may sometimes be written as the product of the radiation patterns in the two planes which contain the principal axes of the antenna. If the radiation patterns in the two principal planes are **$G_1(\theta_e)$** and **$G_2(\theta_a)$** the two-dimensional antenna pattern is

$$G(\theta_e, \theta_a) = G_1(\theta_e)G_2(\theta_a) \quad \textbf{(6)}$$

Thus, the normalized radiation pattern of a uniformly illuminated rectangular array is

$$G(\theta_e, \theta_a) = \frac{\sin^2[N\pi(d/\lambda)\sin\theta_a]}{N^2 \sin^2[\pi(d/\lambda)\sin\theta_a]} \frac{\sin^2[M\pi(d/\lambda)\sin\theta_e]}{M^2 \sin^2[\pi(d/\lambda)\sin\theta_e]} \quad \textbf{(7)}$$

Where **N** = number of radiating elements in **θ_a** dimension with spacing **d** and **M** the number in **θ_e** dimension.

Beam steering and beam width changes:

Beam steering:

The beam of an array antenna may be steered rapidly in space without physically moving large antennae by properly varying the phase of the signals applied to each element. Consider an array of equally spaced elements. The spacing between adjacent elements is **d**, and the signals at each element are assumed to be of equal amplitude. If the same phase is applied to all elements, the relative phase difference between adjacent elements is zero and the position of the main beam will be broadside to the array at an angle **θ** = **0**. The main beam will point in a direction other than broadside if the relative phase difference between elements is other than zero. The direction of the main beam is at an angle θ_0, when the phase difference is $\varnothing = 2\pi\,(d/\lambda)\sin\theta_0$. The phase at each element is therefore $(\varnothing_c + m\,\varnothing)$ where $m = 0, 1, 2 \ldots (N - 1)$ and $\varnothing_c$ is any constant phase applied to all elements. The normalized radiation pattern of the array when the phase difference between adjacent elements is **Ø** is given by:

$$G(\theta) = \frac{\sin^2[N\pi(d/\lambda)(\sin\theta - \sin\theta_0)]}{N^2\sin^2[\pi(d/\lambda)(\sin\theta - \sin\theta_0)]} \qquad (8)$$

The maximum of the radiation pattern occurs when $\sin\theta = \sin\theta_0$.
Equation (8) states that the main beam of the antenna pattern may be positioned to an angle θ_0 by the insertion of the proper phase shift **Ø** at each element of the array. If variable, rather than fixed, phase shifters are used, the beam may be steered as the relative phase between elements is changed **(Fig. 8)**below**.**

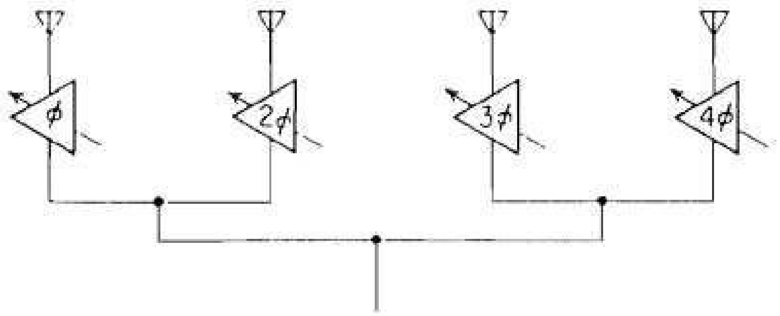

Figure 8: Steering of an antenna beam withvariable phase shifters (parallel-fed array).

Change of beamwidth with steering angle:

The half-power beamwidth in the plane of scan increases as the beam is scanned off the broadside direction. The beamwidth is approximately inversely proportional to $\cos\vartheta_0$, *where* ϑ_0 *is the angle measured from the normal to the antenna.*

It is proved mathematically that the half-power beamwidth Θ_B is given by :

$$\Theta_B = 0.886\,\lambda / Nd \cos \Theta_0 \qquad ..... \qquad [13]$$

Therefore, when the beam is positioned an angle θ_0 off broadside, the beamwidth in the plane of scan increases as $(\cos \theta_0)^{-1}$.

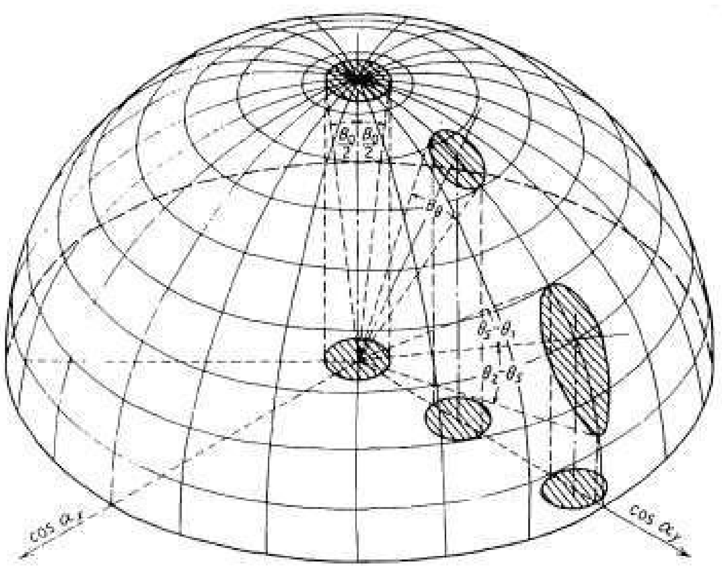

Figure 9: Beamwidth and eccentricity of the scanned beam.

The variation of the beam shape with scan angle is graphically shown in **Fig.9** above.

Applications of the array in radar:

The phased array antenna has seen application in radar for a wide variety of purposes:

- Aircraft surveillance from on board ship
- Satellite surveillance
- Ballistic missile defense
- Air defense
- Aircraft landing systems
- Mortar and artillery location
- Tracking of ballistic missiles and Airborne bomber radar (EAR).
- Many developmental array radars have been developed and built in USA. Although much effort and funds have been spent on this activity, ***except for limited-scan arrays*** there has not been any large serial production of such radars compared to the serial production of radars with mechanically rotating reflector antennas.

Advantages and limitations:

Advantages:

Inertia less rapid beam steering: The beam from an array can be scanned, or switched from one position to another, in a very short time limited only by the switching speed of the phase shifters.Typically, the beam can be switched in several microseconds, but it can be considerably shorter if desired.

Multiple, independent beams: A single aperture can generate many simultaneous independent beams. Alternatively, the same effect can be obtained by rapidly switching a single beam through a sequence of positions.

Potential for large peak and for average power: If necessary, each element of the array can be fedby a separate high-power transmitter with the combining of the outputs made in "space" to obtain a total power greater than that can be obtained from a single transmitter.

Control of the radiation pattern: A particular radiation pattern may be more readily obtained with the array than with other microwave antennas since the amplitude and phase of each array element may be individually controlled. Thus, radiation patterns with extremely low sidelobes or with a shaped main beam may be achieved conveniently. Separate monopulse sum and difference patterns, each with its own optimum shape, can also be generated.

Graceful degradation : The distributed nature of the array means that it can fail only gradually and not at once (catastrophically).

Convenient aperture shape: The shape of the array permits flush mounting and it can be strengthened to resist blast.

Electronic beam stabilization: The ability to steer the beam electronically can be used to stabilize the beam direction when the radar is on an unstable platform, such as a ship or aircraft that is subject to roll, pitch, and yaw disturbances.

Limitations:

- Very rarely we may require a fast switching phased array antenna and for our application a simple mechanically scanned antenna might be adequate in which case such a high cost electronically steered antenna might not be necessary.
- An N-element array can, in principle, generates N independent beams. However, in practice it is very rarely required that a radar generate more than a few simultaneous beams (perhaps no more than a dozen), since the complexity of the array radar increases with increasing number ofbeams.
- Although the array has the potential for radiating large power, it is rare that an array is required to radiate more power than
    - That can be radiated by other antenna types or

  - That can be generated by current high-power microwave tube technology that feeds a single transmission line.
- Conventional microwave antennas cannot generate radiation patterns with side lobes as low as can be obtained by an array antenna. However, when a planar array is electronically scanned, the change of mutual coupling that accompanies a change in beam position makes the maintenance of low side lobes more difficult.
- The full testing of an array radar system is often more complicated than with conventional radar systems.
- The ***major limitation*** that has limited the wide spread use of the conventional phased array in radar is its high cost, which is due to its complexity. The software for the computer system that is needed to utilize the inherent flexibility of the array radar also contributes significantly to the system cost and complexity.

Previous years' ExaminationQuestions:

1. (a) Explain the basic concept of phased array antennas.
(b) Explain characteristics of diffrent radar displays. [8+8]
2. Discuss in detail about Matched filter Receiver with necessary expressions. [16]

3. (a) Explain the functioning and characteristics of PPI display and A-Scope.[8]
4. Derive the impulse response of a matched filter that is commonly used ina radar receiver.[16]
5. (a) Draw the structures of balanced duplexer during transmission and receptionmodes.
(b) List out the merits and demerits of phased array antennas. [8+8]6. (a) Draw and explain the radiation pattern of phased array antennas.

(b) Write notes on various antenna parameters with reference to radar. [8+8]

7. Discuss the relation between the matched filter characteristics and correlation detection.[16]
8.(a)What is meant by correlation? Explain cross correlation with the help of a neat block diagram

(b) Derive the expression for the frequency response of a Matched filter receiver with non white noise input.

9.(a) Explain how the beam width of a Phased array antenna varies with the steering angle.

(b) What is a Duplexer and explain the principle of operation of typical Duplexer with a schematic diagram.

10.(a) Explain the principle and characteristics of a Matched filter. Hence derive the expression

for it's frequency response function

(b)Briefly explain about the efficiency of the nonmatched filters

11.(a) Briefly explain the concept of beam steering of Phased array antennas

(b)Derive an expression for the effective Noise figure of two cascaded networks.

12.(a)Establish the impulse response characteristic for a matched fillter.

13. (a) Define noise figure. Derive the expression for the noise figure of two networks that are in cascade.

14.(a) Derive the frequency response function of the matched filter.

(b) Explain about the efficiency of nonmatched filters.

15. (a) Explain the principle of balanced duplexer.

(b)Write a detailed note on Matched filter Receiver

16. Explain bpout correlation function and cross correlation Reciver

17. Write short notes on the following:

i) Phased array Radar ii) Any two types of Radar Displays.