UNIT-VI

Radar Receivers

Displays: The purpose of the radar display is to visually present the output of the radar receiver in a form such that an operator could readily and accurately detect the presence of a target and extract information about its location.

(or)

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

-> Display is a unit of radar receiver which presents the radars information. It is a coupling link between the information and human operator.

-> The Cathode ray tube (CRT) has been almost universally used as the radar display.

Types of Radar display:

There are two basic Cathode ray tube displays

1. Deflection modulated CRT display, such as the A-scope in which a target is indicated by the deflection of the electron beam. These displays have simple ckts than those & intensity modulated CRTS

2. Intensity modulated CRT display, such as the PPI in which a target is indicated by intensifying the electron beam and representing a luminous spot on the face of the CRT. These displays presenting data in

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a convenient and easily interpreted form.

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

-> The deflection modulated CRTs, such as the A-scope generally employ electrostatic deflection.

-> Intensity modulated CRTs, such as the PPI, generally employ electromagnetic deflection.

Salient features of Type - A scope display:

1. It presents range only
2. Its vertical axis represents echo strength and horizontal axis represents range.
3. Its circuit is simple
4. It is the most popular display
5. It is suitable with tracking radar
6. It is deflection-modulated CRT display

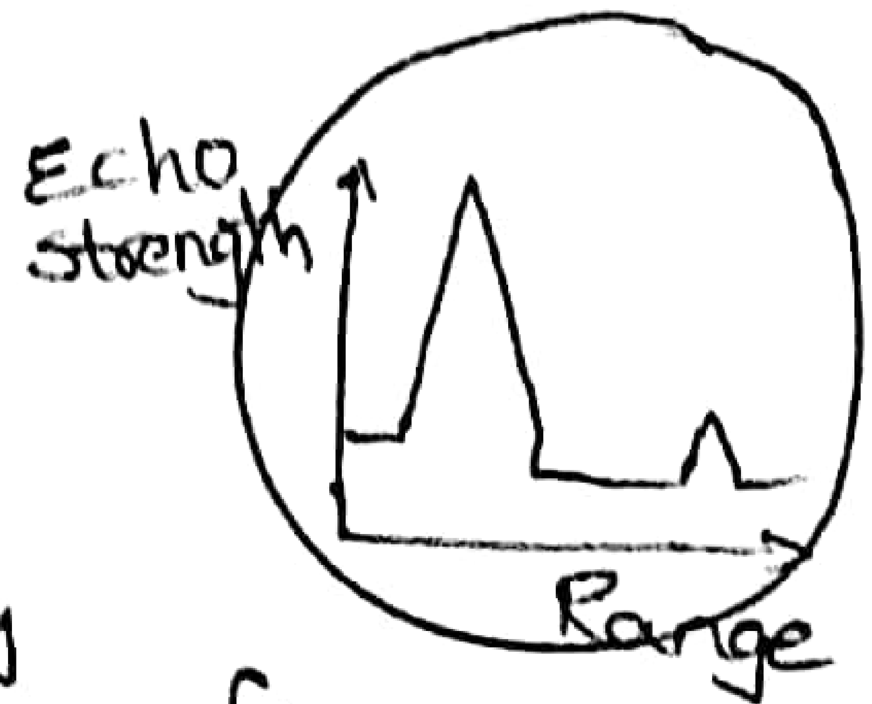

fig: A-scope display

Salient features of PPI

1. It is also called P-scope
2. It displays the map of target area
3. It is intensity modulated CRT display
4. It provides range information
5. It is used in search radars.

types of displays:

The other types of displays are A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, R and RHI Scopes (Range-height Indicator)

Duplexers:

The duplexer is the device that allows a single antenna to serve both the transmitter and the receiver. On transmission it must protect the receiver from burnout or damage and on reception it must channel the echo signal to the receiver.

→ Duplexers, especially for high-power applications, sometimes employ a form of gas-discharge device. Solid-state devices are also utilized.

Def: It isolates transmitter while receiving and isolates receiver while transmitting. It is basically a microwave switch. It permits a single antenna to serve both the transmitter and the receiver.

Functions of Duplexer:

1. It isolates the receiver while transmitting
2. It isolates the transmitter while receiving.
3. It protects the receiver from high power transmitted by isolation.
4. It also protects the receiver from high power radiation from nearby radars during inter-pulse period or when the radar is shut down.

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Types of Dupbxers:

The Common types of duplexer are;

1. Branch type duplexer.

2. Balanced type duplexer.

3. Ferrite Circulator.

Branch-type Duplexer;

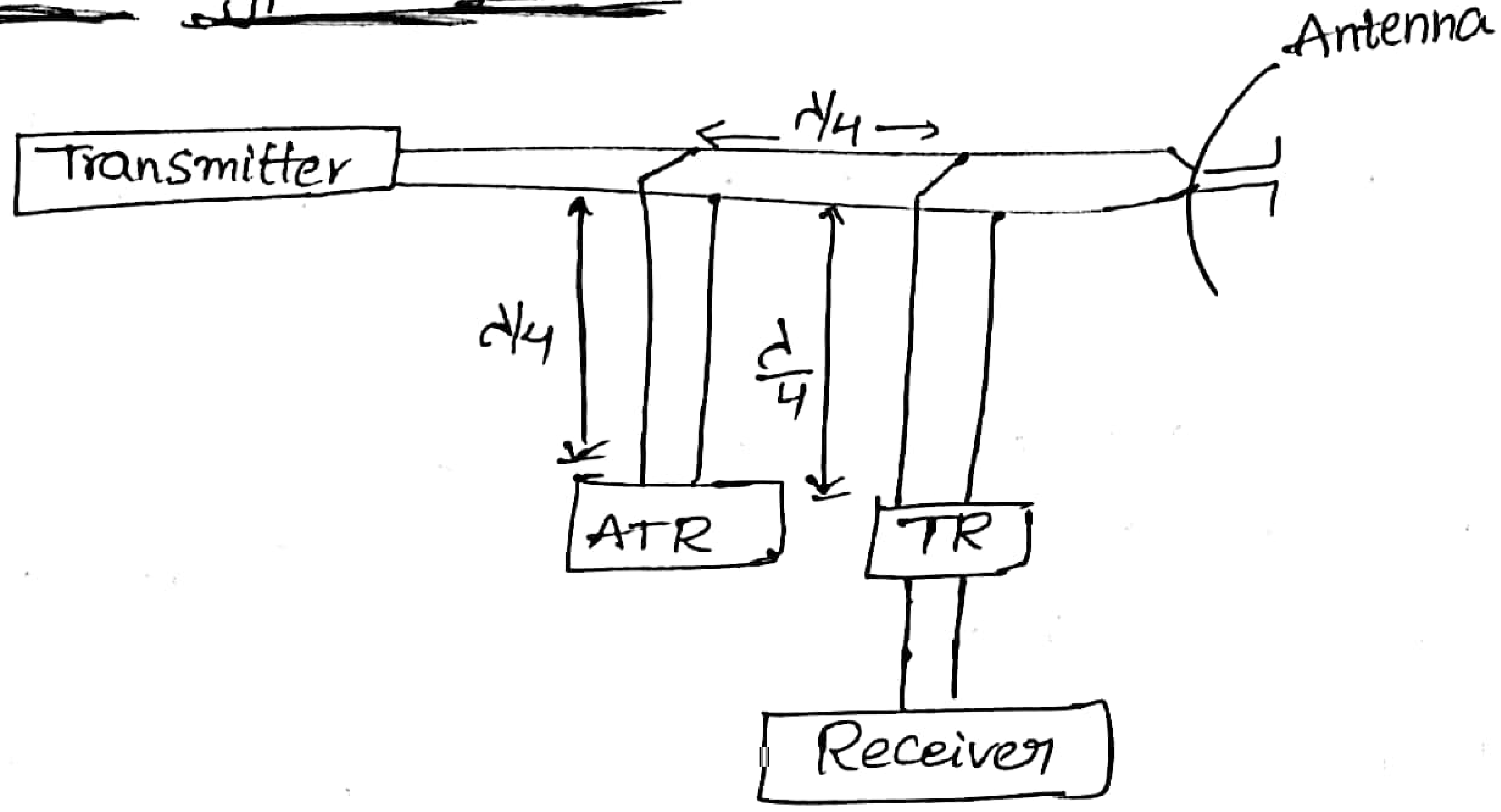

fig: principle of branch-type duplexer

-> The principle of the branch-type duplexer is illustrated in above fig:

-> It Consists of a TR (transmit-receive) switch and an ATR (Anti-transmit-receive) switch, both of which are gas-discharge tubes.

-> When the transmitter is turned on, the TR and the ATR tubes ionize, that is they break down, or fire.

-> The TR in the fired Condition acts as a short circuit to prevent transmitter power from entering the receiver

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...ce the TR is located at 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 TR nor the ATR is fired.

-> The open circuit of the ATR, being a quarter wave 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 above fig is a parallel configuration Series or Series-parallel configurations are possible.

Advantages:

1. Its cost is low.

Disadvantages:

1. Bandwidth is limited
2. power handling Capability is limited.

Balanced Duplexers :

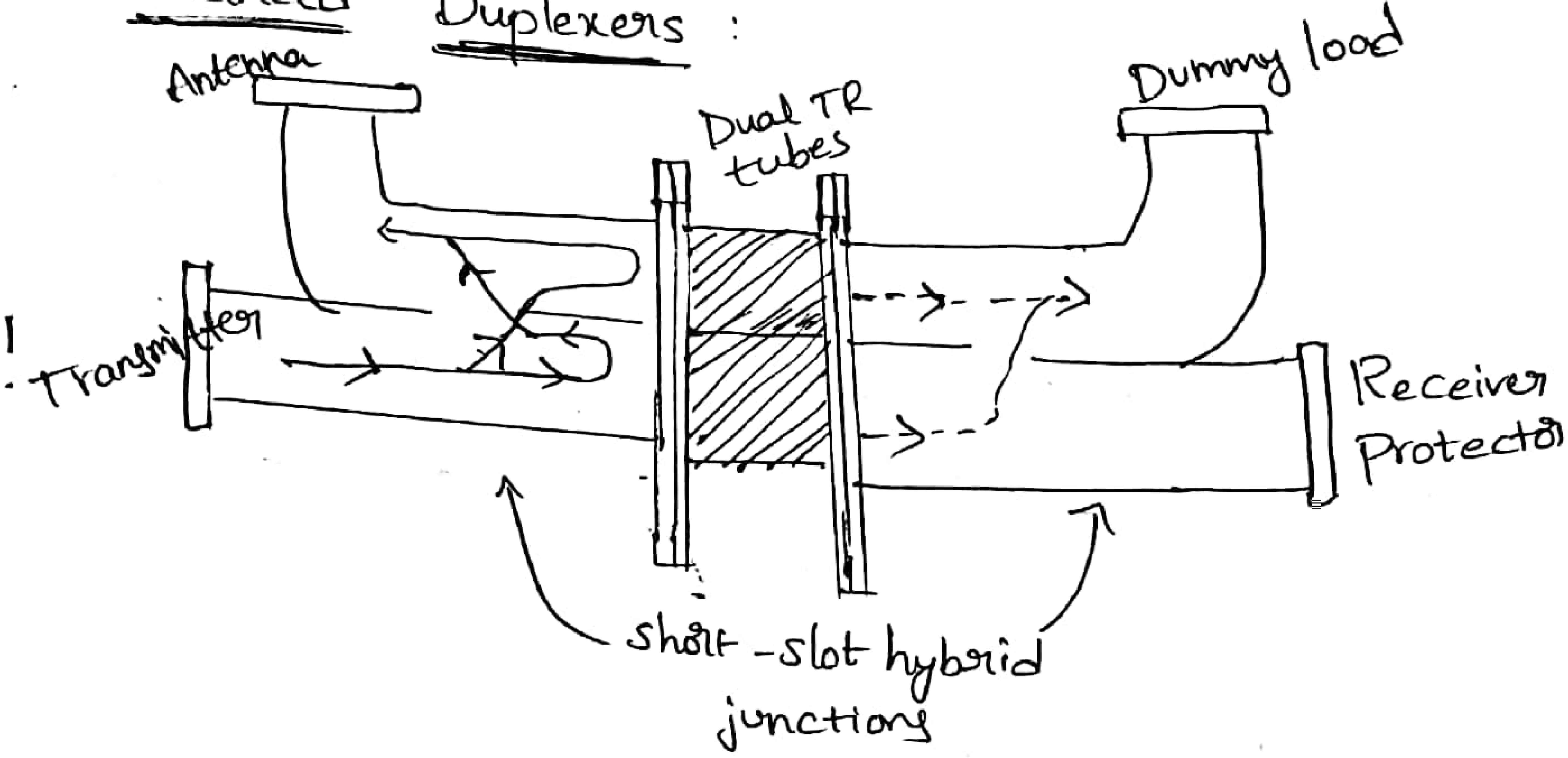
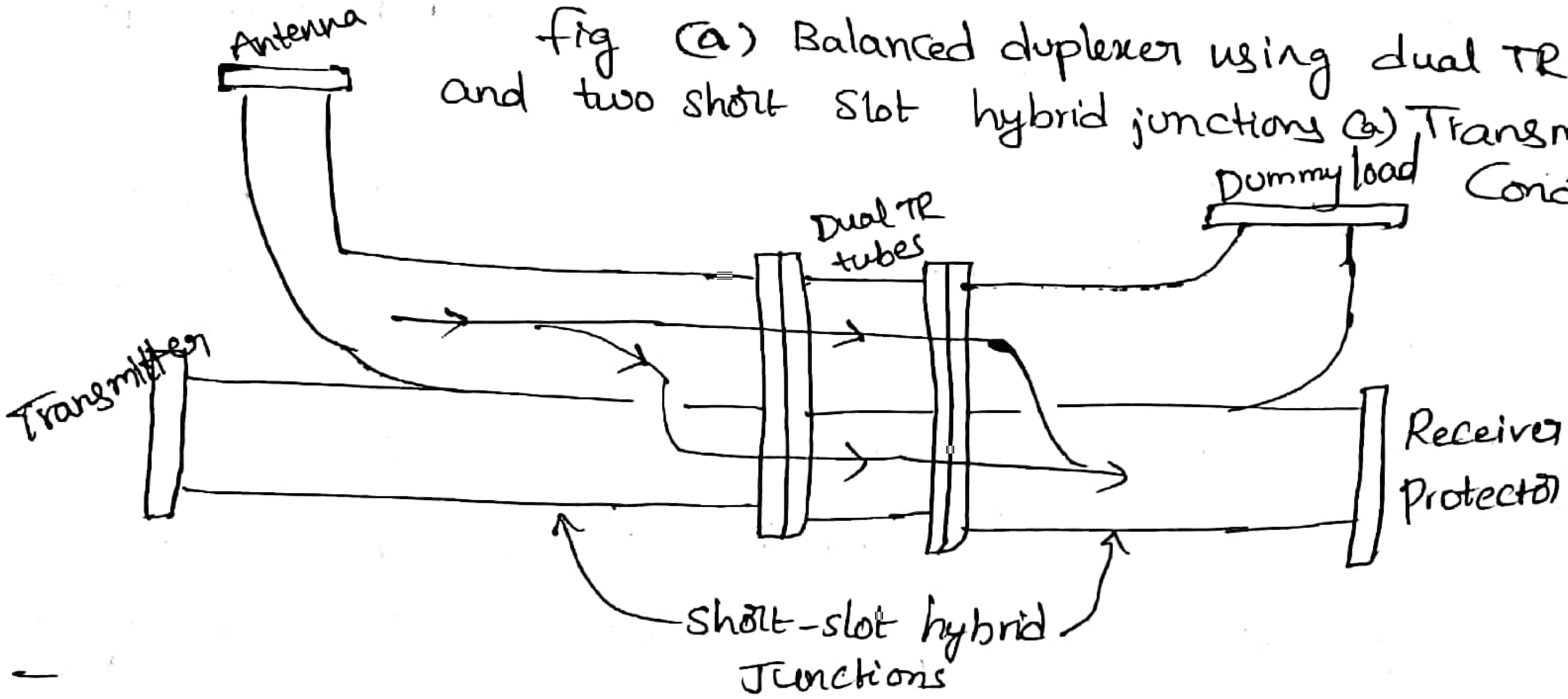


fig (a) Balanced duplexer using dual TR tubes and two short slot hybrid junctions (a) Transmit Condition



(b) Receive Condition.

-> The balanced duplexer is based on the short-circuit hybrid junction which Consists of two sections of waveguide joined along one of their narrow walls with a slot cut in the Common narrow wall to provide Coupling between the two.

to prevent transmitter power from entering the receiver.

shot-slot ... ional Couple ... in the ... to each ... junctio ... -> B short-slot hybrid may be Considered as a broadband -tional Coupler with a Coupling ratio of 3dB.

In the transmit Condition [fig(a)] power is divided equally into each waveguide by the first short-slot hybrid junction.

-> Both TR tubes breakdown and reflect the incident power out the antenna arm as shown.

-> The short-slot hybrid has the property that each time the energy passes through the slot in either direction its phase is advanced 90°. Therfore, the energy must travel as indicated by the solid lines.

-> Any energy which leaks through the TR tubes (shown by the dashed lines) is directed to the arm with the matched dummy load and not to the receiver.

-> In addition 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 Signal pass through the duplexers and into the receiver as shown in fig (b).

-> The power Splits equally at the first junction and because of the 90° phase advance on passing through the slot, the energy recombines in the receiving arm and not in the dummy load arm.

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Advantages:

1. The power handling Capability of the balanced duplexer is greater than that of the branch-type duplexer.
2. It has wide bandwidth.

Circulators as duplexers

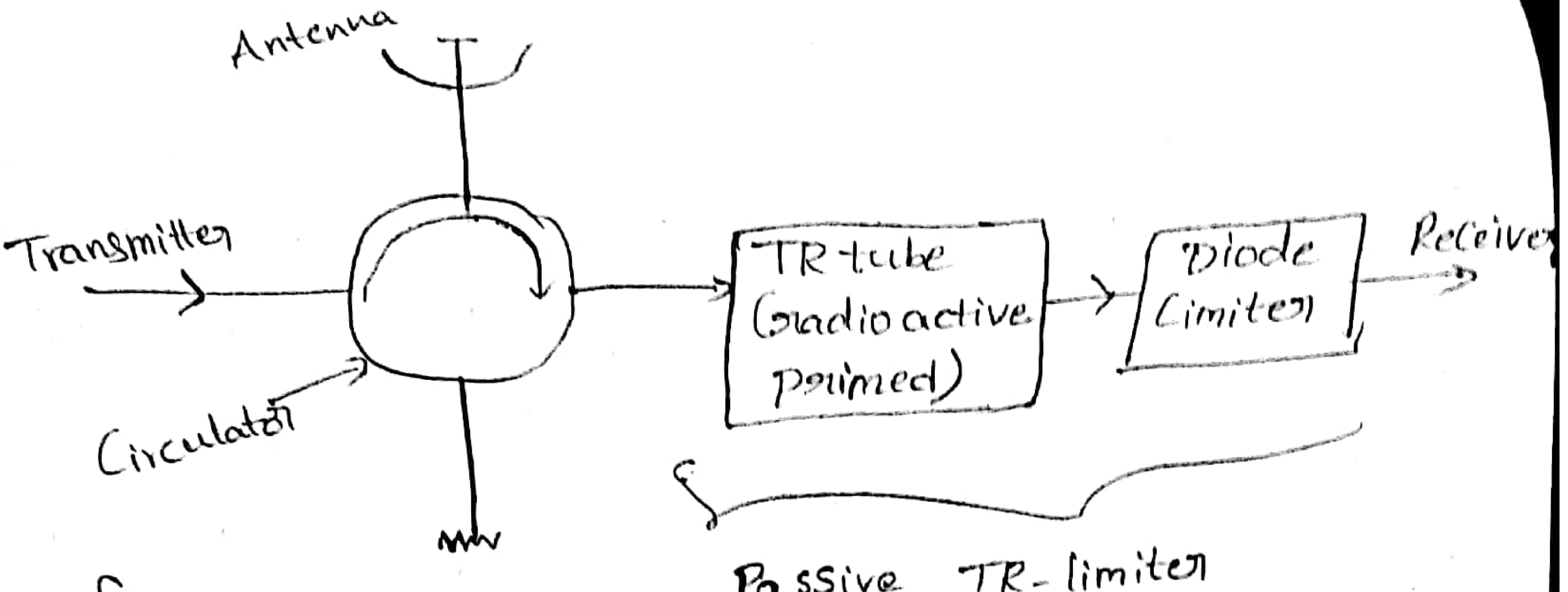

fig: circulator and receiver protector. A four-port circulator is shown with the fourth port terminated in a matched load to provide greater isolation between the transmitter and the receiver than provided by a three port circulator.

→ The ferrite circulator is a three or four-port device that Can offer Separation of the transmitter and receiver without the need for the Conventional duplexer Configurations.

→ The circulator doesnot provide sufficient protection by itself and requires a receiver protector as in above fig.

→ The isolation between the transmitter and receiver

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that usually determines the amount of transmitter Power the receiver, but the impedance mismatch at the antenna which reflects transmitter power back into the receiver.

-> 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 mismatch in the direction of the receiver which corresponding an isolation of only 14 dB. About 11 Percent of the power reflected when the VSWR is 2, Corresponding to less than 10dB isolation.

-> Thus a receiver protector is almost always required. It also reduces to a safe level radiations from nearby transmitters.

-> The receiver protector might use solid-state diodes for an all solid-state Configuration, or it might be a Passive TR-limit Consisting of radioactive primed TR tube followed by a diode limiter.

Advantages:

1. Long life
2. wide bandwidth
3. Compact design

-> Ferrite circulator provides isolation of about 20 to 30 dB between the transmitter and receiver.

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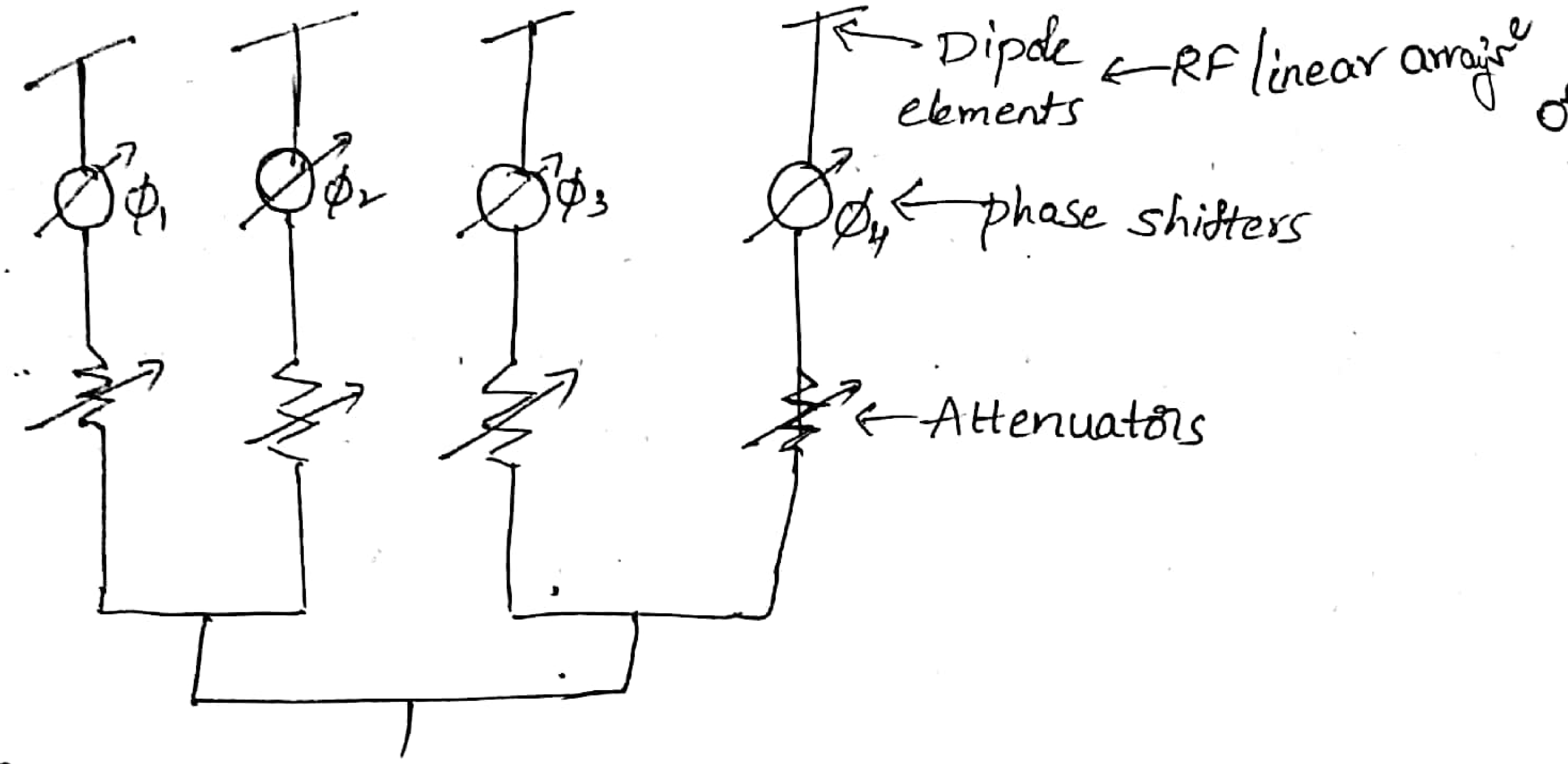
-> Small size circulator along with the receiver pro can be used as duplexer in solid state TR modules on active aperture phase arrays.

Introduction to phased array antennas



(a) phase array fed by Corporate structure (or phased array with parallel feed).

-> Def: A phased array is a directive antenna made up of individual radiating elements or antennas, which generate a radiation pattern whose shape and direction is determine 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 wave guides, slots cut in waveguide, or any other type of antenna.

-> The inherent flexibility offered by the phased array antenna in steering the beam by means of electronic control is what has made it of interest for radar.

-> It has been considered in those radar applications where it is necessary to shift the beam rapidly from one

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...odules in space to another, or where it is required to obtain ...tion about many targets at a flexible, rapid data ...

The full potential of a phased array antenna requires the use of a Computer that Can determine in real time, on the basis of the actual operational situation, how best to use the Capability offered by the radar.

> The above fig. is the Schematic of a phased array with phase shifter and attenuator at each element.

-> Although the elements of any antenna array must be phased in some manner, the term phased array has Come to mean an array of many elements with the phase of each element being a variable, providing Control of the beam direction and pattern shape including side lobes.

-> Specialized phased arrays given different names are the frequency Scanning array, the retro array and the adaptive array.

-> In the scanning array, Phase change is accomplished by Varying the frequency. These frequency Scanning arrays are among the simplest phased arrays Since no phase Control is required at each element.

-> A retro array is one which automatically reflects an in Common Signal back toward its source.

-> An adaptive array Can automatically steer its beam toward a desired Signal while steering a null toward an undesired or interfering signal.

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→ An objective of a phased array is to accomplish beam steering without the mechanical and inertial problems of rotating the entire array. In principle, the beam steering of a phased array can be instantaneous and with suitable n/w's all beams can be formed simultaneously.

→ Another objective of the phased array is to provide beam control at a fixed frequency or at any number of frequencies within a certain bandwidth in frequency-independent manner.

→ Instead of controlling the beam by switching cables, a phase shifter can be installed at each element. Phase shifting may be accomplished by a ferrite device. The same effect may be reduced by the insertion of sections of cable (delay line) by electronic switching. Thus insertion of cables of $\lambda/4$, $\lambda/2$, $3\lambda/4$ and no cable provides phase increments of 90°.

Basic Concepts of arrays:

An array antenna consists of a number of individual radiating elements suitably spaced with respect to one another.

→ The relative amplitude and phase of the signals applied to each of the elements are controlled to obtain the desired radiation pattern from the combined action of all the elements.

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common geometrical forms of array antennas of interest in the 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.

-> A broadside array is one in which the direction of maximum radiation is perpendiclur, or almost perpendiclur to the line of the array.

-> An end-fire array has its maximum radiation parallel to the array.

-> The linear array generates a fan beam when the phase relationships are such that the radiation is perpendicular to the array.

-> When the radiation is at some angle other than broadside the radiation pattern is a conical-shaped beam.

-> The broadside linear-array antenna may be used when broad coverage in one plane and narrow beamwidth orthogonal plane are desired.

-> The linear array can also act as a feed for a parabolic cylinder antenna.

-> The combination of the linear array feed and the parabolic cylinder generates a more controlled fan beam than is possible with either a simple linear array or with

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a section of a parabola.

—> The Combination of a linear array and the parabo Cylinder Can also generate a pencil beam.

—> The end fire array is a special case of the line or the planar array when the beam is directed along the array.

—> End-fire linear arrays have not been widely used in radar applications. They are usually limited to low or medium gains since an endfire linear antenna of high gain require an excessively long array.

—> The two-dimensional planar array is probably the array of most interest 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 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 whose elements are distributed on a non-plane surface is called a Conformal array.

—> An array in which the relative phase shift between elements is controlled by electronic devices is called an electronically scanned array.

Patte
in Phased
Path difference
90-10

Pattern of N-element linear array or Radiation in Phased arrays

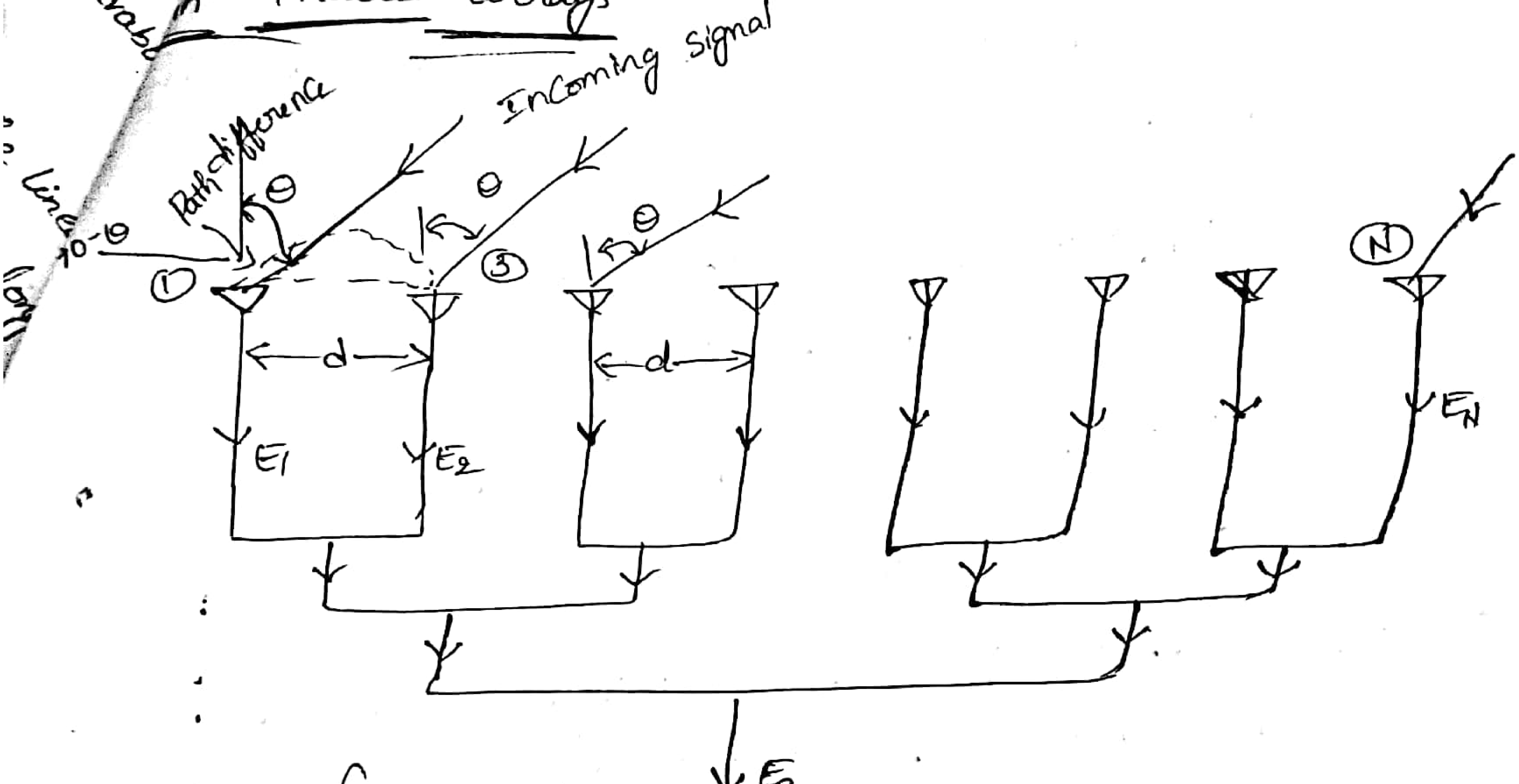

fig : N-element Linear array.

-> Consider a linear array made up of N elements equally spaced a distance 'd' a part. The elements are assumed to be isotropic point sources with equal amplitude and phase.

-> element 1 will be taken as reference signal with zero phase.

-> θ is the direction of incoming radiation.

-> It is 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 convience, will be taken to be unity.

-> The above array is a parallel feed, linear array.

-> Path difference :

$$\cos(90^{\circ}-\theta) = P.d/d \Rightarrow \sin\theta = Pd/d \Rightarrow Pd = d\sin\theta$$

Path difference $= \frac{d}{\lambda} \sin\theta$ wavelength.

→ The difference in the phase of the signals in adajac elements is

- Phase difference, $\psi = 2\pi \times$ path difference.

$$\psi = 2\pi \frac{d}{\lambda} \sin\theta$$

λ is wave length of received Signal

θ is direction of the incoming radiation.

→ The output from N receiving elements are summ to produce output voltage E_a

→ The sum of all the voltages from the individual elements can be written as

$$E_a = \sin \omega t + \sin(\omega t + \psi) + \sin(\omega t + 2\psi) + \cdots + \sin(\omega t + (N-1)\psi)$$

where ω is the angular frequency of the signal.

→ The Sum Can be written

$$E_a = \underbrace{\sin\left[\omega t + (N-1)\frac{\psi}{2}\right]}_{\text{frequency \& phase shift}} \underbrace{\frac{\sin\left(\frac{N\psi}{2}\right)}{\sin\left(\frac{\psi}{2}\right)}}_{\text{amplitude factor.}} \longrightarrow (1)$$

→ The field intensity pattern is the magnitude of eq (1) or

$$E_a(\theta) = \left| \frac{\sin[n\pi(d/\lambda)\sin\theta]}{\sin[\pi(d/\lambda)\sin\theta]} \right|$$

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field intensity pattern has zeros (or nulls) when [numerator] is zero. It occurs if

$$n\pi\left(\frac{d}{\lambda}\right)\sin\theta = 0, \pm\pi, \pm 2\pi + \cdots \pm n\pi$$

where n is integer.

Also the field intensity pattern has zeros when denominator zero. It occures if $\pi\left(\frac{d}{\lambda}\right)\sin\theta = 0, \pm\pi, \pm 2\pi \cdots \pm n\pi$

When the denominator is zero, numerator also becomes zero and the value $|E_a(\theta)| = \frac{0}{0}$ is indeterminate. Applying L-hospitals rule (differentiating numerator and denominator separately it concludes that $|E_a(\theta)|$ is maximum and equals to N when $\sin\theta = \pm n\frac{\lambda}{d}$.

→ The maximum at $\sin\theta = 0$ indicates the main beam of field intensity pattern. The other maxima are called grating lobes. The grating lobes are of some magnitude as main beam hence they are undesirable and are to be avoided. The grating lobes can be avoided by adjusting spacing 'd' between elements equal to or less than λ.

→ To avoid ambiguities, the backward radiation is usually eliminated by placing a reflecting screen behind the array.

Array factor: The normalized radiation pattern of an array of isotropic elements is called array factor and is expressed as

$$G_a(\theta) = \frac{|E_a|^2}{N^2} = \frac{\sin^2\left[N\pi\left(\frac{d}{\lambda}\right)\sin\theta\right]}{N^2\sin^2\left(\pi\left(\frac{d}{\lambda}\right)\sin\theta\right)}$$

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-> When non-isotropic radiators (directive antennas) used, the resultant array antenna radiation pattern

$$G(\theta) = G_e(\theta) \frac{\sin^2\left(N\pi\left(\frac{d}{\lambda}\right)\sin\theta\right)}{N^2\sin^2\left(\pi\left(\frac{d}{\lambda}\right)\sin\theta\right)} = G_e(\theta)\, G_a(\theta)$$

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 array factor has also been called the space factor

Two-dimensional Radiation Pattern

If the radiation Pattern in the two principal planes are $G_1(\theta_e)$ and $G_2(\theta_a)$ the two-dimensional antenna pattern is

$$G(\theta_e,\theta_a) = G_1(\theta_e)\, G_2(\theta_a)$$

Note that the angles θ_e and θ_a are not necessarily the elevation and azimuth angles normally associated with radar.

-> The normalized radiation pattern of a uniformly illuminated rectangular array is

$$G(\theta_e,\theta_a) = \frac{\sin^2\left[N\pi\left(\frac{d}{\lambda}\right)\sin\theta_a\right]\sin^2\left[M\pi\left(\frac{d}{\lambda}\right)\sin\theta_e\right]}{N^2\sin^2\left[\pi\left(\frac{d}{\lambda}\right)\sin\theta_a\right]M^2\sin^2\left[\pi\left(\frac{d}{\lambda}\right)\sin\theta_e\right]}$$

Where

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

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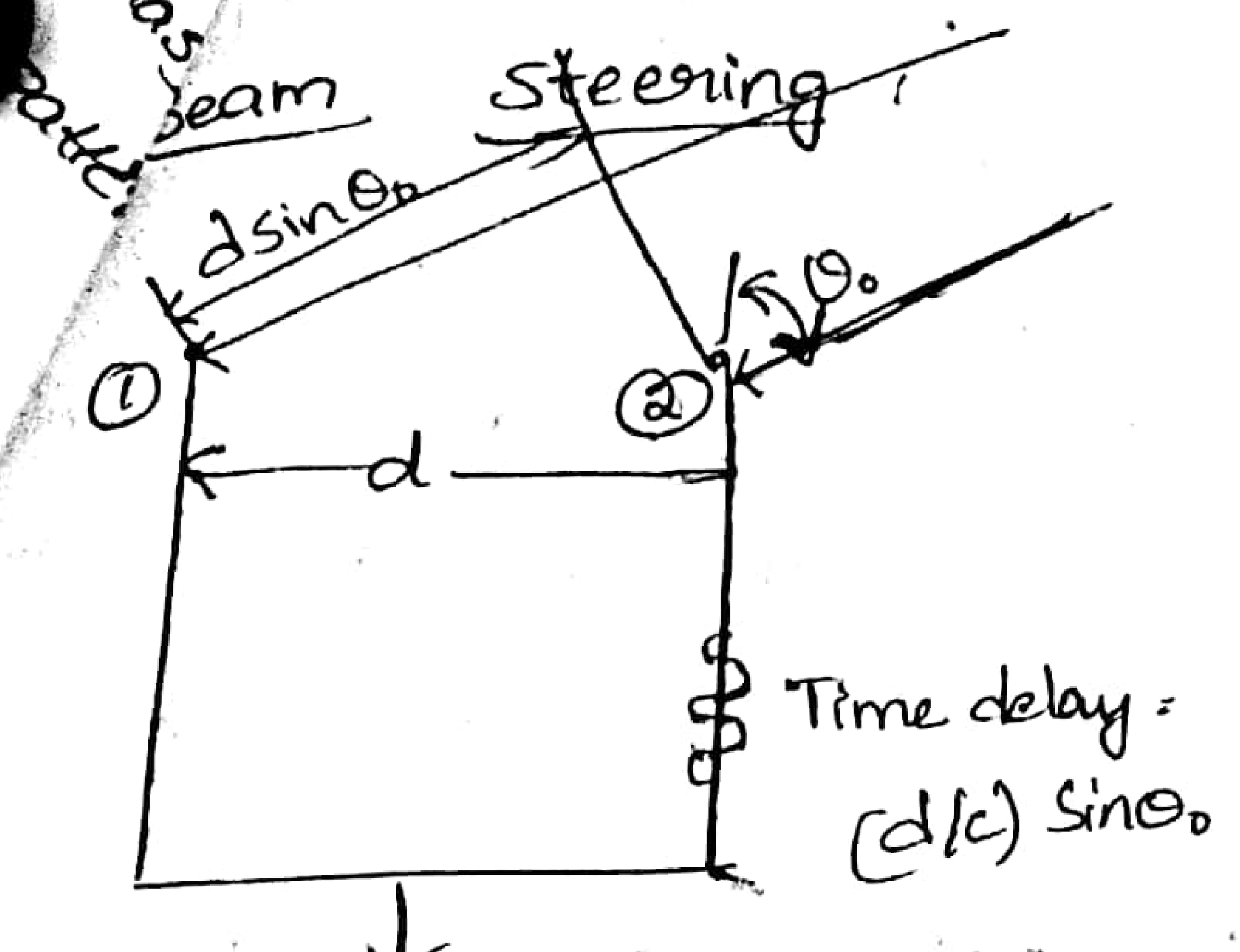
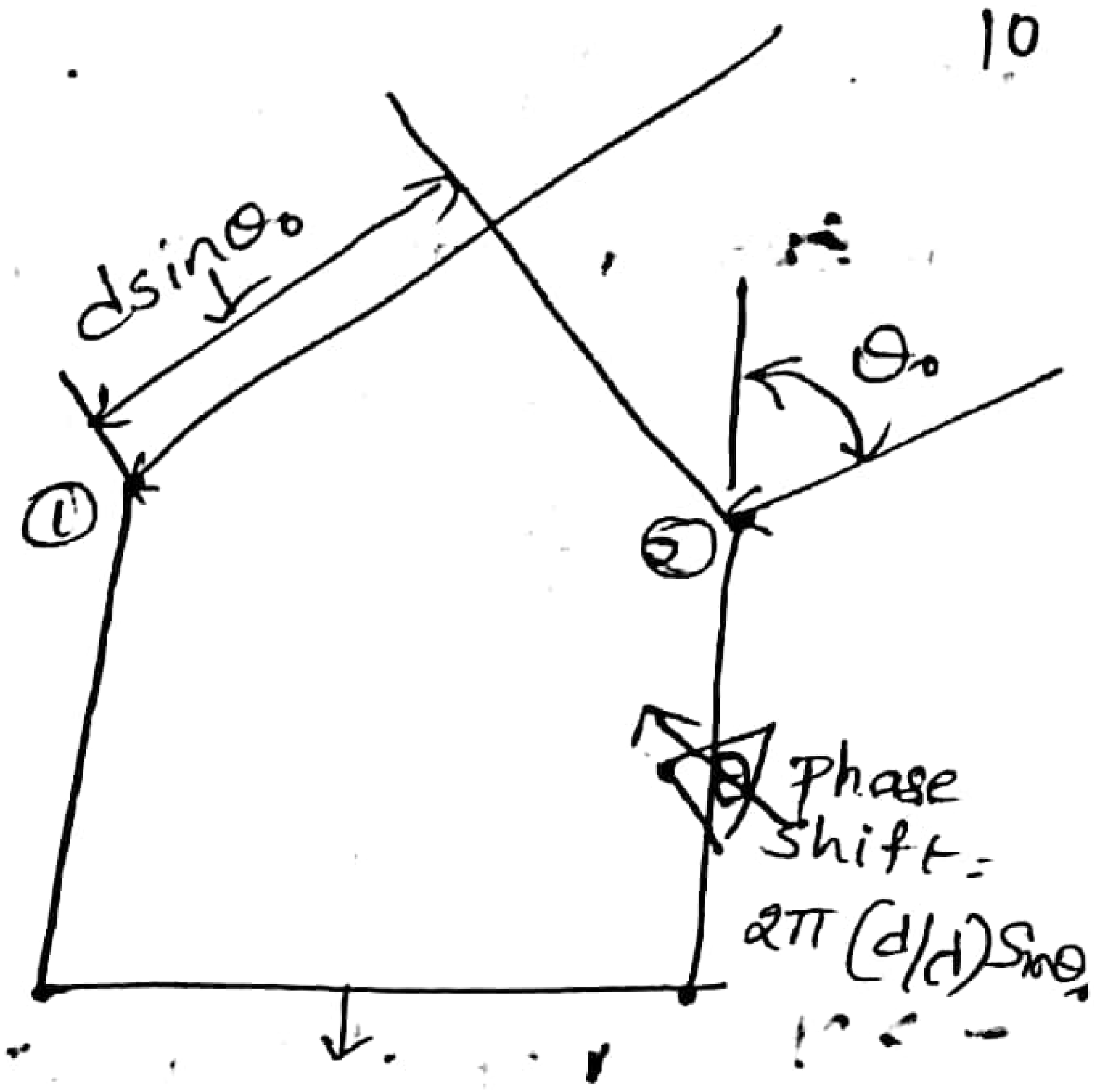


(a) Beam steering based on true time-delay



(b) Beam steering using phase shifter.

-> The beam of a linear array can be steered in angle by changing the relative time delays between the elements.

-> Consider two array elements spaced at a distance 'd' apart.

-> The signal from a direction θ_0, relative to the normal to the two elements, arrive at element 2 before it arrives at element.

-> If the signal is delayed at element ② for a time $\Delta T = (d/c)\sin\theta$ it will be in time coincidence with the signal at element 1. If they are added together it is as though the "main beam" of this simple two-element array was pointed in the direction θ_0. Beam steering occurs by changing time delay.

-> Beam steering is also possible by using a phase shifter which provides a phase shift equal to

$$\phi = 2\pi f_0 \Delta T = 2\pi \left(\frac{d}{\lambda}\right) \sin\theta_0 .$$

as shown in fig (b). The signals are in phase rather than coincident in time. This is shown in fig (b).

→ In a linear array, the phase shift that needs to be inserted at each of the elements in order to have the signals with the same phase is $m\phi$, where m, integer from 0 to $N-1$, is the number of the element relative to the reference element. This means that the phase difference between the elements is ϕ

→ The normalised radiation pattern of a linear array of isotropic elements is

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

→ The maximum of this pattern occurs when $\sin\theta = \sin\theta_0$ hence θ_0 is the direction at which the main beam points.

→ As before, the element pattern should multiply this equation to get the antenna radiation pattern. Thus the beam can be steere in an array by changing the phase shift at each element.

<u>Change of beamwidth with steering angle:</u>

As the beam of a phased array scans in angle θ_0 from broadside, its beamwidth increases as $(1/\cos\theta_0)$. This may be shown by assuming the sine in the denominator of eq $G(\theta)$ can be replaced by its argument, so that the radiation pattern is of the form $\sin^2 u/u^2$, where $u = N\pi(d/\lambda)(\sin\theta - \sin\theta_0)$

Sin value Denote

of $\sin^2 u / u^2$ antenna pattern is reduced to half its maxi-mum value when $u = \pm 0.443\pi$.

Denote by θ_+ the angle corresponding to the half-power point when $\theta > \theta_0$, and denote by θ_- the angle correspondi-ng $u = +0.443\pi$ and θ_- to $u = -0.443\pi$

→ The $\sin\theta - \sin\theta_0$ term in the expression for u can be written as $\sin\theta - \sin\theta_0 = \sin(\theta - \theta_0)\cos\theta_0 - [1 - \cos(\theta - \theta_0)]\sin\theta_0$

→ The second term on the right-hand side of this equation can be neglected when θ_0 is small so that $\sin\theta - \sin\theta_0 \approx \sin(\theta - \theta_0)\cos\theta_0$ with this approximation, the two angles corresponding to the half-power (3dB) point of the antenna pattern is

$$\theta_+ - \theta_0 = \sin^{-1}\frac{0.443\lambda}{Nd\cos\theta_0} \approx \frac{0.443\lambda}{Nd\cos\theta_0}$$

$$\theta_- - \theta_0 = \sin^{-1}\frac{-0.443\lambda}{Nd\cos\theta_0} \approx \frac{-0.443\lambda}{Nd\cos\theta_0}$$

→ The half-power beam width is

$$\theta_B = \theta_+ - \theta_- \approx \frac{0.886\lambda}{Nd\cos\theta_0}$$

Thus when the beam is scanned an angle θ_0 from broadside, the beamwidth in the plane of scan increase-s as $(\cos\theta_0)^{-1}$.

This expression, however, is not valid when θ_0 is large, and the array performance can be much worse

→ Eq ① applies for a uniform line-source distribution, which seldom is used in radar with a cosine-on-a-pedestal "aperture illumination of the form $a_0 + 2a_1 \cos(2\pi n$ ... a linear array of N elements with spacing d,' the ... width is approximately.

$$\theta_B \approx \frac{0.886\lambda}{Nd \cos\theta_0}\left[1 + 0.636\left(2a_1/a_0\right)^2\right]$$

where a_0 and a_1 are Constants and the parameter n in the aperture illumination represents the position of the element.

The beam width varies approximates inversly as $\cos\theta_0$

$$\therefore \theta_B \propto \frac{1}{\cos\theta_0}$$

-> A Consequence of the beam width increasing with scan angle is that the antenna gain also decreases with scan angle as $\cos\theta_0$

Parallel-fed array

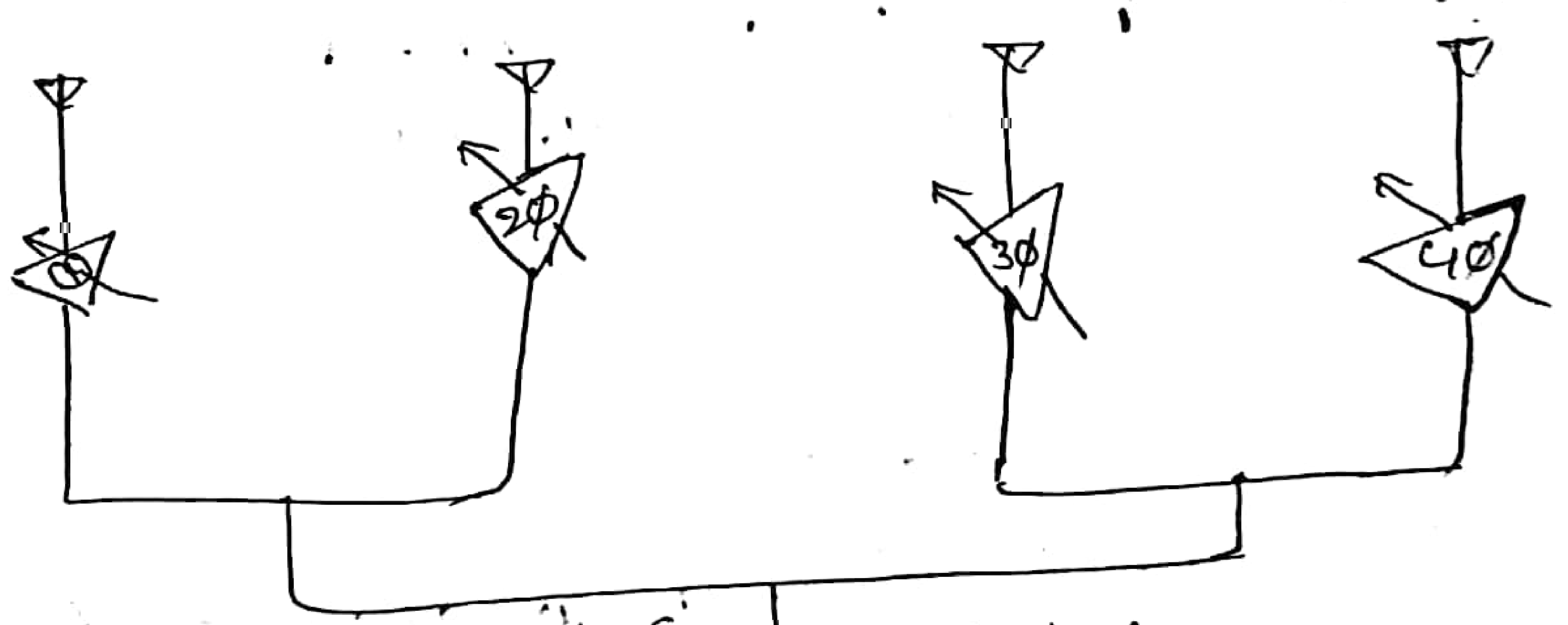


fig: parallel-fed (Corporate-fed) linear array.

-> Variable phase shifters may be used at each element of a linear array to steer the beam is Called parallel-fed antenna array.

-> The above shows four element array

-> for N element array (N-1) Phase Commands are to be generated.

the phase difference between elements is given by

$$\phi = 2\pi \left(\frac{d}{\lambda}\right) \sin\theta_0$$

Series fed array:

fig: Series-fed linear array.

-> In Series fed linear array each phase shifter has the Same phase and only one steering Command is to be generated

-> The above fig shows series fed linear array.

-> One major disadvantage of series fed array is its high loss. The total loss in Series fed array network is given by

$$\text{Total loss} = (N-1) L_{ps}$$

Where L_{ps} is loss of each phase shifter.

Series Vs parallel feeds

Series feeds	Parallel feeds
1. Each phase shifter has Same phase.	1. Each element has variable phase shifter.
2. Only one steering Command is needed	2. (N-1) steering Commands are needed.
3. High Loss in array	3. Low Loss
4. Losses change with frequency	4. Almost fixed losses

Advantages of phased array radar:

1. The primary advantage is that phased array radar eliminates the need for mechanically rotating antenna elements.
2. The radiation pattern is capable of changing rapidly to follow the moving target.
3. The array has the ability to generate simultaneously many independent beams from the same antenna aperture. The array might generate fixed beams, scanning beams or both at the same time.
4. Large peak or large average powers may be obtained with separate transmitters at each of the elements of the array.
5. The spill over loss is almost absent in phased array.
6. The efficiency of phased array radar is higher compared to all other systems.

Limitations of phased array:

1. Limited coverage available from a single plane array. Theoritically, a single plane array should be able to cover hemisphere but practically it is difficult.
2. The phased array radars are the costliest and the complexity is the biggest disadvantage.

ions of phased array antenna

radar antenn

1. used array antennas are electrically steerable.
2. A phased array may be used to point a fixed radiation pattern or to scan rapidly in azimuth or elevation.
3. It is used in optical Commmunication as a wavelength selec--tive Spliter.
4. Am broad Casting : used in many Am broadcast radio statio--ns to enhance signal strength and therfore Coverage in the city of License while minimising interference to other areas.
5. FM broadcasting : which greatly increase the antenna gain magnifying the emitted RF energy toward the horizantal which greatly increases the stations broadcast range.
6. Naval usage : phased array radars allow a warship to use one radar system for surface detection and tracking, air detection and tracking and missile uplink Capabilities.
7. Weather research usage : for better understanding of thunder storms and tornados, eventually leading to increased warning times and enhanced prediction of tornados

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8. Radio frequency Identification: phased arrays has been included in RFID systems in order to significantly boost the reading capability of passive UHF tags passing from 30 feet to 600 feet.