(Jntuh)

RADAR SYSTEMS

- EC812PE: RADAR SYSTEMS (PE – V)

(ELECTIVE V)
UNIT – 5A
B.TECH IV YEAR II SEMESTER
BY

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Acknowledgements

The contents , figures , graphs etc., are taken from the following Text book & others

“ INTRODUCTION TO RADAR SYSTEMS “

Merill I.Skolnik

Second Edition

Tata Mcgraw – Hill publishing company

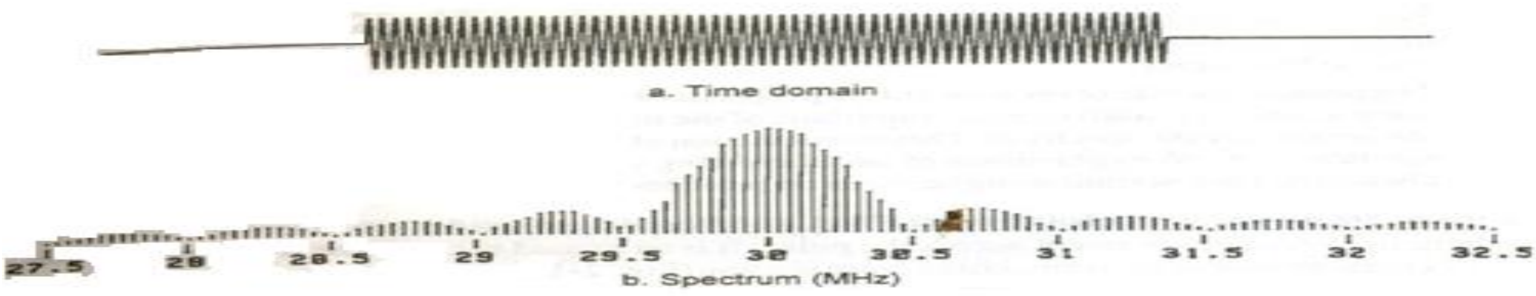
Special indian edition

SYLLABUS
(EC 812PE)
ELECTIVE-V
B.TECH IV YEAR II SEMESTER
UNIT 5

- **Detection of Radar Signals in Noise: Introduction, Matched Filter Receiver – Response Characteristics and Derivation, Correlation Function and Cross correlation Receiver, Efficiency of Non-matched Filters, Matched Filter with Non-white Noise.**
- **Radar Receivers – Noise Figure and Noise Temperature, Displays – types, Duplexers – Branch type and balanced type, Circulators as Duplexers. Introduction to Phased Array Antennas – Basic Concepts, Radiation Pattern, Beam Steering and Beam Width changes, Applications, Advantages and Limitations.**

INTRODUCTION

➤ TIME & FREQUENCY DOMAINS



- Any physical process can be described in 2 ways.

  (**A) Time domain:** Value of the quantity 'h' as a function of time that is h(t) where $-\infty < t < +\infty$

  (B) Frequency Domain: Amplitude and phase of the quantity as a function of frequency 'f' that is H(f) where

  $-\infty < f < +\infty$

- h(t) and H(f) are 2 different representations of the same quantity.

INTRODUCTION (CONTD ..)

➢ FOURIER TRANSFORM

- One can go back and forth between Time Domain & Frequency Domain by Fourier Transform
- $H(f) = \int_{-\infty}^{+\infty} h(t)\, e^{-j 2 \pi f t}\, dt$
- $h(t) = \int_{-\infty}^{+\infty} H(f)\, e^{j 2 \pi f t}\, df$

➢ Elementary properties of Fourier Transform

$h(t) \longleftrightarrow H(f)$ Fourier pair

$h(at) \longleftrightarrow \frac{1}{a} H(f)$ Time scaling

$h(t - t_0) \longleftrightarrow H(f)\, e^{-j 2 \pi f t_0}$ Time shifting

INTRODUCTION (CONTD ..)

➢ Correlation:

- Correlation is used to compare the similarity of two signals.
- Result of correlation of 2 signals shows the similarity and reaches maximum at the time when 2 signals match best.
- Correlation can be used to measure the delay of a certain system.
- When signals are aperiodic
- $z(t) = \int_{-\infty}^{+\infty} x(\tau)\, h\,(t+\tau)\, d\tau$

where z(t) = correlation function

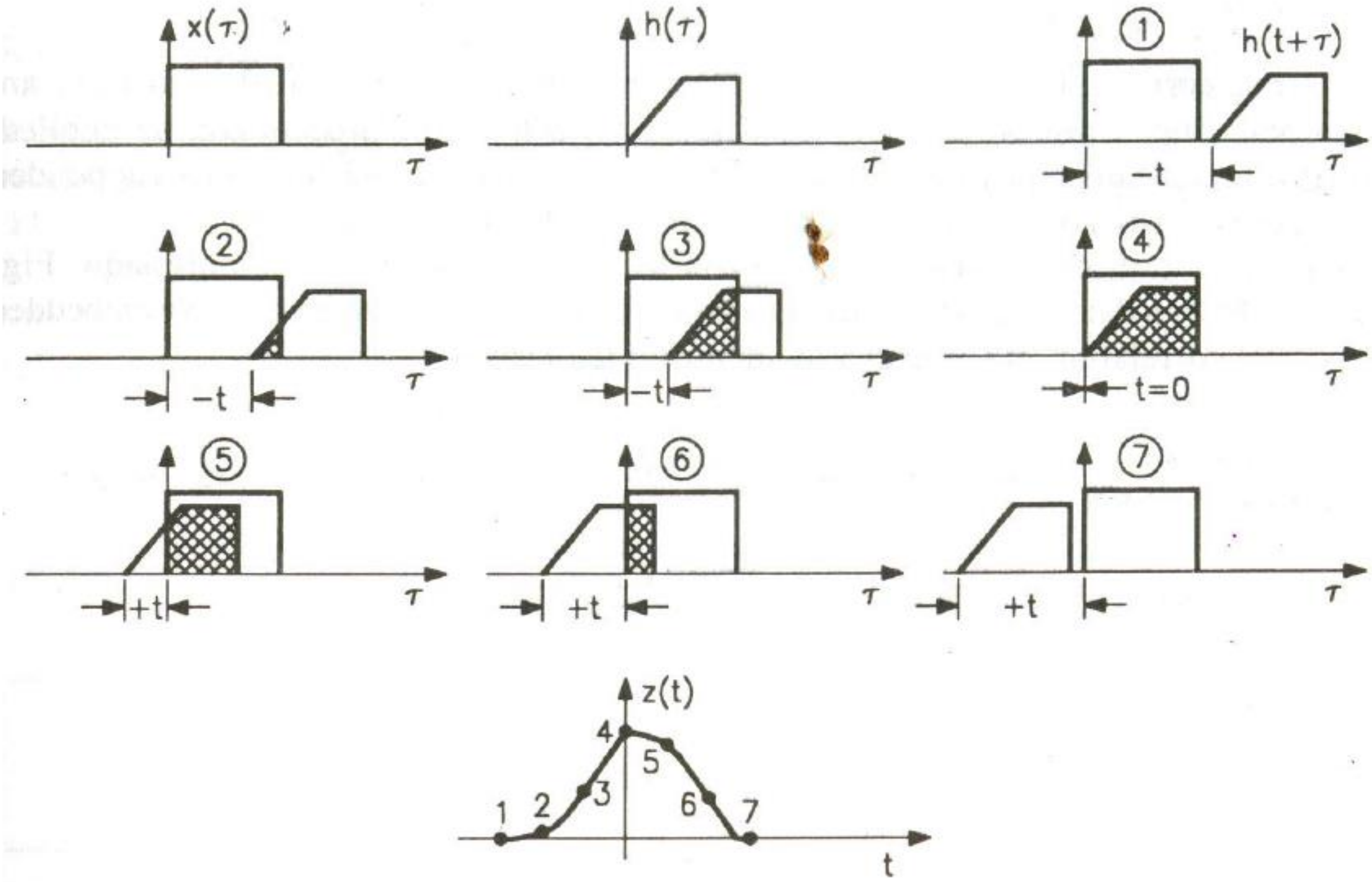
x(t) , h(t) are two functions

CORRELATION (CONTD ..)

- $z(t) = \int_{-\infty}^{+\infty} x(\tau)\, h\,(t+\tau)\, d\tau$

- X (τ) is held stationary and h (t + τ) is displaced in time and slides across it. Common area under the curves is the value of correlation.

CORRELATION (CONTD..)



Correlation

INTRODUCTION (CONTD ..)

➢ Convolution:

- Convolution is used to compute the output of linear system when a certain input signal is applied to it. This is done by applying convolution between input signal and the impulse response of the system
- $y(t) = \int_{-\infty}^{+\infty} x(\tau)\, h\,(t-\tau)\, d\tau$

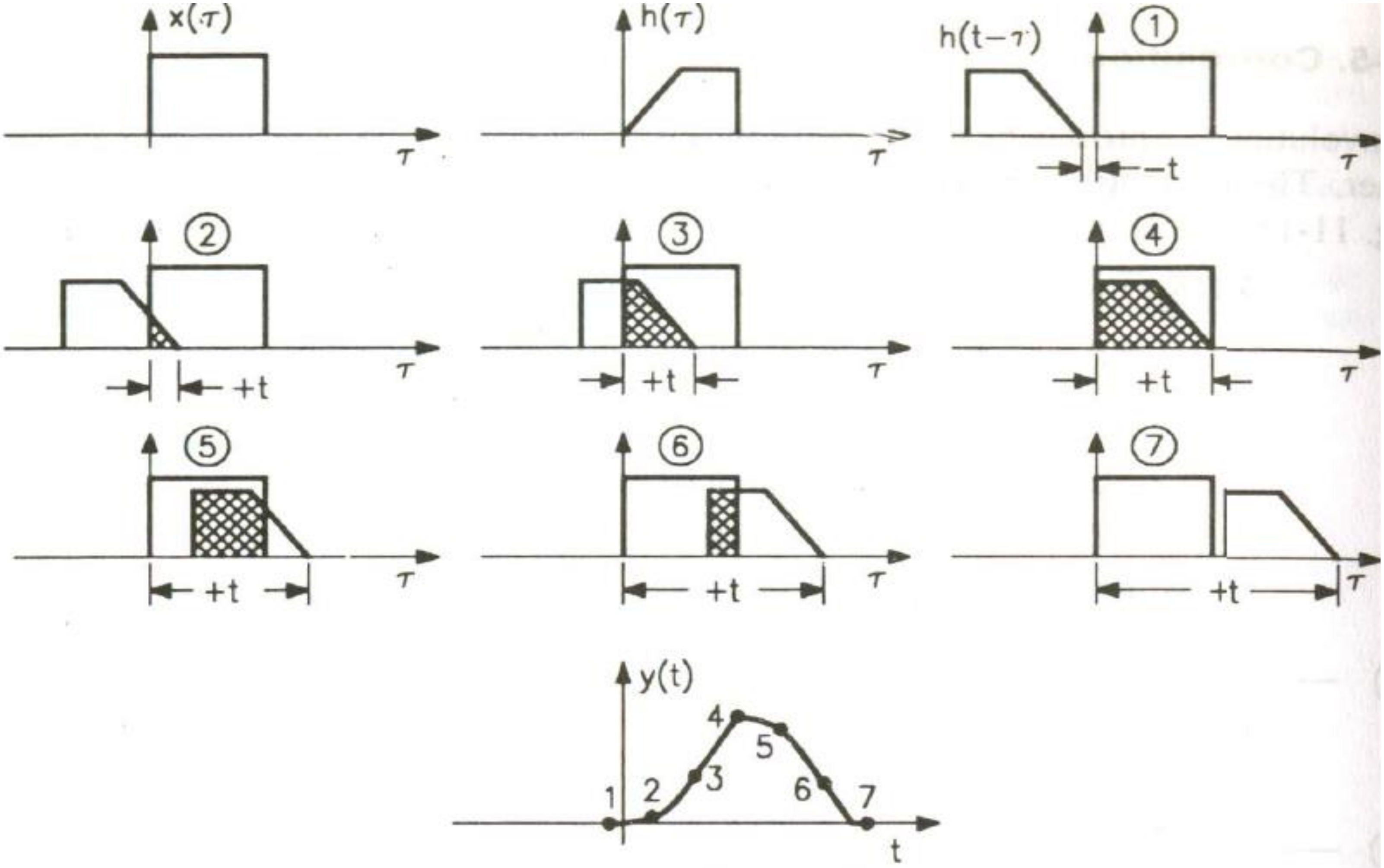
$$FT\{x(t) * h(t)\} = FT\{x(t)\} \times FT\{h(t)\}$$

where FT stands for Fourier Transform

CONVOLUTION (CONTD ..)

- Convolution of x (τ) and h (τ) is graphically done as follows
  1. In 't' domain just reverse (fold) the signal h(τ) to h($-\tau$)
  2. Multiply and integrate (find the area)

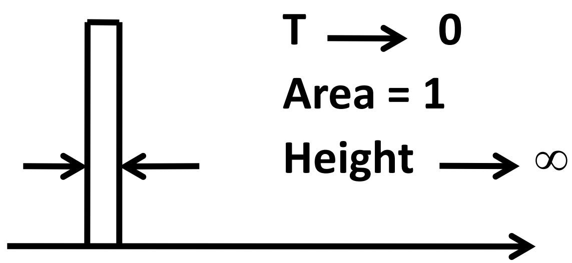
CONVOLUTION (CONTD ..)

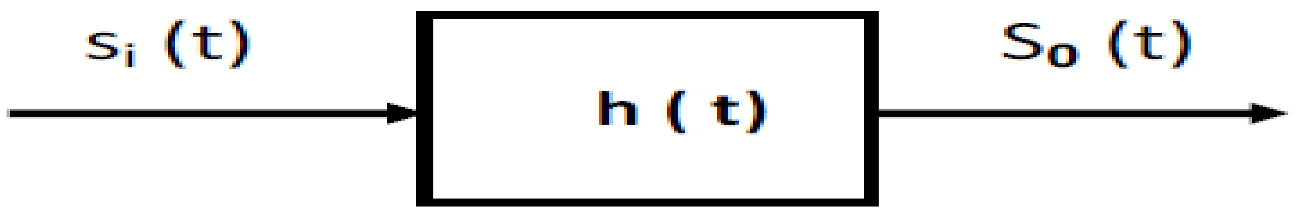


Convolution.

INTRODUCTION (CONTD ..)

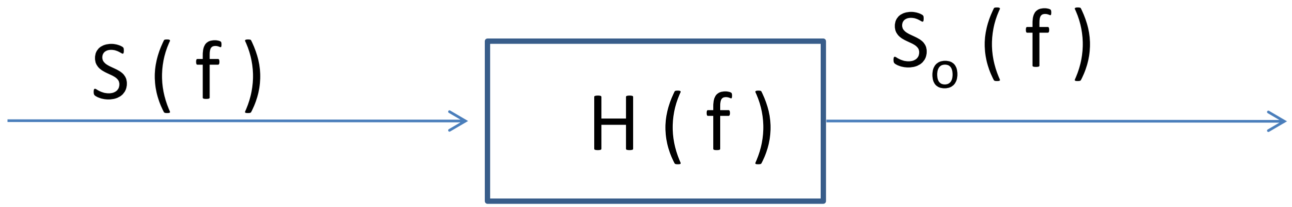
➢ Impulse Response:





- $S_o(t) = \int_{-\infty}^{+\infty} S_i(\tau)\, h\,(t-\tau)\, d\tau$
- S_0 (t) = s (t) $*$ h (t) where $*$ stands for Convolution
- Convolution in time Domain = Multiplication in Frequency Domain

INTRODUCTION (CONTD ..)



- S_0 (f)= H (f) x S (f)
- $H(f) = \int_{-\infty}^{+\infty} h\,(t)\, e^{-j\,2\,\pi\, f\, t}\, dt$
- H (f) is complex. It has amplitude and phase

Example: H (f) = a + Jb

Amplitude $|H(f)| = \sqrt{a^2 + b^2}$

Phase = $e^{-j\,\phi(f)}$

where $\phi\,(f) = \mathrm{Tan}^{-1}\frac{b}{a}$ and $H(f) = |H(f)|\; e^{-j\,\phi(f)}$

INTRODUCTION (CONTD ..)

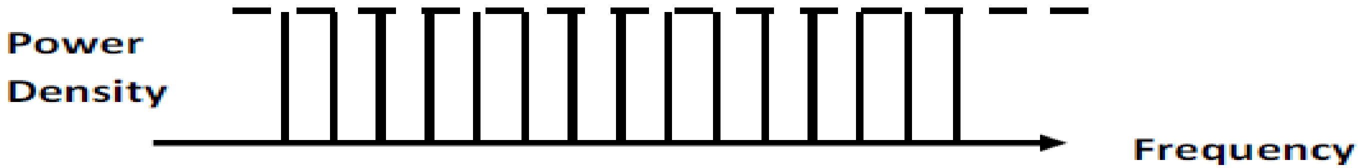
- **Energy :**

- Energy in a signal s (t) is the energy dissipated by a voltage s(t) applied to a resistor of 1 ohm.
- $E = \int_{-\infty}^{+\infty} S^2 \, dt$

- Parsvel Theorem says
- $E = \int_{-\infty}^{+\infty} S^2(t) \, dt = \int_{-\infty}^{+\infty} |S(f)|^2 \, df$

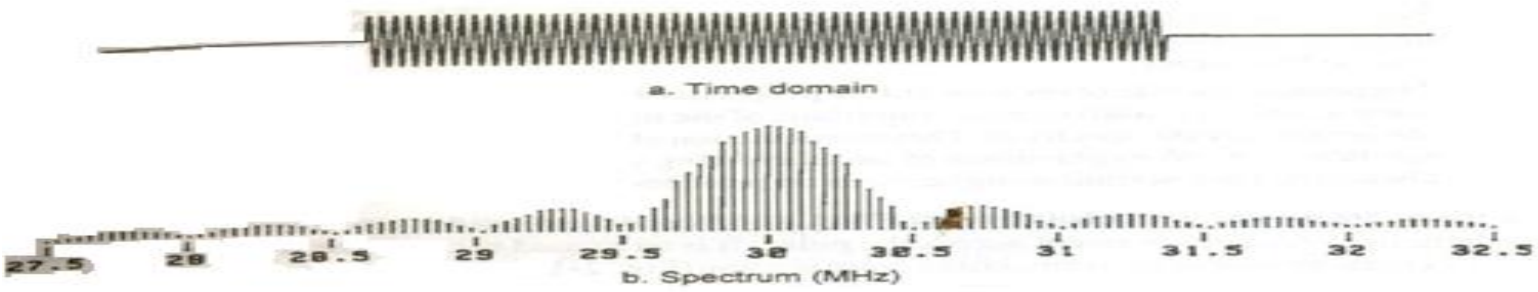
INTRODUCTION (CONTD ..)

- **Frequency components in White Noise:**



- **Frequency components in Echo pulse.**

- $$\text{Sinc}\,(x) = \frac{\text{Sin}\,(\pi x)}{\pi x} = \frac{\text{Sin}\,\pi\,(f - f_0)\,\tau}{\pi\,(f - f_0)\,\tau}$$



- where f_o – Center frequency and τ = Pulse Width

MATCHED FILTER RECEIVER

MATCHED FILTER RECEIVER

- Basic operations of radar
  i. Detection of reflecting object.
  ii. Extraction of information about the target like position & velocity.
- Noise ultimately limits the capability of any radar.
- Detection of target and extraction of information about the target in the presence of noise led to the development of Matched Filter.

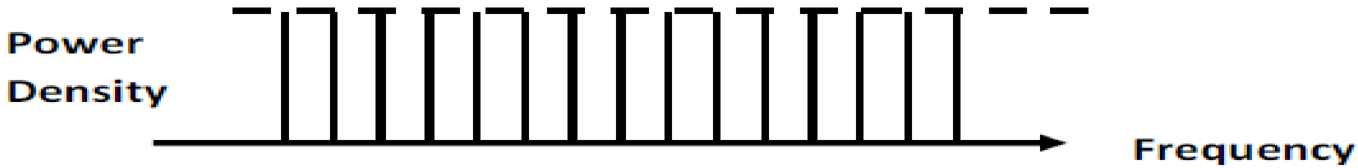
MATCHED FILTER (CONTD ..)

➢ Matched Filter:

- A network whose frequency-response function maximizes the output peak-signal-to-mean noise (power) ratio is called a matched filter.
- Maximizes $\frac{\text{output peak signal power}}{\text{mean noise power}}$
- H (f) = Frequency response of matched filter.
- H (f) = Magnitude of frequency response, gives the pass band characteristics.

INTRODUCTION (CONTD ..)

- Frequency components in White Noise:



- Frequency components in Echo pulse.

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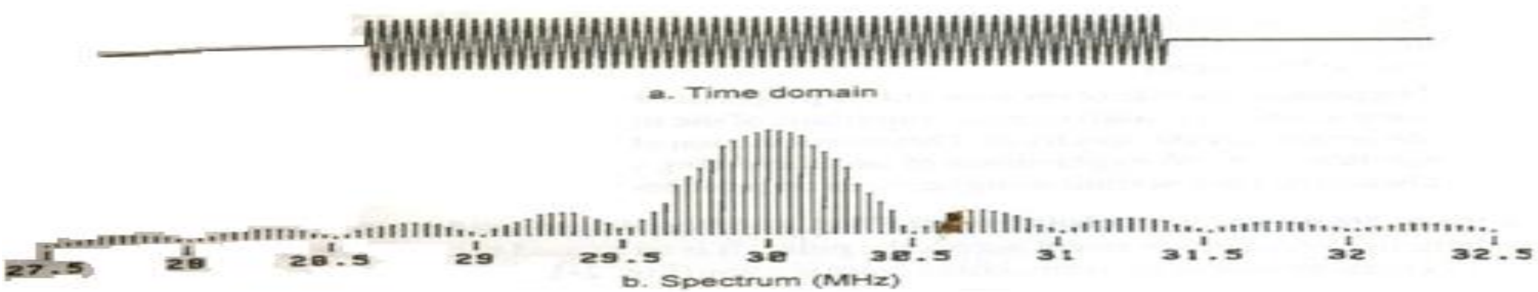


- where f_o – Center frequency and τ = Pulse Width

MATCHED FILTER (CONTD ..)

- If the band width of pass band is made wide, extraneous noise is introduced by the excess band width. This lowers the output S/N ratio.
- On the other hand if the R_X band width is narrower, considerable part of signal energy is rejected. This again lowers the output S/N ratio.
- Thus these two requirements can not be met simultaneously . So an optimum band width is chosen at which S/N is maximum.
- Purpose of matched filter is to filter as much noise as possible, while retaining as much as signal as possible . This optimizes the S/N ratio.

MATCHED FILTER RECEIVER

FREQUENCY RESPONSE   CHARACTERISTICS

(Jntuh) **Explain the characteristics of a matched filter receiver with necessary equations**

FREQUENCY RESPONSE OF A MATCHED FILTER

- s(t) = Received waveform (Echo waveform)
- E = Signal Energy
- N_o = Noise Power (Noise power per hertz of Band width)
- "North" showed that the (Linear Time Invariant) LTI filter which maximizes.
- $$\frac{\text{output peak signal power}}{\text{mean noise power}}$$

has a frequency response function H (f) .

$$\mathbf{H (f) = G_a S^* (f) \exp (- J 2 \pi f t_1)}$$

where H (f) is the transfer function of matched filter

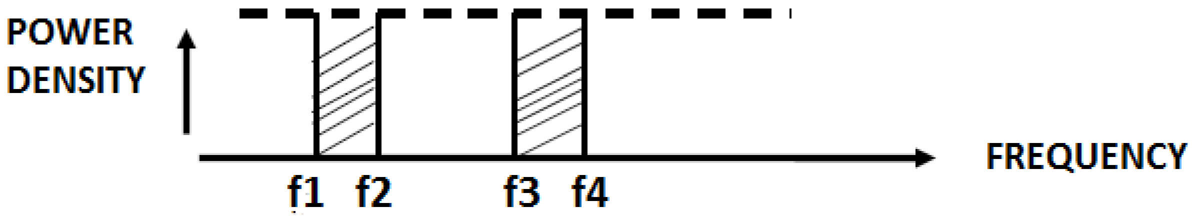
FREQUENCY RESPONSE (CONTD ..)

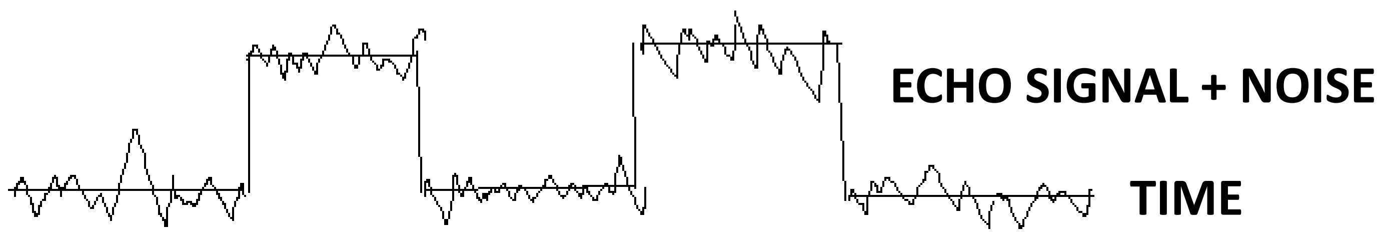
$$H(f) = G_a S^*(f) \exp(-J 2 \pi f t_1)$$

- Where $S(f) = \int s(t) \exp(-J\, 2\, \pi\, f\, t_1)\, dt$
- $S(f)$ = Voltage frequency spectrum of input signal.
- $S^*(f)$ = Complex conjugate of $S(f)$
- t_1 = fixed value of time at which signal is observed to be maximum (related to time delay between transmission and reception).
- G_a = Filter Gain taken as ‘1’ for simplification.

FREQUENCY RESPONSE (CONTD ..)

- Characteristics of Noise is assumed to be white noise.
- White noise is stationary and has a uniform spectrum





- $H(f) = G_a S^*(f) \exp(-J 2 \pi f t_1)$
- Matched filter is also called North Filter or conjugate filter.

FREQUENCY RESPONSE (CONTD ..)

- $S(f) = |S(f)| \exp\{-J \varnothing_s(f)\}$
- where $|S(f)|$ = Amplitude (Magnitude) spectrum of input echo
- $\{-J \varnothing_s(f)\}$ = Phase spectrum of echo
- $S^*(f) = |S(f)| \exp\{+J \varnothing_s(f)\}$
- similarly $H(f) = |H(f)| \exp\{-J \varnothing_m(f)\}$
- where $|H(f)|$ = Amplitude spectrum of matched filter
- $-J \varnothing_m(f)$ = Phase spectrum of matched filter

FREQUENCY RESPONSE (CONTD ..)

$H(f) = |H(f)| \exp\{-J\,Ø m(f)\}$ Eq-1

$S^{*}(f) = |S(f)| \exp\{+J\,Ø_s(f)\}$

But $H(f) = G_a S^{*}(f) \exp(-J\,2\pi f t_1)$

$H(f) = G_a |S(f)| \exp\{+J\,Ø_s(f)\} \exp\{-J\,2\pi f t_1\}$

$H(f) = G_a |S(f)| \exp(+J\,\{Ø_s(f) - 2\pi f t_1\}$ Eq-2

$H(f) = |H(f)| \exp\{-J\,Ø m(f)\}$ Eq-1

Comparing eq-2 and Eq-1 above and taking $G_a = 1$

$|H(f)| = |S(f)|$

$Ø m(f) = -Ø_s(f) + 2\pi f t_1$

FREQUENCY RESPONSE (CONTD ..)

- Amplitude spectrum of matched filter = Amplitude spectrum of the echo signal.
- Phase spectrum of matched filter = Negative of the phase spectrum of the echo signal + Phase shift proportional to frequency.

IMPULSE RESPONSE (CONTD ..)

- **Impulse Response:**
- h (t) = impulse response (Transfer function) of matched filter.
- $h(t) = \int_{-\infty}^{+\infty} H(f) \exp(J\, 2\pi f t)\, df$

But $H(f) = G_a S^*(f) \exp(-J\, 2\pi f t_1)$

Substituting H (f) in h (t)

- $h(t) = G_a \int_{-\infty}^{+\infty} S*(f) \exp(-J\, 2\pi f t_1) \exp(J\, 2\pi f t)\, df$
- $h(t) = G_a \int_{-\infty}^{+\infty} S*(f) \exp\{-J\, 2\pi f (t_1 - t)\}\, df$
- But $S^*(f) = S(-f)$ [from theory]

IMPULSE RESPONSE (CONTD ..)

- $h (t) = G_a \int_{-\infty}^{+\infty} S * (f) \exp \{- J 2 \pi f (t_1 - t)\} \, df$

  $h (t) = G_a \int_{-\infty}^{+\infty} S (-f) \exp \{- J 2 \pi f (t_1 - t) \} \, df$

- But $df = - d (- f)$[From fundamentals]

$h (t) =$

$- G_a \int_{-\infty}^{+\infty} S (-f) \exp \{ J 2 \pi (- f) (t_1 - t) \} \, d(-f)$

$= - G_a \int_{+\infty}^{-\infty} S (f) \exp \{ J 2 \pi f (t_1 - t) \} \, df$

IMPULSE RESPONSE (CONTD ..)

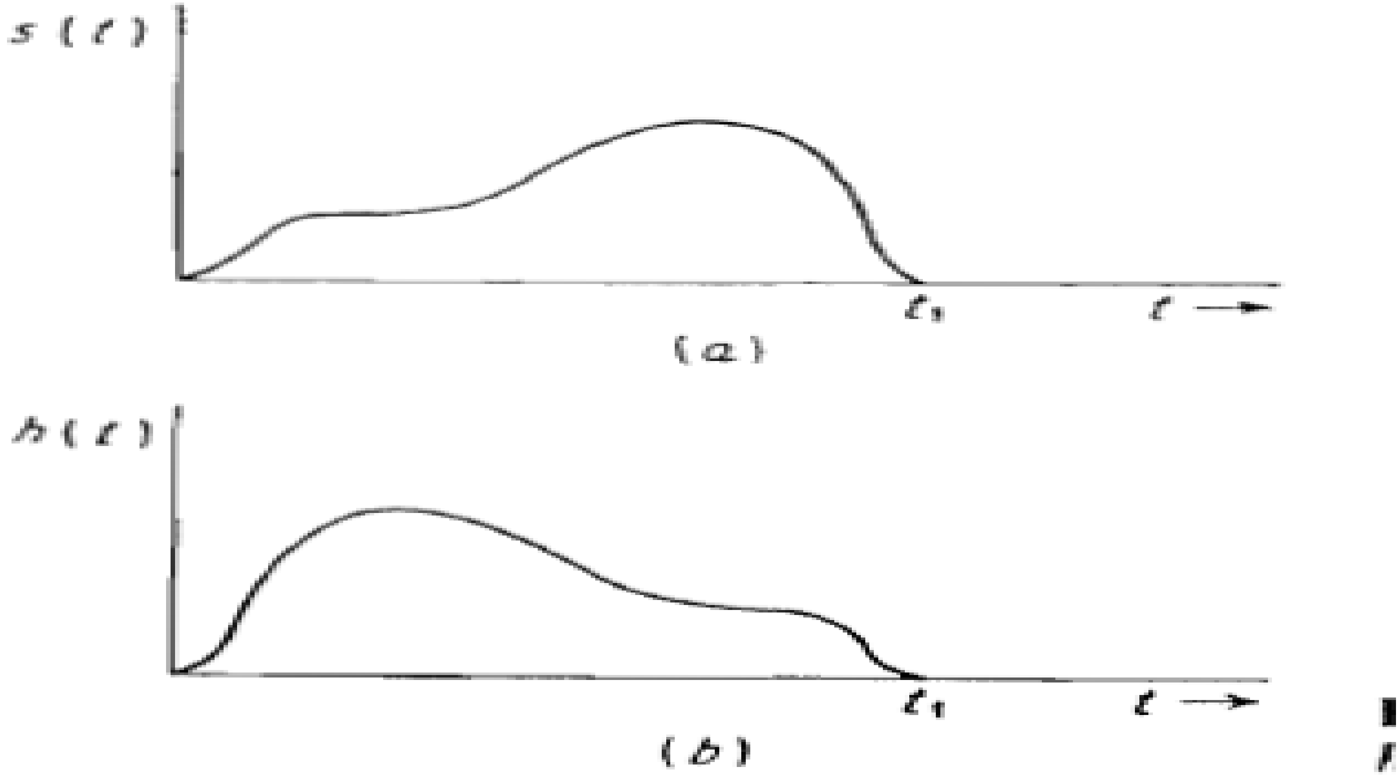
- $h(t) = G_a \int_{-\infty}^{+\infty} S(f) \exp\{J 2 \pi f (t_1 - t)\} \, df$

- But $s(t) = \int_{-\infty}^{+\infty} S(f) \exp\{J 2 \pi f t\} \, df$ [inverse Fourier]

- So $h(t) = G_a \, s(t_1 - t)$

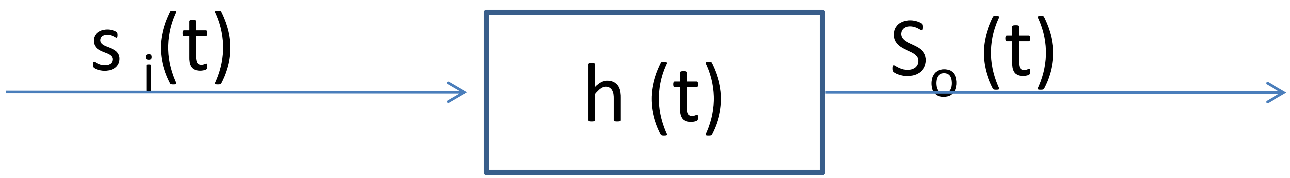
IMPULSE RESPONSE (CONTD ..)

- $h(t) = G_a \, s(t_1 - t)$
- So impulse response of matched filter = image of the echo signal wave form = echo signal run backward in time starting from fixed time 't_1'.



FORMULAS/EQUATIONS REQUIRED FOR DERIVATION OF MATCHED FILTER EQUATION

➢ Matched Filter Equation Time Domain:

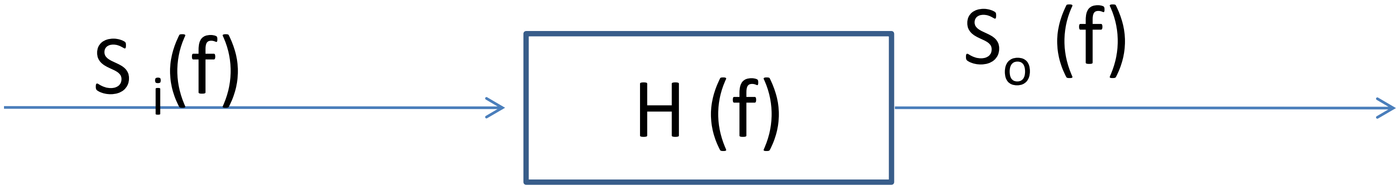


- $s_o(t) = s_i(t) * h(t)$ (where $*$ is convolution)

- $s_o(t) = \int_{-\infty}^{+\infty} s_i(t)\; h(t - \tau)\; d\tau$

FORMULAS (CONTD ..)

Matched Filter Frequency Domain:



- $S_o(f) = S_i(f) \times H(f)$ ——— **EQ 1**
- Where $S_i(f) = \int s_i(t) \exp(-J 2 \pi f t)\, dt$

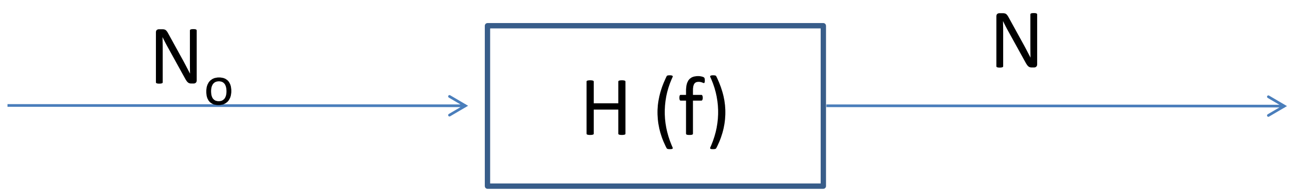
$$H(f) = \int h(t) \exp(-J 2 \pi f t)\, dt$$

$$S_o(f) = \int s_o(t) \exp(-J 2 \pi f t)\, dt$$

$$s_o(t) = \int S_o(f) \exp\{J 2 \pi f t\}\, df$$

$$s_o(t) = \int S_i(f) \times H(f) \exp\{J 2 \pi f t\}\, df$$

MEAN OUT PUT NOISE POWER



- N_o = Input Noise Power per unit Bandwidth.
- N = Mean Output Noise Power.

- $N = \frac{N_0}{2} \int | H (f) |^2 df$

➢ **Parsvel's Theorem:**

- $\int s^2 (t) dt$ = Signal energy = E
- $E = \int | S (f) |^2 df$

FORMULAS (CONTD ..)

➢ Conjugate:

- If $P^{*} = S(f)\ \exp\{J 2 \pi f t\}$If
- $P = S^{*}(f)\ \exp\{-J 2 \pi f t\}$

FORMULAS (CONTD ..)

➢ Schwartz's Inequality:

Let P and Q are complex functions

- $\left| \int P^{*} \, Q \, dx \right|^{2} \leq \int P^{*} \, P \, dx \int Q^{*} \, Q \, dx$
- Equality sign applies when P = K Q when K is constant.

- $P^{*} \, P = |P|^{2}$
- $\int P^{*} \, P \, dx = \int |P|^{2} \, dx$

- Similarly $\int Q^{*} \, Q \, dx = \int |Q|^{2} \, dx$

DERIVATION OF MATCHED FILTER CHARACTERISTICS

(Jntuh) **Explain the principle and characteristics of a matched filter. Hence derive the expression for its frequency response function**

DERIVATION OF MATCHED FILTER CHARACTERISTICS

- 2 methods (i) Calculus of variations

  (ii) Schwartz Inequality.

- **Schwartz Inequality** is used

Derivation:

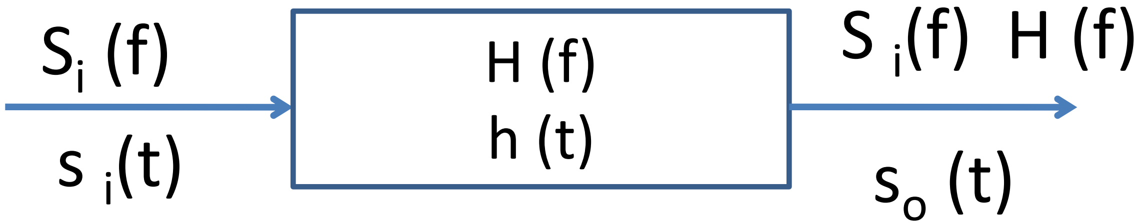
To prove $\frac{output\ peak\ signal\ power}{mean\ noise\ power} = R_f$

- $R_f = \frac{|S_0\ (t)|^2}{N} =$ EQ-1

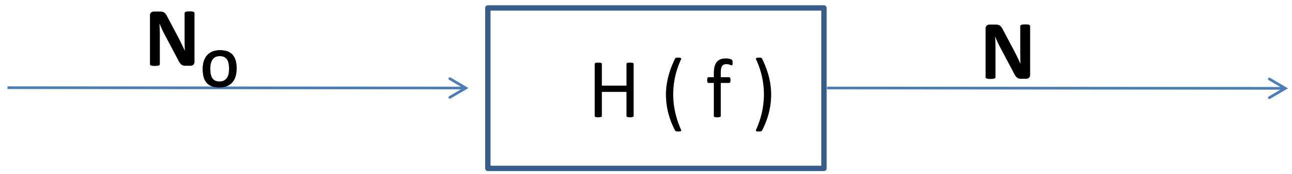
  is optimum (maximum) when

➢ $H\ (f) = G_a\ S^*\ (f) \exp\ (-J\ 2\ \pi\ f\ t_1)$

DERIVATION (CONTD ..)



- $| s_o (t) | = \left| \int S_i(f) H (f) \exp \{ J 2 \pi f t \} df \right|$ EQ-2



$$B_n = \frac{\int_{-\infty}^{+\infty} |H(f)|^2 \, df}{|H(f_{o})|^2}$$

when $H(f_o)$ is normalised to unity at mid band Bandwidth

$$B_n = \int_{-\infty}^{+\infty} |H(f)|^2 \, df$$

Let N_o = Input noise Power per unit band width

Mean Noise out power is $N = \frac{N_O}{2} \int_{0}^{+\infty} |H(f)|^2 \, df$ EQ-3

1 / 2 is because N is computed for 0 to ∞

DERIVATION (CONTD ..)

Substitute EQ (2) & (3) in EQ (1)

- $$R_f = \frac{\left| \int_{-\infty}^{+\infty} S(f) \times H(f) \ \exp\ (J\, 2\, \pi\, f\, t)\, df \right|^2}{\frac{N_0}{2} \int_{-\infty}^{+\infty} |H(f)|^2\ df}$$

- Since $|s_0(t)|^2$ maximum occurs at $t=t_1$.

- $$R_f = \frac{\left| \int_{-\infty}^{+\infty} S(f) \times H(f) \ \exp\ \left(J\, 2\, \pi\, f\, t_1\right) df \right|^2}{\frac{N_0}{2} \int_{-\infty}^{+\infty} |H(f)|^2\ df}$$ **EQ-4**

DERIVATION (CONTD ..)

- Numerator of EQ-4 is $| \int S(f) H(f) \exp(J 2 \pi f t_1) |^2$
- $= | \int S(f) \exp\{J 2 \pi f t_1\} \ H(f) \ df |^2$ **EQ-5**
- Schwartz inequality says that
- $| \int P^* Q \ df |^2 \leq \int P^* P \, df \ \int Q^* Q \, df$
- $\leq$ becomes when P = K Q where K is a constant
- (But according to Parsvel $\int P^* P \, df = \int |P|^2 \ df$)
- So $| \int P^* Q \ df |^2 \leq \int |P|^2 \ df \ \int |Q|^2 \ df$ **EQ-6**
- EQ-6 & EQ-5 are similar when
- $P^* = S(f) \ \exp(j 2 \pi f t_1)$

and Q = H (f)

DERIVATION (CONTD ..)

- Since $P^* = S(f)\ \exp\{j\,2\,\pi\,f\,t_1\}$

$$P = S^*(f)\ \exp(-j\,2\,\pi\,f\,t_1)$$

So $|P|^2 = |S(f)|^2$ (Parsvel)

Similarly since Q = H (f)

- So $|Q|^2 = |H(f)|^2$
- **EQ – 5 is** $\left| \int S(f)\exp\{J\,2\,\pi\,f\,t_1\}\ H(f)\ df \right|^2$
- $| \int |S(f)|^2\, df \int |H(f)|^2\ df$ **EQ-7**

DERIVATION (CONTD ..)

- $$R_f \le \frac{\int |S(f)|^2\, df \quad \int |H(f)|^2\, df}{\frac{N_0}{2} \int |H(f)|^2\, df}$$

- $$R_f \le \frac{\int |S(f)|^2\, df}{\frac{N_0}{2}}$$

But Parsvel's Theorem says

- $\int |S(f)|^2\, df = \int s^2(t)\, dt$ = E (Energy)

- $$R_f \le \frac{2E}{N_0}$$

∴ R_f is maximum when $R_f = \dfrac{2E}{N_0}$

DERIVATION (CONTD ..)

- Equality sign appears when P = K Q
- $R_f = \dfrac{2\ E}{N_0} \le \dfrac{\int |S(f)|^2\ df}{\frac{N_0}{2}}$
- When P = K Q
- But $P = S^*(f)\ \exp\{-j\,2\,\pi\,f\,t_1\}$

  $Q = H(f)$

So $S^*(f)\ \exp\{-j\,2\,\pi\,f\,t_1\} = K\,H(f)$

$$H(f) = \frac{1}{K}\ S^*(f)\ \exp\{-j\,2\,\pi\,f\,t_1\}$$

$H(f) = G_a\ S^*(f)\ \exp\{-j\,2\,\pi\,f\,t_1\}$

DERIVATION (CONTD ..)

➢ Interesting Property of Matched Filter:

- Irrespective of shape of input signal waveform
-
- $R_f = \dfrac{\text{Output peak signal power}}{\text{mean noise power}}$
- $R_f = \dfrac{2E}{N_0} = \dfrac{2 \times \text{Energy contained in signal}}{\text{Noise power per hertz bandwidth } N_0}$

DERIVATION (CONTD ..)

➢ Interesting Property of Matched Filter (contd.)

- i.e. maximum ratio of peak signal power to mean noise

  power is simply twice the energy contained in the signal

  divided by the noise power per hertz of band width
- Noise power per hertz of Bandwidth $N_0 = K\,T_0\,F$

  Where K = Boltzmann constant

  T_0 = Standard Temperature.

  F = Noise Figure

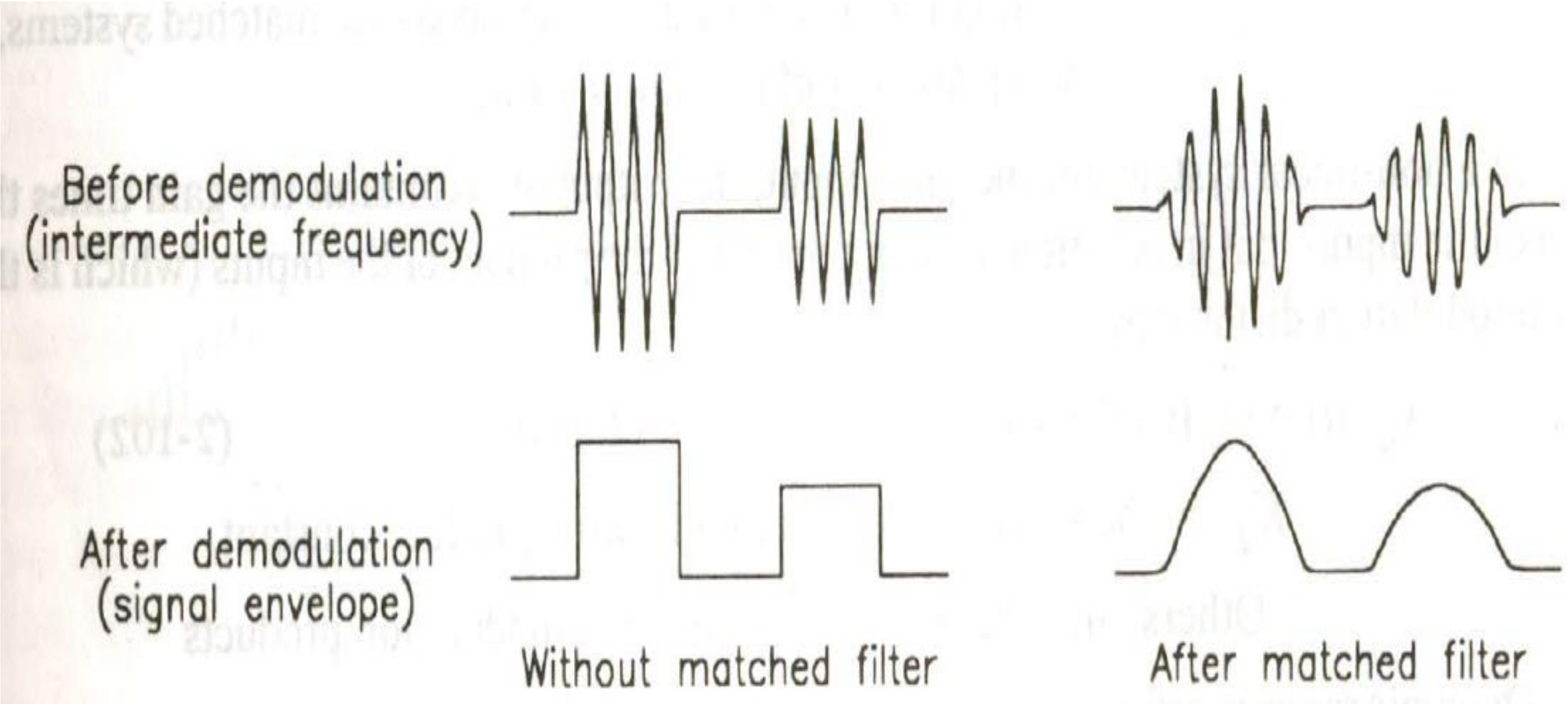
MATCHED FILTER & CORRELATION FUNCTION

(Jntuh) **Discuss the relations between the matched filter characteristics and correlation function**

(Jntuh) **Explain the principle and process of correlation detection**

MATCHED FILTER & CORRELATION FUNCTION

- Output of matched filter is not a replica (same shape of wave form) of input signal. However preserving shape is of no importance for detection.



MATCHED FILTER & CORRELATION FUNCTION (CONT)

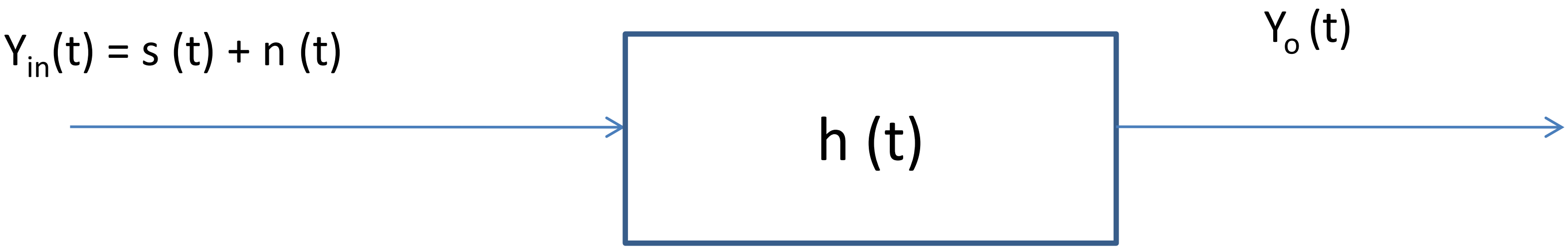
- Matched filter output is proportional to input signal (Echo) cross correlated with replica of transmitted signal, expect for the time delay t_1
- Proof:

  $y(\lambda)$, $s(\lambda)$ are 2 signals each of finite duration

  $R(t)$ is cross correlation of $y(\lambda)$ and $s(\lambda)$

- $R(t) = \int y(\lambda)\, s(\lambda - t)\, d\lambda$ --- EQ (1)

CORRELATION FUNCTION (CONTD)



- $y_o(t) = \int y_{in}(\lambda)\, h(t-\lambda)\, d\lambda$ -----EQ (2)
- Since the filter is matched filter $h(\lambda) = s(t_1 - \lambda)$
- EQ (2) becomes

$$y_o(t) = \int y_{in}(\lambda)\, s(t_1 - t + \lambda)\, d\lambda \quad \text{---EQ (3)}$$

Comparing EQ (3) & EQ (1)

$y_o(t) = R(t - t_1)$

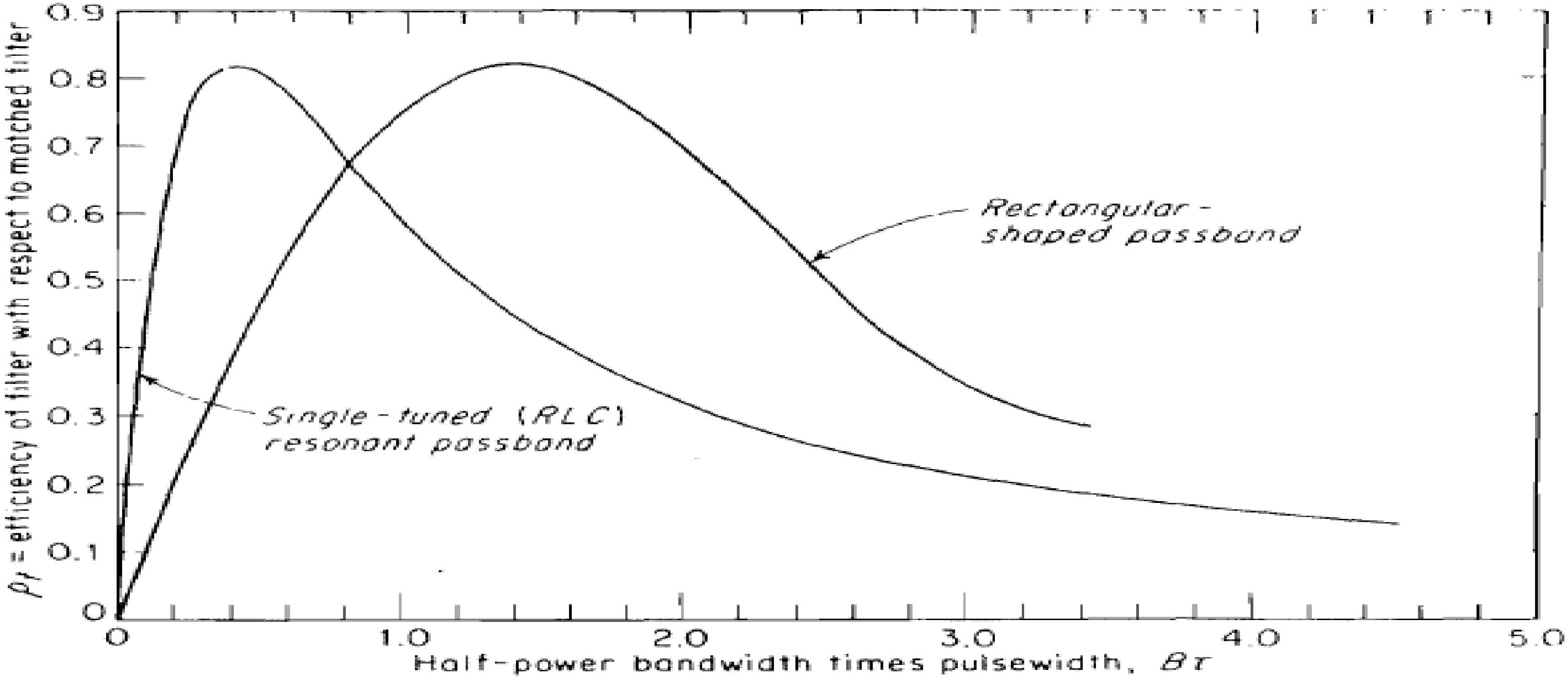
CORRELATION FUNCTION (CONTD ..)

- So matched filter response = Cross correlation of received signal corrupted by noise and replica of transmitted signal
- Replica of the transmitted signal is “built in” to the matched filter via the frequency response function
- If input signal $y_{in}(t)$ were the same as the signal $s(t)$ for which the matched filter was designed the output is the Autocorrelation function (noise is assumed zero)

(Jntuh) Briefly explain about the efficiency of non matched filters

EFFICIENCY OF NON MATCHED FILTERS

- Matched filter cannot be realized exactly in practice.
- Efficiency
- $= \dfrac{Peak\ S/N\ ratio\ of\ nonmatched\ filter}{peak\ S/N\ ratio\ of\ matched\ filter}$



EFFICIENCY OF NON MATCHED FILTERS (CONTD ..)

Input signal	Filter	Optimum $B\tau$	Loss in SNR compared with matched filter, dB
Rectangular pulse	Rectangular	1.37	0.85
Rectangular pulse	Gaussian	0.72	0.49
Gaussian pulse	Rectangular	0.72	0.49
Gaussian pulse	Gaussian	0.44	0 (matched)
Rectangular pulse	One-stage, single-tuned circuit	0.4	0.88
Rectangular pulse	2 cascaded single-tuned stages	0.613	0.56
Rectangular pulse	5 cascaded single-tuned stages	0.672	0.5

MATCHED FILTER WITH NON WHITE NOISE

(Jntuh) **Derive the expression for frequency function of the matched filter with non-white noise**

MATCHED FILTER WITH NON WHITE NOISE

- White noise is assumed in derivation of equation for matched filter.
- For Non White Noise (NWN) the frequency response is
- $H(f) = \dfrac{G_a \; S*(f) \; \exp \; (-J \, 2 \; \pi \, f \; t_1)}{|N_i \; (f)|^2}$
- $| \, N_i \, (\, f \,) \, |^2$ = Constant for white noise.
- $H(f) = \dfrac{1}{N_i \; (f)} \; G_a \; \left| \dfrac{S \; (f)}{N_i \; (f)} \right|^* \exp \; (-J \; 2 \, \pi \, f \, t_1)$

NON WHITE NOISE FILTER (CONTD ..)

- $H(f) = \frac{1}{N_i(f)} \; G_a \left| \frac{S(f)}{N_i(f)} \right|^{*} \exp\left(-J\, 2\pi f t_1\right)$

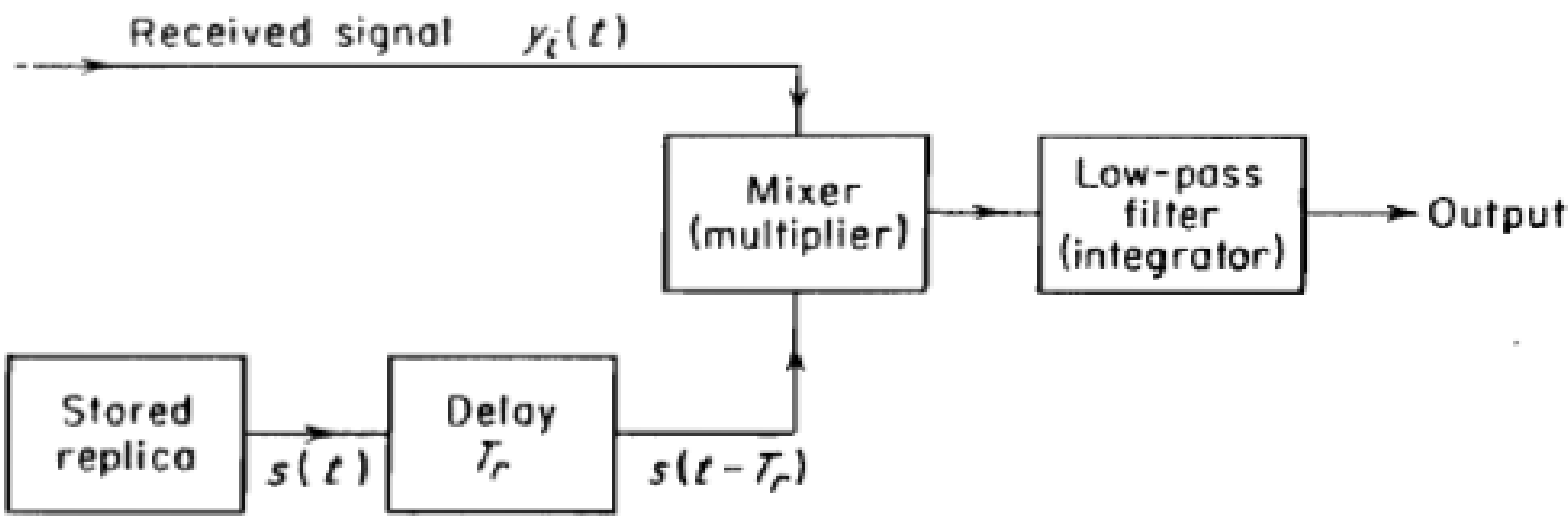
- $|\, N_i(f) \,|^2$ = Constant for white noise.
- The above is a cascade of 2 filters.

- First filter $\frac{1}{N_i(f)}$ acts to make noise spectrum uniform and called whitening filter.

- Second filter is matched filter when input is white noise & signal spectrum is $\frac{S(f)}{N_i(f)}$

CROSS CORRELATION R_x

- Alternate implementation of matched filter is the cross – correlation R_x. The matched filter is replaced by cross-correlation R_x.
- Output of matched filter = cross correlation between the input signal (echo) and delayed replica of the transmitted signal.



BLOCK DIAGRAM OF CORRELATION R_x

- Input signal y(t) is multiplied by delayed replica of the transmitted signal s ($t-T_r$).
- Product is passed through a low-pass-filter to perform integration.
- Rx tests the presence of target at a single delay T_r
- Targets at other time delays are dealt with by varying the time delays (takes more time) or by using parallel channels.

CONTINUED IN RADAR 5B

(Jntuh)

RADAR SYSTEMS

- EC812PE: RADAR SYSTEMS (PE – V)

(ELECTIVE V)

UNIT – 5B

B.TECH IV YEAR II SEMESTER

BY

Prof.G.KUMARASWAMY RAO

(Former Director DLRL Ministry of Defence)

BIET

Acknowledgements
The contents , figures , graphs etc., are taken from the following Text book & others
“ INTRODUCTION TO
RADAR SYSTEMS “
Merill I.Skolnik
Second Edition
Tata Mcgraw – Hill publishing company
Special indian edition

RADAR RECEIVER

(Jntuh) List out the general characteristics and requirements for a radar receiver

RADAR RECEIVER

- **Function:**

1. Detect desired echo signal in the presence of noise,interference,clutter etc.
2. Amplify the wanted signal to a level, where it is easily displayed on a Display or used in a Automatic Data Processor.
3. R_x design depends on (i) Type of waveform to be detected (ii) nature of noise, interference ,Clutter echoes

RADAR RECEIVER (CONTD ..)

- **Noise in R_xs:**

i. Noise enters the R_x along with signal. It enters via the antenna. (This is quite low compared to Internal noise generated)

ii. Noise is generated with in the R_x. Measurement of this internal noise is the Noise-Figure.

- **R_x Design:**

i. Should have sufficient gain and phase.

ii. Should have amplitude stability

iii. Should have sufficient dynamic range

iv. Protection against overload or saturation

v. Protection from burnout due to nearby T_xs.

RADAR R_XS (CONTD ..)

- **Types of Radar R_xs used in Radar:**

i. Superhterodyne

ii. Homodyne

iii. Crystal Video

iv. Turned R F

- **Superhetrodyne R_xs:**

- Radar Rxs are mostly Superhterodyne.
- R F is converted to IF for the following reasons.

- **Advantages:**

i. Easier to achieve good filter shape

SUPERHETERODYNE (CONTD ..)

Example:

- Frequency of Carrier = 10 GHz
- Band width of filter = 1 MHz
- Component Tolerance
- $\frac{1}{10\times10^{9}} \times 10^{6}\times100 = .01\%$

Example:

- Frequency of IF = 60 MHz
- $\frac{1}{60} \times 1\times100 = 1.6\%$
- Band width of filter = 1 MHz
- Component tolerance =

(ii) Easier to achieve necessary Bandwidth

(iii) Easier to realise IF amplifier than RF amplifier.

SUPERHETERODYNE (CONTD ..)

- **FRONT END IN A RADAR R_x:**
  i. Mixer stage after Antenna.
  ii. Low noise Amplifier.

RADAR RX (CONTD ..)

- **(i) Mixer Stage:**

- Merits:
- 1.Greater Dynamic Range

  2. Lesser sensitivity avoids saturation
     when jamming signals are present.
- De Merits: Larger noise Figure, affects range.
- $$R_{max}^4 = \frac{P_t \, G \, A_e \, \sigma}{(4\pi)^2 \, K \, T_0 \, B \, F_n \, S/N}$$
- Compensated by using i) a bigger antenna.

  ii) Larger T_x power.

RADAR RX (CONTD ..)

ii) LNA Front End:

- Merits:

i) Greater MTI Improvement factor (MTI Improvement Factor = Clutter Attenuation x Average gain)

ii) Higher sensitivity which achieves larger maximum range.

- De Merits:
- Cost of systems goes up.
- Vulnerability to Burnout because of high sensitivity.

(Jntuh) **Define noise figure. Derive the expression for the two networks that are cascaded**

(Jntuh) **Define the noise figure for a radar receiver and obtain an expression for the noise figure for three networks in cascade**

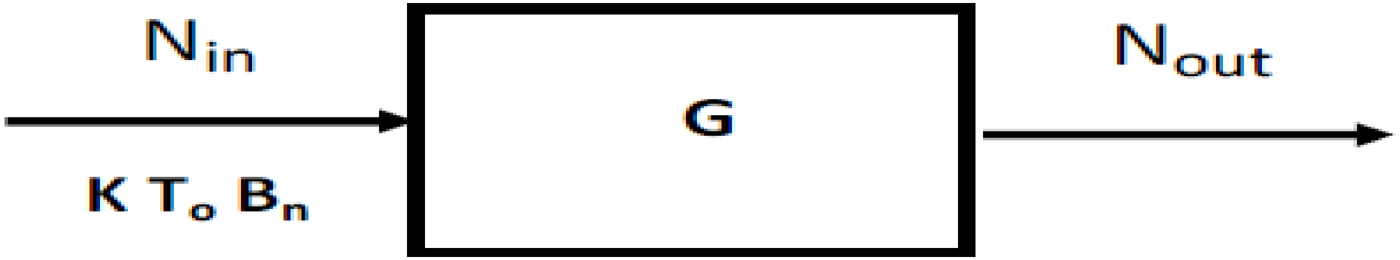
(Jntuh) **Define and distinguish between terms: noise figure ,noise temperature and system noise temperature of receiver**

NOISE FIGURE

- **Ideal Receiver:**
  - i) No noise due to external source
  - ii) Rx does not generate any noise
  - iii) only Thermal noise is present
- **Practical Receiver :**
  - Noise power of Practical Rx greater than that from thermal noise alone
- **Noise Figure : (F_n)**
- $$F_n = \frac{\text{Noise output power of practical reciver}}{\text{Noise output of ideal receiver}}$$

NOISE FIGURE (CONT)

➢ Definition:



- Noise Figure

➢ $$F_n = \frac{N_{out}}{K\ T_0\ B_n\ G} = \frac{\text{Input S/N Ratio}}{\text{output S/N Ratio}} = \frac{S_{in}/N_{in}}{S_{out}/N_{out}}$$

RECEIVER NOISE & S/N RATIO (CONTD..)

- **Noise Figure:**

$$F_n = \frac{\text{Noise output power of practical reciver}}{\text{Noise output of ideal receiver}}$$

$$= \frac{N_{out}}{K\ T_0\ B\ G}$$

N_{out} = Noise output of practical Rx

G = available Gain = $\frac{S_{out}}{S_{in}}$

S_{in} = signal input of Rx,

S_{out} = signal output of Rx

T_0 = 290 K (273 + 17) Room temp =17^0 C

RECEIVER NOISE & S/N RATIO (CONTD..)

- $G = \frac{S_{out}}{S_{in}}$
- Noise input in an Ideal Rx = $N_{in} = K\ T_0\ B_n$

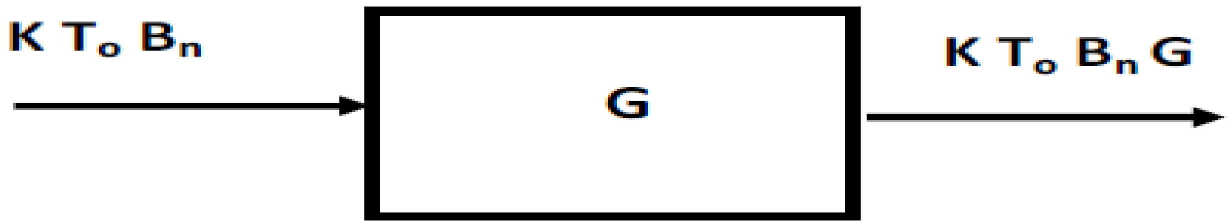
But $F_n = \frac{N_{Out}}{K\ T_0\ B_n\ G} = \frac{N_{out}}{N_{in}\ \frac{S_{out}}{S_{in}}}$

So $F_n = \frac{\left\{\frac{S_{in}}{N_{in}}\right\}}{\left\{\frac{S_{Out}}{N_{out}}\right\}} = \frac{S_{in}/N_{in}}{S_{out}/N_{out}}$

❖ Noise figure is interpreted as the degradation of S/N ratio as signal passes through Rx

NOISE FIGURE (CONTD ..)

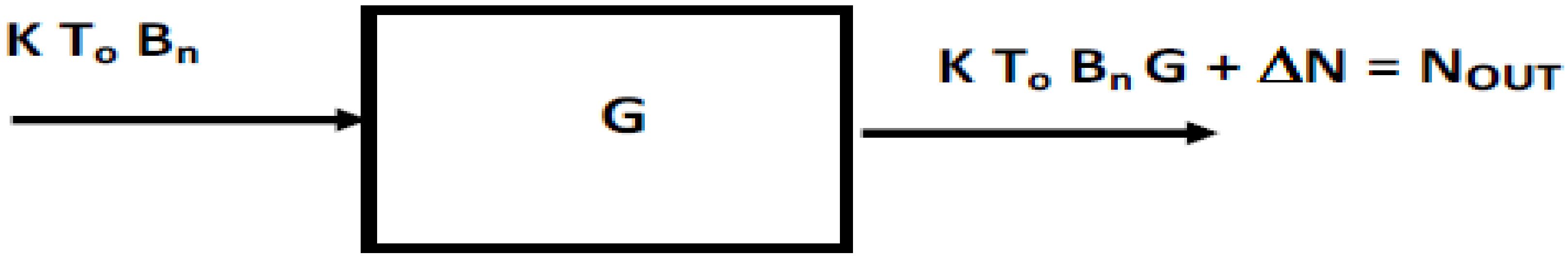
- **Interpretation 1:** Noise figure is the degradation in Signal to Noise Power as the signal passes through the network.
- **Interpretation 2:** Noise Figure is the ratio of output Noise power of practical receiver to output Noise power of an ideal receiver.
- **Ideal R_x :**



- Noise figure F_n = 1 or 0 dB

NOISE FIGURE (CONTD ..)

- **Practical Rx**

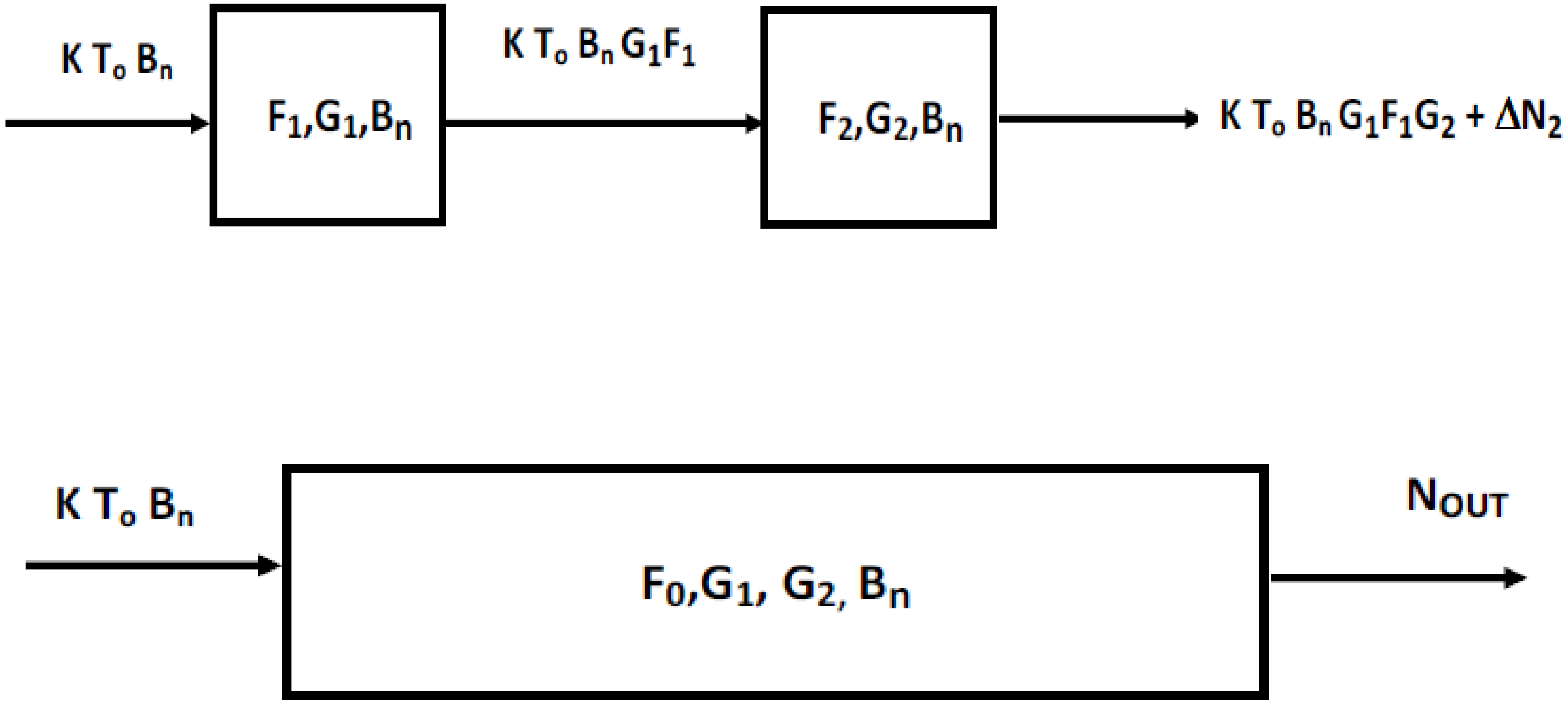


- $$F_n = \frac{K\ T_0\ B_n\ G + \Delta N}{K\ T_0\ B_n\ G} = 1 + \frac{\Delta N}{K\ T_0\ B_n\ G}$$

- ΔN is the additional Noise introduced by the network

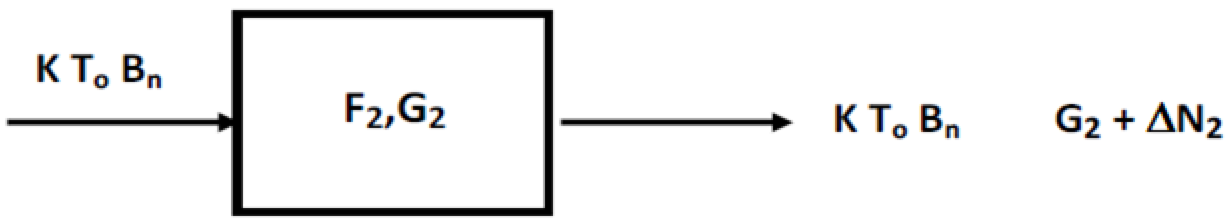
$$\Delta N = [F_n - 1]\, K\, T_o\, B_n\, G$$

NOISE FIGURE OF NETWORKS IN CASCADE



Noise Figure of Networks in Cascade

- Taking the 2nd network alone



- $F_n = \dfrac{K\ T_0\ B_n\ G + \Delta N_2}{K\ T_0\ B_n\ G_2} = 1 + \dfrac{\Delta N_2}{K\ T_0\ B_n\ G_2}$

- $(F_2 - 1)\ K\ T_0\ B_n\ G_2 = \Delta N_2$ — EQ (2)

NOISE FIGURE OF NETWORKS IN CASCADE

N_{OUT} = Noise from Network 1 at output of Network 2

+

Noise ΔN_2 Introduced by Network 2

→Taking the resultant cascaded Network (by definition)

→ $$F_0 = \frac{N_{out}}{K\ T_o\ B_n\ G_1\ G_2}$$ EQ-1

NOISE FIGURE OF NETWORKS IN CASCADE

EQ (1) states

- $$F_0 = \frac{N_{out}}{K\ T_o\ B_n\ G_1\ G_2}$$
- $N_{out} = F_o\ K\ T_o\ B_n\ G_1\ G_2 = F_1\ K\ T_o\ B_n\ G_1\ G_2 + \Delta\ N_2$
- $F_o\ \cancel{K\ T_o\ B_n}\ G_1\ \cancel{G_2} = F_1\ \cancel{K\ T_o\ B_n}\ G_1\ \cancel{G_2}$
  $+ (\ F_2 - 1)\ \cancel{K\ T_o\ B_n\ G_2}$
- $F_O\ G_1 = F_1\ G_1 + (\ F_2 - 1)$
- $$F_0 = F_1 + \frac{(\ F_2\ - 1\ )}{G_1}$$

NOISE FIGURE OF NETWORKS IN CASCADE

- F_0 Noise figure of Cascade Network =
- F_1 (Noise Figure of Network I) + $\frac{(F_2 - 1)}{G_1}$
- [(Noise Figure of Network 2) – 1] $\div G_1$

- Noise Figure of cascaded Network = Noise Figure of Network 1 (if G_1 is large)
- Noise Figure of N networks in Cascade:
- $F_0 = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \ldots + \frac{F_n - 1}{G_1 G_2 \ldots\ldots G_{n-1}}$

NOISE TEMPERATURE

- Some times Performance of Rx is expressed in terms of Effective Noise temperature T_e
- T_e is the Temperature at input of network that account for additional noise ΔN at output

- $$F_n = \frac{K\,T_0\,B_n\,G + \Delta N}{K\,T_0\,B_n\,G} = 1 + \frac{\Delta N}{K\,T_0\,B_n\,G}$$

NOISE TEMPERATURE (CONTD..)

- Let $\Delta N = K\, T_e\, B_n\, G$

- From previous slide $F_n = 1 + \dfrac{\Delta N}{K\, T_0\, B_n\, G}$

- $F_n = 1 + \dfrac{K\, T_e\, B_n\, G}{K\, T_0\, B_n\, G} = 1 + \dfrac{T_e}{T_0}$

- So $T_e = [\, F_n - 1\,]\; T_o$

NOISE TEMPERATURE OF CASCADED NETWORK

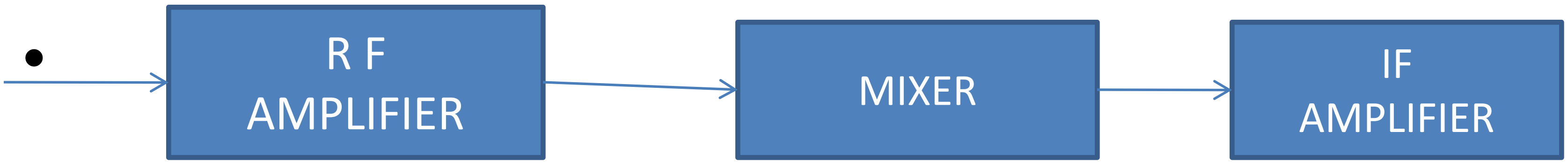
- System Noise Temperature = T_s
- Antenna Temperature = T_a
- Rx Effective noise temperature = T_e
- $T_s = T_a + T_e = (F_s - 1)\, T_0$
- where F_s = system noise figure

➢ **Cascade of Networks :**

➢ $$T_e = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 G_2} + \ldots\ldots + \frac{T_n}{G_1 G_2 \ldots G_{n-1}}$$

PROBLEMS IN NOISE FIGURE

- **Problem 1:** Determine Noise Figure for a Rx that has RF Amplifier of Gain 10 dB & Noise figure of 6 dB, a Mixer down converter with a noise figure of 10 dB and converter gain of –6 dB and an IF stage with 40 dB gain & Noise figure of 6 dB

- 

- $G_1 = 10\text{dB}\ (10)$ $G_2 = -6\text{dB}\ (.25)$ $G_3 = 40\text{dB}(10^4)$
- $F_1 = 6\text{dB}\ (3.98)$ $F_2 = 10\text{dB}\ (10)$ $F_3 = 6\text{dB}(3.98)$
- $F_0 = F_1 + \dfrac{F_2 - 1}{G_1} + \dfrac{F_3 - 1}{G_1\ G_2} = 3.98 + \dfrac{10 - 1}{10} + \dfrac{3.98 - 1}{10 \times 0.25}$

$= 6.07$ or 7.83 dB

PROBLEMS IN NOISE FIGURE

- (Jntuh) **Problem 2:** Three networks units each of 6 db noise figure and 10 dB, 6dB, and 6 dB gain respectively are cascaded . Determine overall Noise figure of system
- G_1 = 10 dB (10) ; F_1 = 6 dB (3.98)
- G_2 = 6 dB (3.98) ; F_2 = 6 dB (3.98)
- G_3 = 6 dB (3.98) ; F_3 = 6 dB (3.98)
- $$F_0 = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 \, G_2} = 3.98 + \frac{3.98 - 1}{10} + \frac{3.98 - 1}{10 \times 3.98}$$

$$= 4.35 \text{ or } 7.83 \text{ dB}$$

(Convert all values in dB to ratios before applying the formulae)

RADAR DISPLAYS

RADAR DISPAYS

- **Purpose :**
  - Echo signal should be presented to operator in an understanding format
- **Raw Video:**
  - Video output from Rx connected to display directly without processing
- **Synthetic Video:**
  - Raw video processed by automatic detection and tracking processor (ADT). Output of ADT is called Synthetic Video

CATHODE RAY TUBE (CRT)

- Used extensively in 19 th century
- 2 Basic types are available
- **A. Deflection modulated CRT :**
- Target indicated by Deflection of Electron beam
- Example : A Scope
- **B. Intensity modulated CRT :**
- Target indicated by increasing luminious spot called Blip.
- Example : PPI (Plan Position Indicator)

CATHODE RAY TUBE (CONTD..)

➢ Phosphor :

- Phosphor is coated on screen so that glow persists even after video is removed.
- Glow persists until next scan.

➢ Decay Characteristics:

- Every phosphor has its own decay time of luminescence.
- Decay time should be long enough for operator to detect echo, short enough not to interfere with information of next echo.

CATHODE RAY TUBE (CONTD..)

➢ Information & Resolution Cells:

- Resolution of cell limited by spot size.
- Examples:

\# No. of Resolution cells (pixels) in a given diameter for CRT = 2000

\# Range maximum = 60,000 mts

\# Cell resolution = $\frac{60000}{2000} = 30 \text{ Mts}$

\# Pulse width of Radar Pulse = 100 nsec.

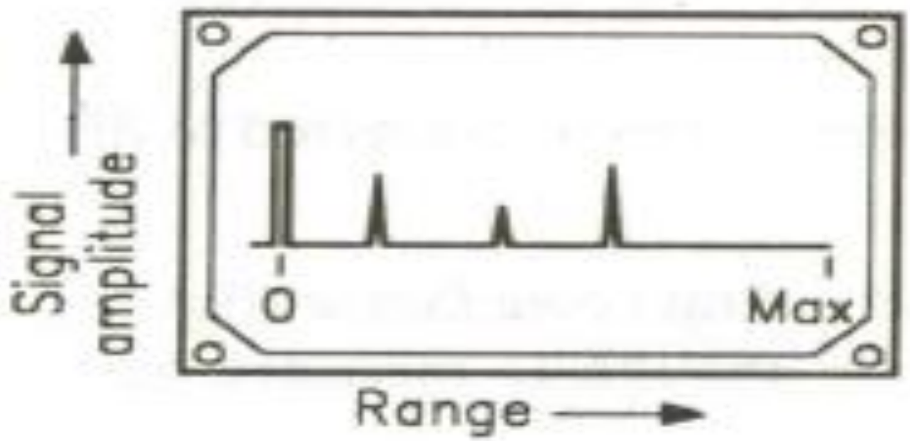
(Jntuh) **List out the different types of displays used for radar applications and their characteristics**

(Jntuh) **Explain various types of radar displays**

(Jntuh) **Explain the characteristics and requirements of radar display units**

TYPES OF DISPLAYS

➢ (1) 'A' SCOPE :

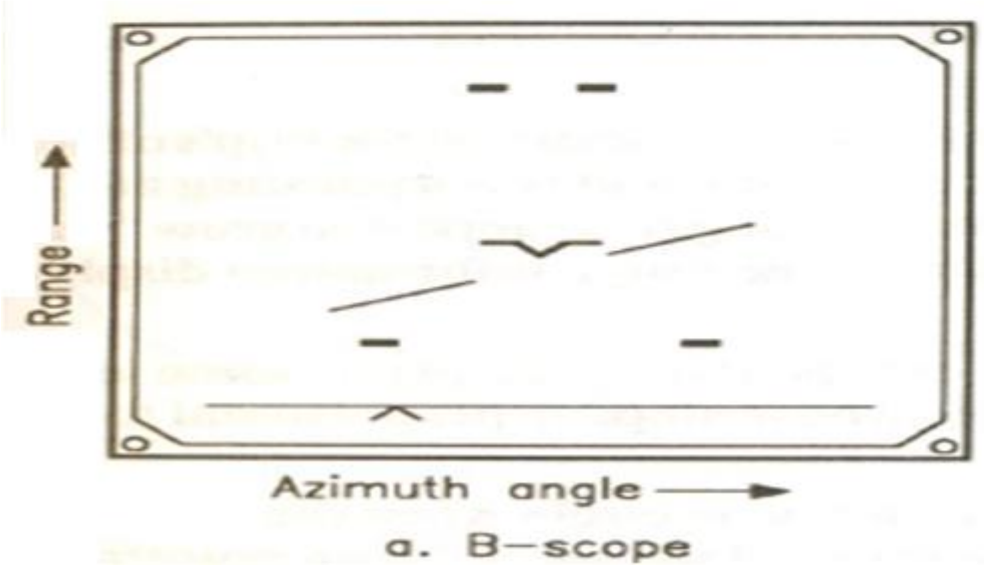


a. A–scope

- Deflection modulated display.
- X Axis (Horizontal co-ordinate) = Time (Range)
- Y Axis (Vertical co-ordinate) = Target echo signal strength
- Most commonly used display.
- Used in Tracking Radar for weapon control.

TYPES OF DISPLAYS (CONTD..)

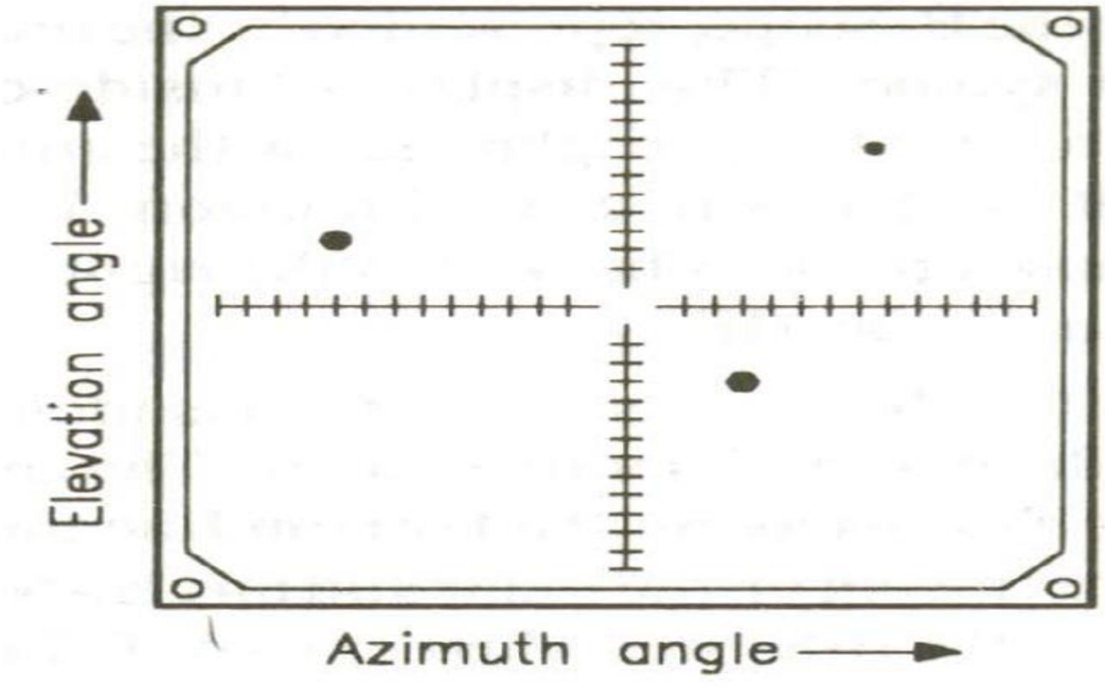
➢ (2) 'B' SCOPE :



- Intensity modulated display.
- X Axis = Azimuth angle
- Y Axis = Range
- Echo signal strength is shown by brightness of spot.
- Used in air – to – air combat display.

TYPES OF DISPLAYS CONTD..

- **(3) 'C' SCOPE :**

- 

a. C—scope

- Intensity modulated display.
- X Axis = Azimuth angle
- Y Axis = Elevation angle

TYPES OF DISPLAYS (CONTD..)

- **(4) ‘D’ SCOPE :**

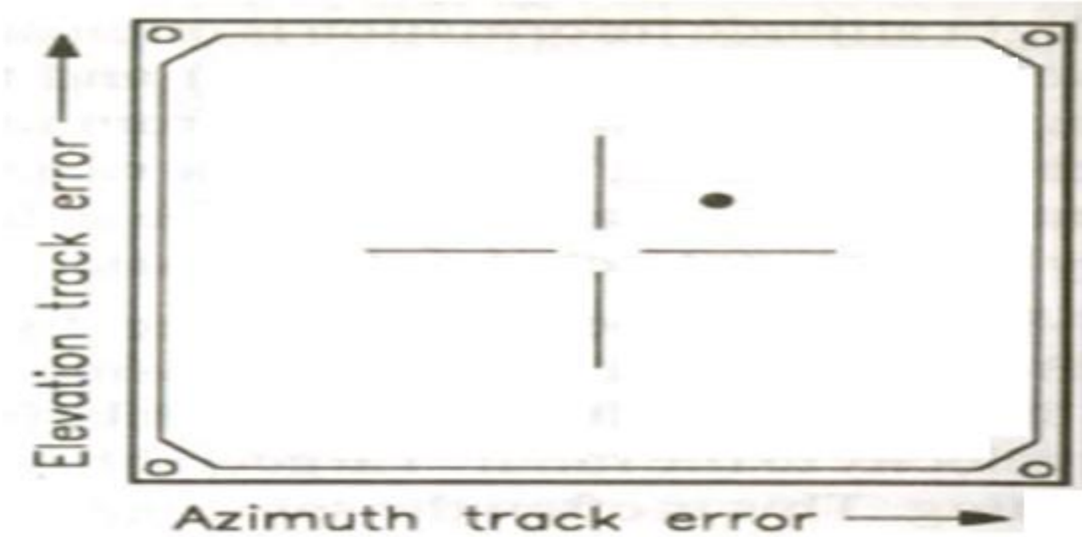
- This is same as ‘C’ Scope.
- Except that the Blip extends vertically to give rough estimate of range.

- **(5) ‘E’ SCOPE :**

- This is similar to ‘B’ Scope except in place of Azimuth, Elevation is displayed.
- X Axis = Range
- Y Axis = Elevation

TYPES OF DISPLAYS (CONTD..)

➢ (6) 'F' SCOPE :



b. F—scope

- Centre of Display = Axis of antenna beam.
- Blip's displacement from centre indicates target position relative to beam axis.
- X Axis = Azimuth track error
- Y Axis = Elevation track error

TYPES OF DISPLAYS CONTD..

- Other Displays used are:

  (i) 'G' Scope (ii) 'H' Scope (iii) 'I' Scope

  (iv) 'J' Scope (v) 'K' Scope (vi) 'L' Scope

  (vii) 'M' Scope (viii) 'N' Scope (ix) 'O' Scope

➢ **PPI – Plan Position Indicator- 'P' Scope**

- Most commonly used Display
- Intensity modulated circular display
- Echo signals are shown on a map (plan position) viewed from above the radar.

(Jntuh) **Explain the functioning and characteristics of PPI display**

TYPES OF DISPLAYS CONTD..

➢ PPI – Plan Position Indicator- 'P' Scope

- Most commonly used Display
- Intensity modulated circular display
- Echo signals are shown on a map (plan position) viewed from above the radar.

PPI DISPLAY (CONTD..)

- Range is indicated by radial position from radar.
- Azimuth angle indicated by target angle clock wise from top of scope (usually north).
- 2 Types of PPI Scope
- Most commonly used for search radars
- 2 types of PPI Display

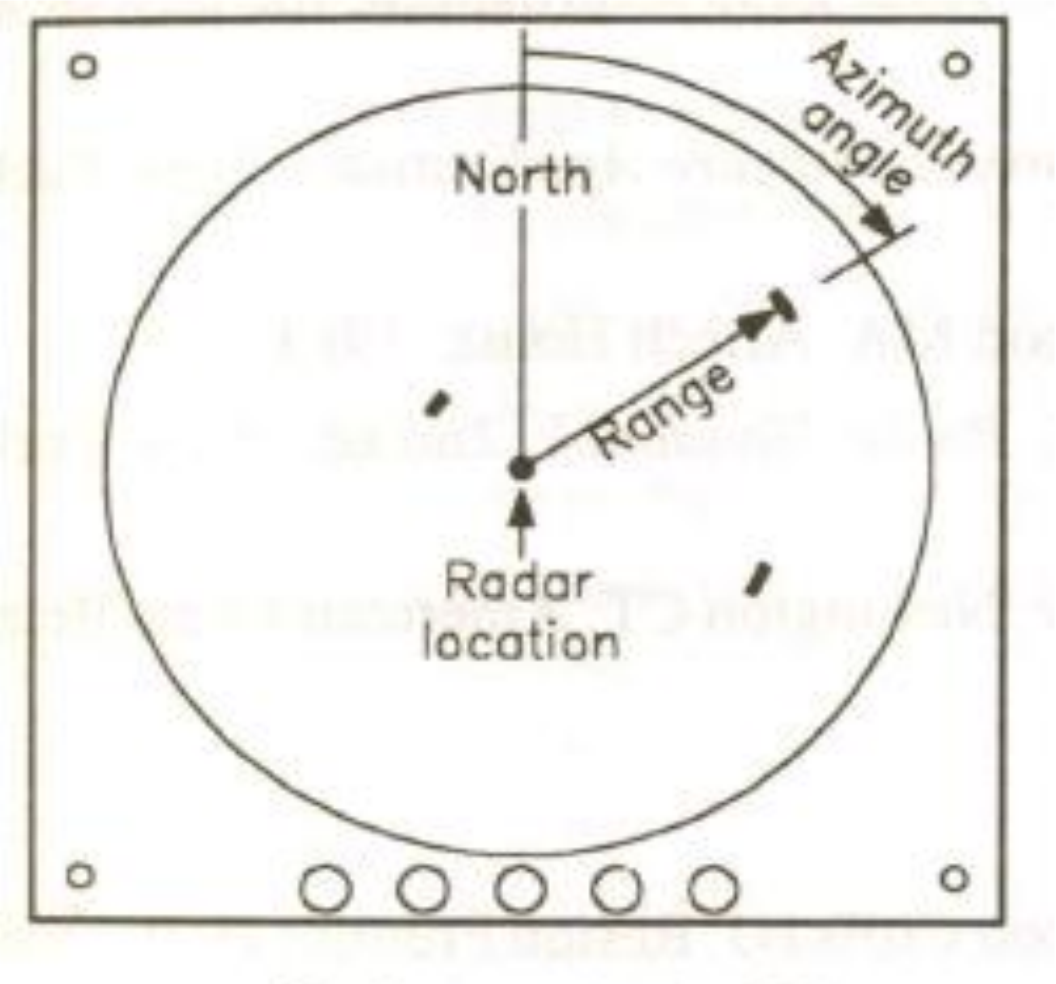
(i) Radar centered PPI

(ii) Offset PPI

PPI DISPLAY (CONTD..)

- **(i) Radar centered PPI**

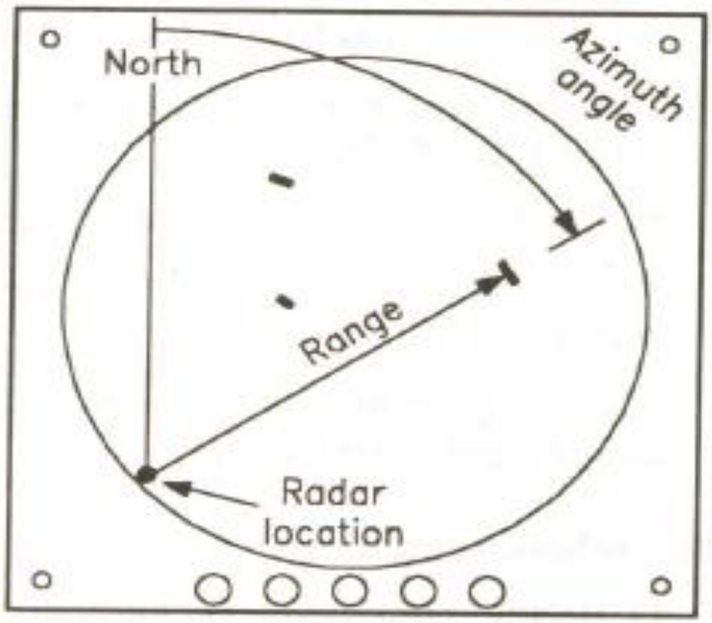
-



a. Radar-centered PPI

PPI DISPLAY (CONTD..)

➢ (ii) Offset PPI



b. Sector (offset) PPI

- Zero position of time base at a position other than at the centre of the display.
- Provides larger display for a selected position

PPI DISPLAY (CONTD..)

- **Range – Height Indicator**

- Intensity modulated display
- X Axis = Range
- Y Axis = Altitude
- Primarily height finding display
- All types of displays are defined in IEEE standard definitions.

(Jntuh) **Explain the need for a Duplexer and its requirement for a Pulse radar**

DUPLEXER

- **Duplexer:** is a Fast Acting Switching device. It enables the antenna to time share between T_x and R_x. 2 modes of operation.
- **1. Transmission:**

a. Connects T_x to antenna

b. Protect R_x from damages or burnouts.

c. Loss between T_x and Antenna Low.

- **2. Reception:**

a. Connects echo signal to R_x and disconnects T_x from antenna

b. Switch rapidly changes from Transmission mode to reception within nano seconds.

c. Loss between Antenna and R_x low.

DUPLEXER (CONTD..)

- Duplexer is a Gas – Discharge device and called TR (Transmit – Receive) Switch.

➢ **Operation of TR Switch**:

- High Power Pulse Causes Gas Discharge device to breakdown and short circuit the path going to R_x. Thus R_x is protected from damage.
- During reception the device is cold and directs, echo signal to the R_x and not to T_x.

TR SWITCH (CONTD..)

- T_x Power $\approx$ 1 mega watt
- Safe Power of tolerance in $R_x \approx$ 1 watt
- Isolation provided by Duplexer = $\left[\frac{1 \times 10^6}{1}\right]$

$$= 10^6 \text{ or } 10 \log 10^6 = 60 \text{ dB}$$

TR TUBE

- **TR Tube :**
- Gas – Discharge Device.
- Break down & Ionize quickly when high R.F. Power is applied.
- Deionize quickly once power is removed.
- **Construction of TR Tubes:**
- Contain Resonate filters.
- 2 Glass – to – Metal windows sealed
- Noble Gas like Argon is filled in tube.
- Argon has a low Break – down voltages.

CONSTRUCTION OF TR TUBES (CONTD..)

- Water vapour or Halogen gas added. This speeds up deionizing time.
- To speed up break down, auxiliary source of Electronics is attached to help initiate discharge
- Small source of Radio activity ‘Tritium’ (Radio Active Isotope of Hydrogen) produces low energy ‘Beta’ rays to generate supply of electrons. This is called Tritiated Ignitior.
- This has more leakage during transmission.

TR TUBE (CONTD..)

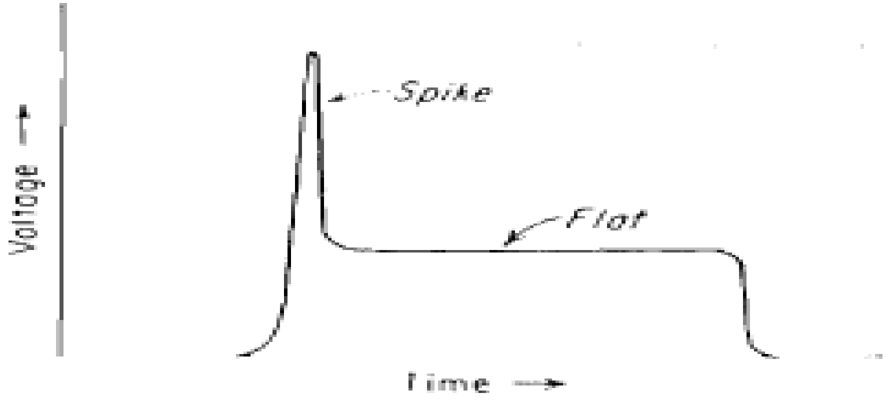
- Because of leakage, pin diode limiter stages are used to attenuate leakages.
- Tritium Igniter needs no active voltages. So R_x protection is ensured when Radar is OFF.
- This avoids use of mechanical shutter.

➢ **Disadvantage :**

- Because of Radio activity, the unit should be carefully handled from hazards.

TR TUBE (CONTD..)

- T_x Power always leaks to the R_x
- Spike is of short duration, but has large amplitude. Finite time of sharp pulse is due to the time it takes for ionization. Typical time for ionization is 10 nano secs



LEKAGE PULSE THROUGH TR TUBE

TR TUBE (CONTD..)

- Damage to R_x occurs when combined energy of spikes and flat portions of curve is too large Typical leakage energy is one ‘ERG’

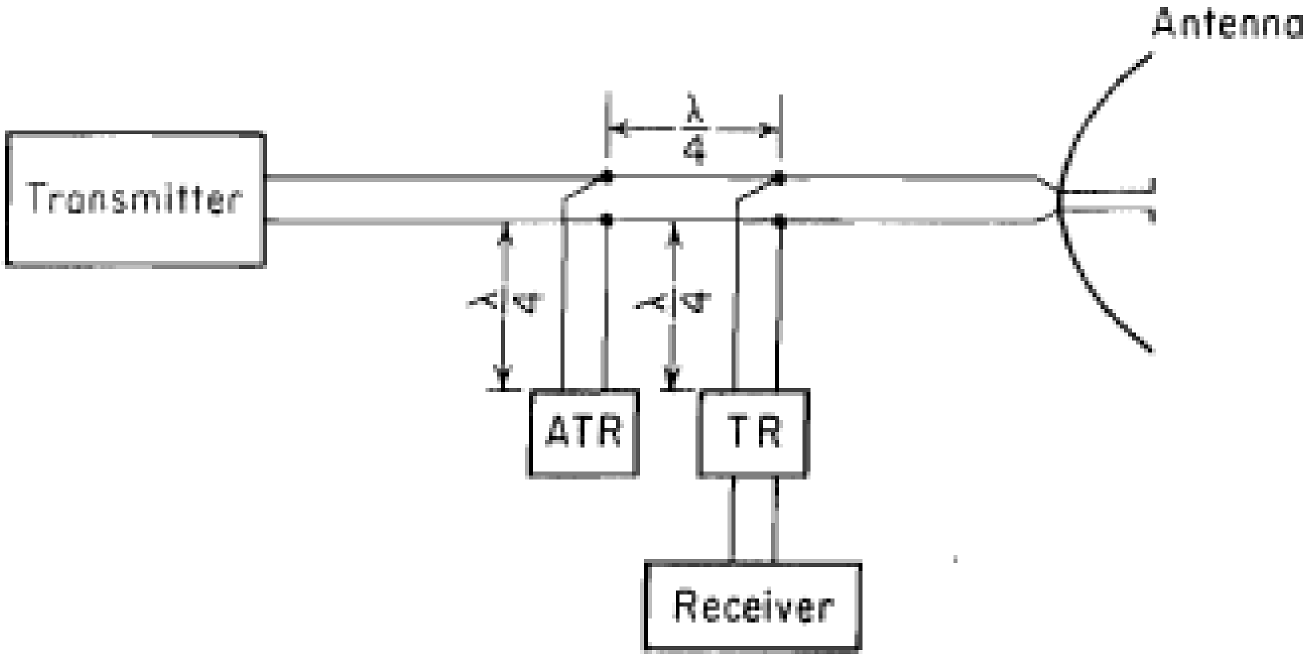
- Protection against leakage is 70 to 90 dB.

- TR tube loss in signal is 0.5 to 1 dB.

(Jntuh) **Explain and distinguish between the branch type and balanced duplexers**

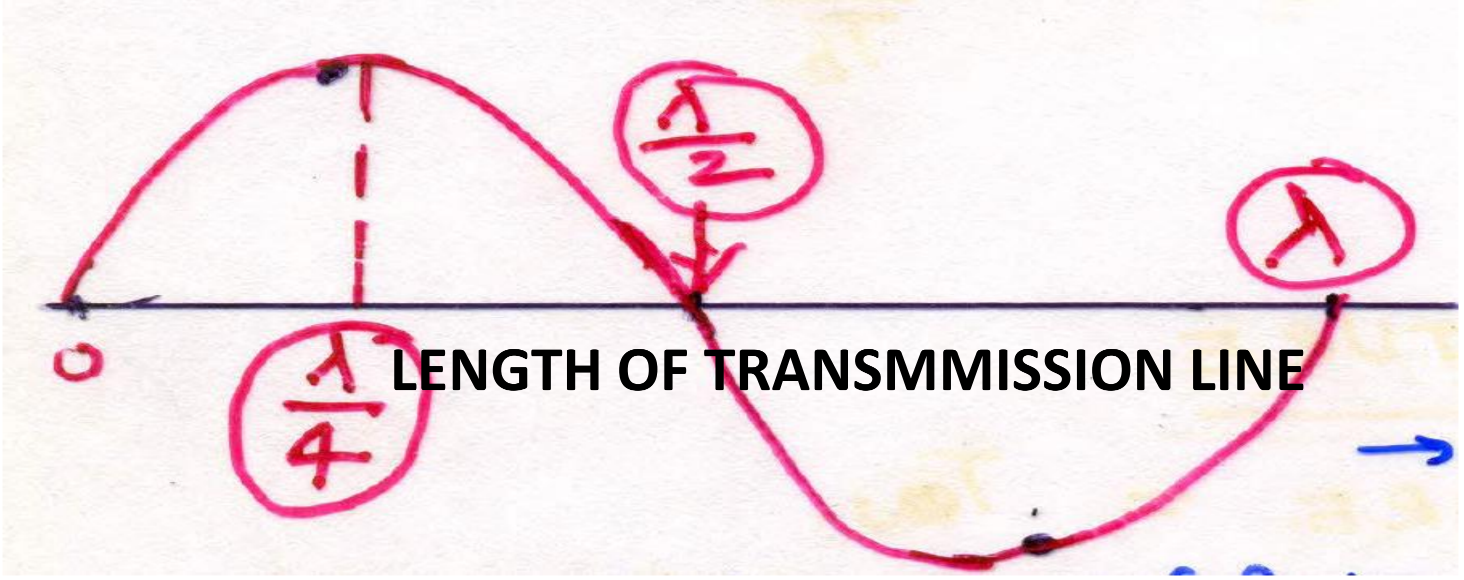
BRANCH TYPE DUPLEXER

- Branch Type Duplexer :



BRANCH TYPE DUPLEXER (CONTD..)

- One of the earliest configuration.
- Consists of TR (Transmit – Receive) Switch.
- Consists of ATR (Anti TR) Switch.
- Both are Gas – Discharge Tubes.



BRANCH TYPE DUPLEXER (CONTD..)

- **Transmit**:

(i) TR and ATR tubes ionize and break down.

(ii) TR located at λ/4 distance from main transmission appears as short circuit at R_x and open circuit at transmission line.

(iii) ATR is λ/4 distance, so it allows power from T_x - open circuits at transmission line.

BRANCH TYPE DUPLEXER (CONTD..)

- **Receive :**

(i) TR and ATR not fired since T_x is off.

(ii) ATR is open circuited. But it is $\lambda/4$ distance from reception line. So it shorts transmission line. All echo power directed to R_x.

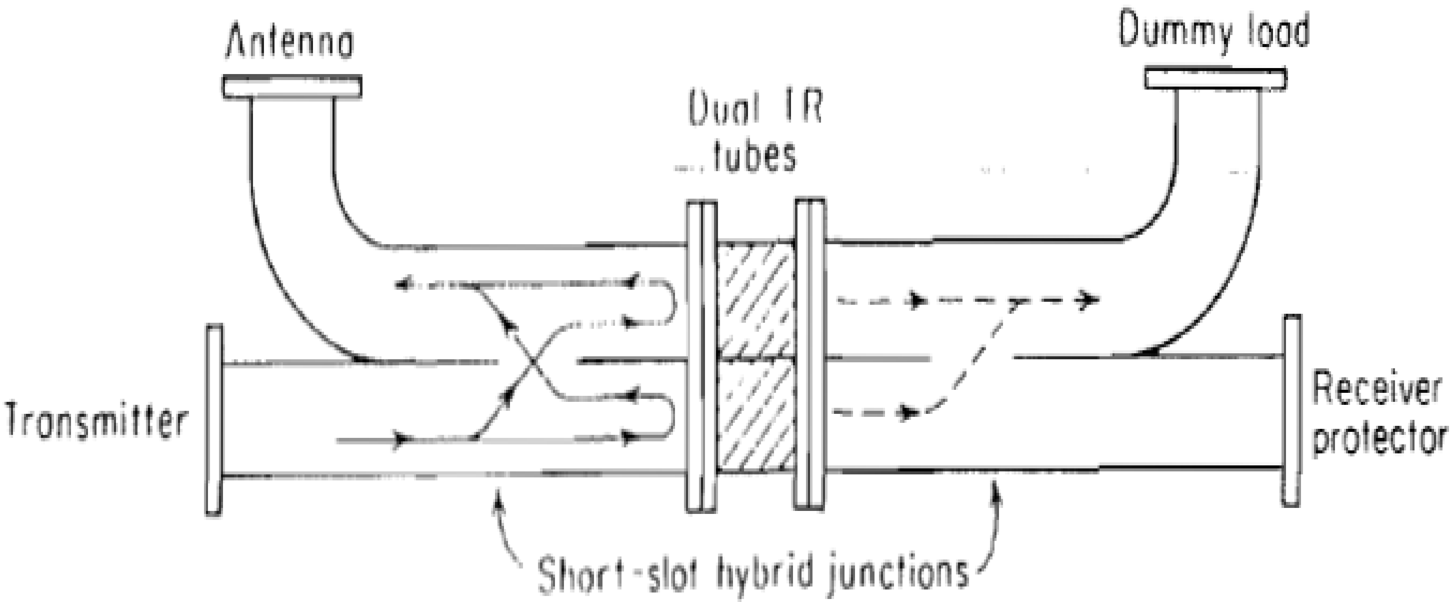
(iii) TR is open circuited. But it is $\lambda/4$ distance from Receiving line. So it is short circuited at Receiving line. T_x is effectively disconnected.

- **Disadvantages of Branch Type Duplexer:**

(i) Limited Bandwidth (ii) Limited Power.

BALANCED DUPLEXER

- **Transmit Mode** :

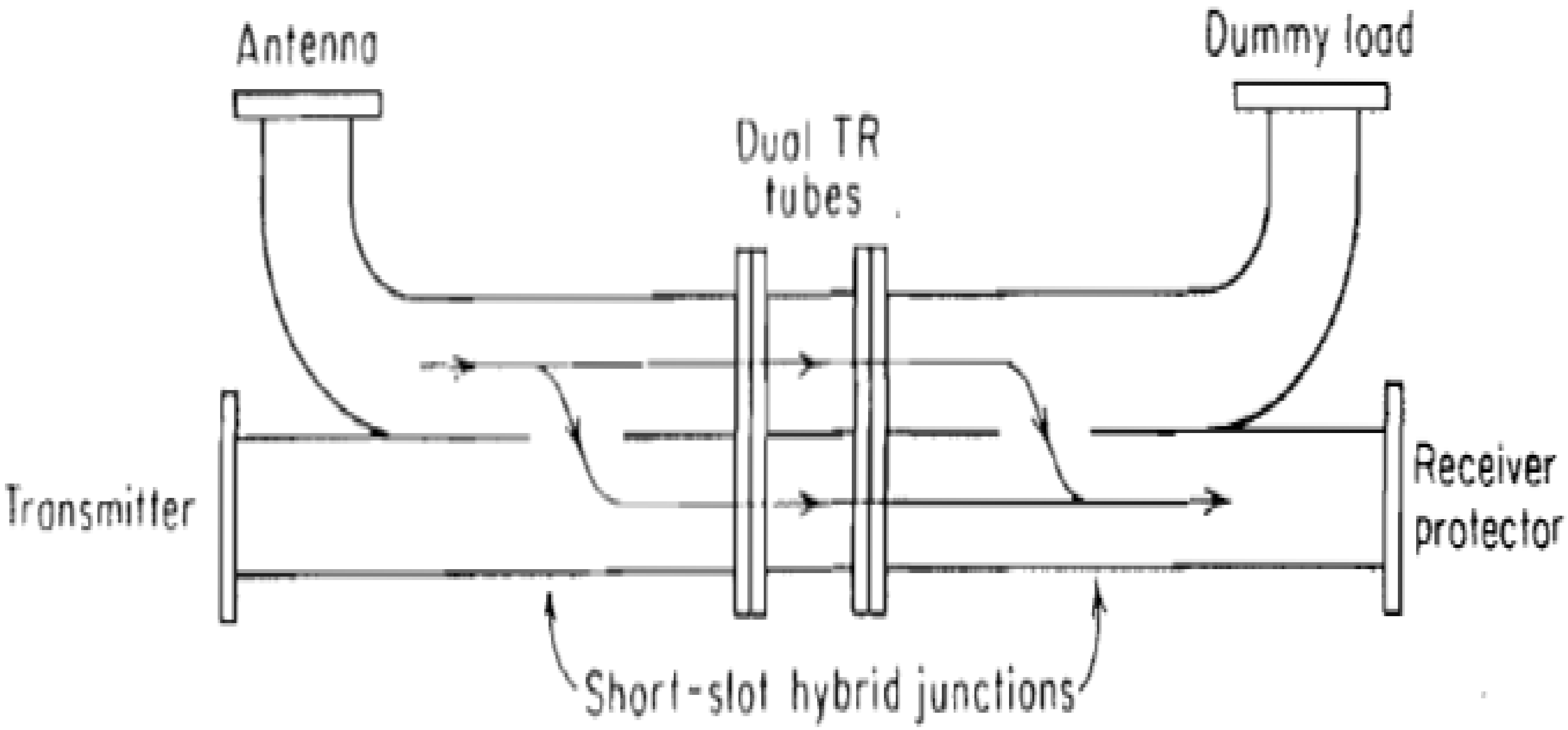


BALANCED DUPLEXER (CONTD..)

- **Transmit Mode** :
- Consists of 2 sections of waveguide.
- Slots cut in common wall.
- 2 TR tubes one in each section.
- Both Gas – Discharge TR tubes break down and reflect power to Antenna.
- When power passes through slit, 90^0 phase advance occurs.
- Leakage power directed to Dummy load instead of to $R_{x.}$

BALANCED DUPLEXER (CONTD..)

- **Receive Mode** :



BALANCED DUPLEXER (CONTD..)

➢ **Receive Mode** :

- TR tube does not break down (fire).
- Echo signals pass through TR tubes
- Power splits at First junction. Power passing through slit undergoes 90^0 phase advance.
- Power recombines in receiving arm but not in arm with dummy load.

R_x PROTECTORS

- In addition to gaseous 'TR' switch. R_x needs additional protection.
- Additional protecting devices are called Receiver Protectors.
- They may be (i) Diode Limiters (ii) Ferrite Limiters
- High Power radiation from nearby Radar antennas enters the R_x. However the power is less and so cannot activate Duplexer and causes damage to R_x
- In addition Mechanical Shutters short circuit waveguide path whenever Radar is not operated.

R_x PROTECTORS

- To obtain large range, sensitivity R_x needs to be improved.
- Higher sensitivity R_x is prone to damage from RF leakage.
- Sensitive front ends are protected by placing PiN Diode limiters in front of $R_{x.}$
- Diode limiters passes low power with negligible attenuation.

PASSIVE DIODE LIMITERS

- Passive Diode Limiters
- No external power supply required. Diodes are unbiased.
- Unlimited operating life.
- Fast recovery.

PASSIVE DIODE LIMITERS

- **Typical Example** :
  (1) WR 90 Waveguide
  (2) 7% Bandwidth
  (3) 1 Micro sec pulse width
  (4) Peak Power capability 10 Kw
  (5) CW Power Capability 10 W
  (6) Insertion loss 0.6 dB
  (7) Leakage power = 10 mws
  (8) Recovery time = 1 µS

SENSITIVITY TIME CONTROL (STC)

- At short ranges gain is less.
- At longer ranges gain is high.
- Reduce nearby large clutter echoes.
- STC is change of R_x Gain with time (Ranges)
- Sensitive front ends are protected by placing PiN Diode Limiters in front of R_x.

TO BE CONTINUED IN RADAR 5C

(Jntuh)

RADAR SYSTEMS

- EC812PE: RADAR SYSTEMS (PE – V)

(ELECTIVE V)

UNIT – 5C

B.TECH IV YEAR II SEMESTER

BY

Prof.G.KUMARASWAMY RAO

(Former Director DLRL Ministry of Defence)

BIET

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" INTRODUCTION TO RADAR SYSTEMS "

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Second Edition

Tata Mcgraw – Hill publishing company

Special indian edition

PHASED ARRAY ANTENNAS

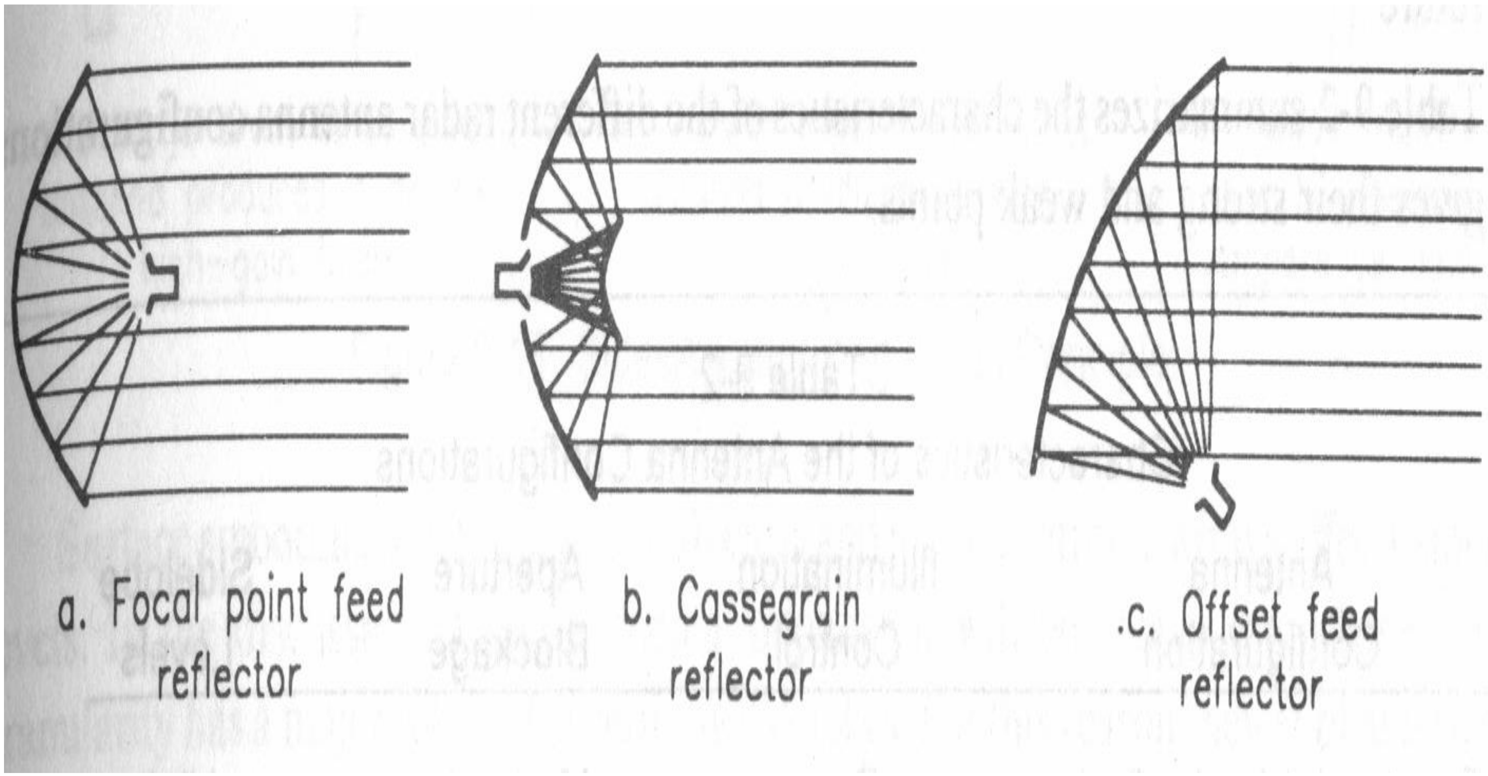
PAVE PAWS

RAF FLYINGDALES

COBRA DANE

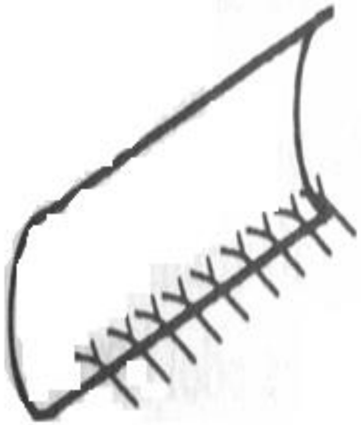
RADAR ANTENNA CONFIGURATIONS

➢ Types of Radar Antennas:

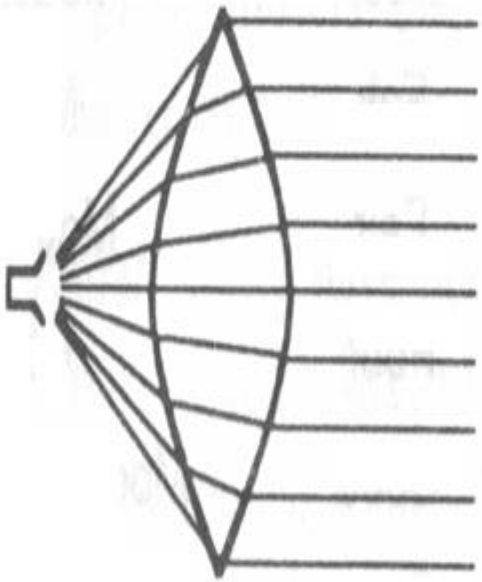


RADAR ANTENNA CONFIGURATIONS (CONTD..)

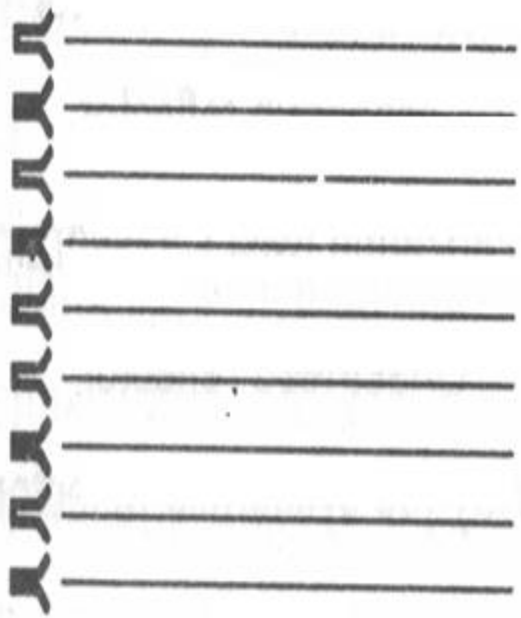
- **Types of Radar Antennas (contd..):**



d. Array–fed cylindrical reflector

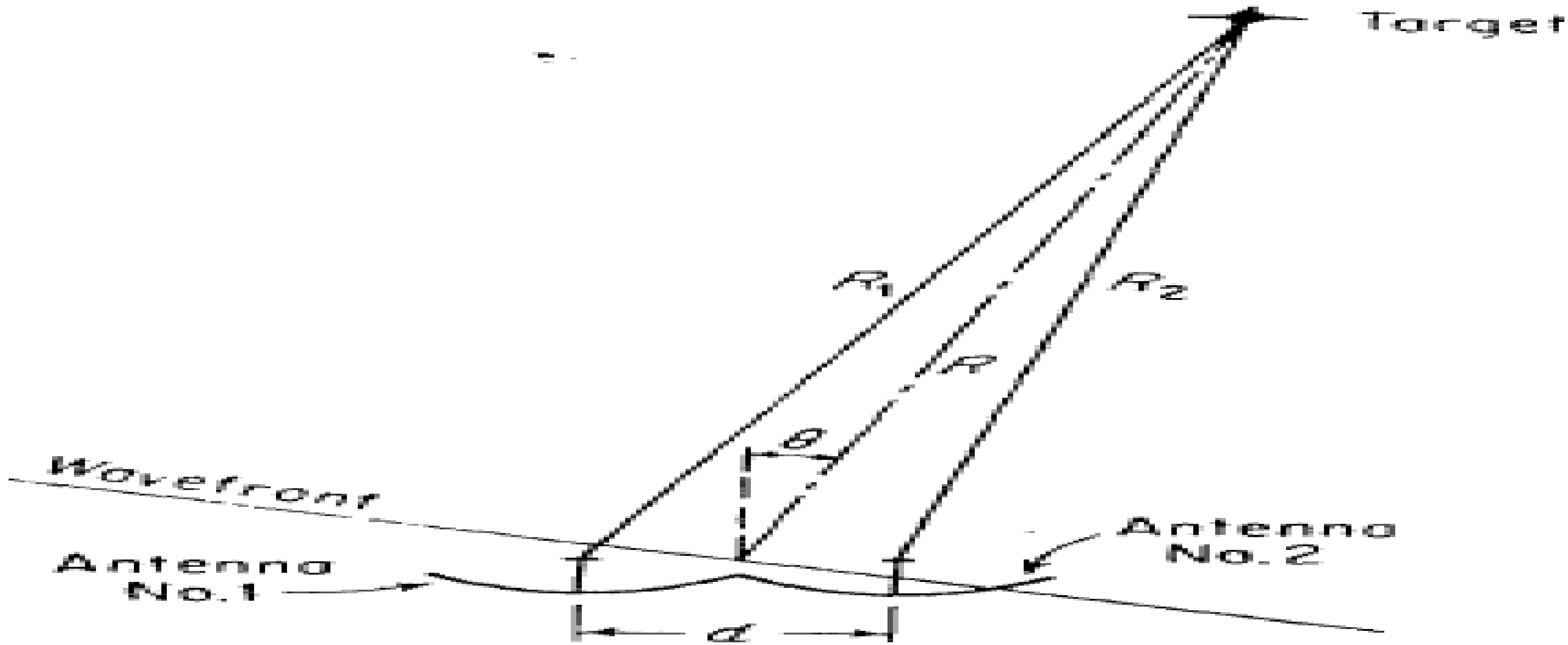


e. Lens



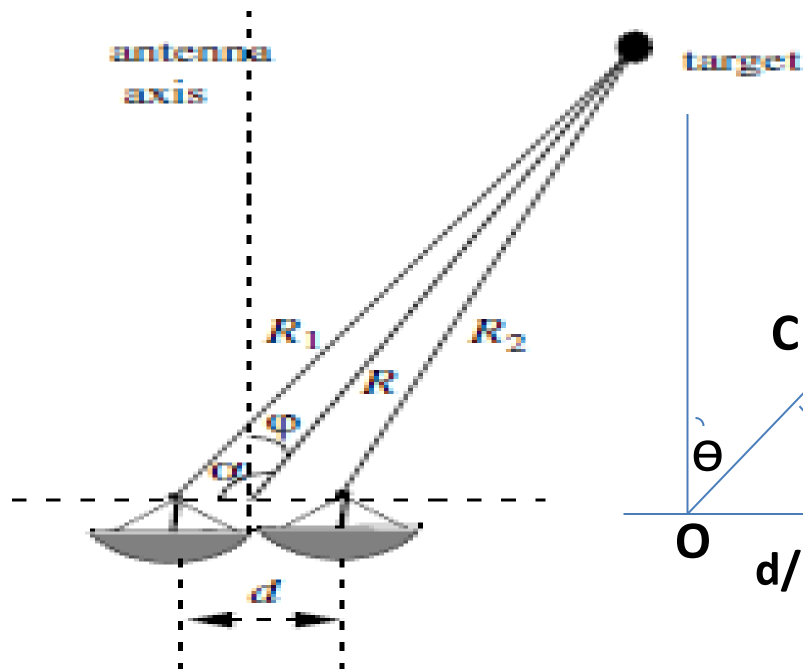
f. Array

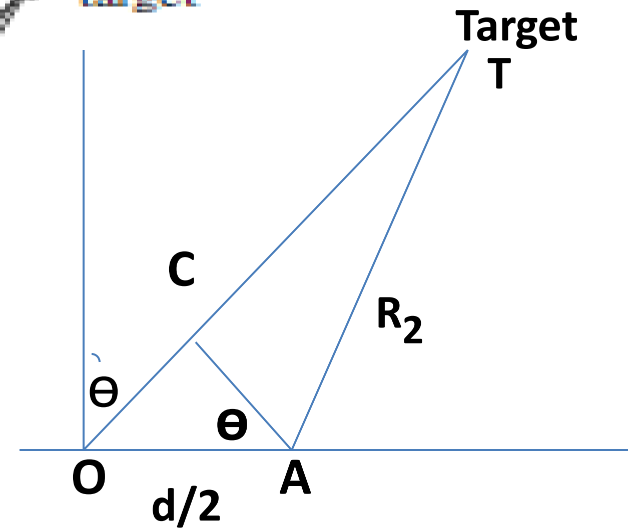
PHASE VS ANGLE ERROR



- 2 Antennas are located by a separation distance ‘d’
- Distance to target R is very large compared to ‘d’.
- θ = Angle between target line (LOS) to perpendicular bisector of line joining the 2 antennas

PHASE VS ANGLE ERROR





SIN θ = OC / OA

OC = OA × SIN θ

OC = d/2 × SIN θ

AT = R_2 = CT

OT = R = OC + CT

R_2 = CT = R – OC

R_2 = R – d/2 × SIN θ

- $R_2 = R - \frac{d}{2} \sin\theta$
- $R_1 = R + \frac{d}{2} \sin\theta$

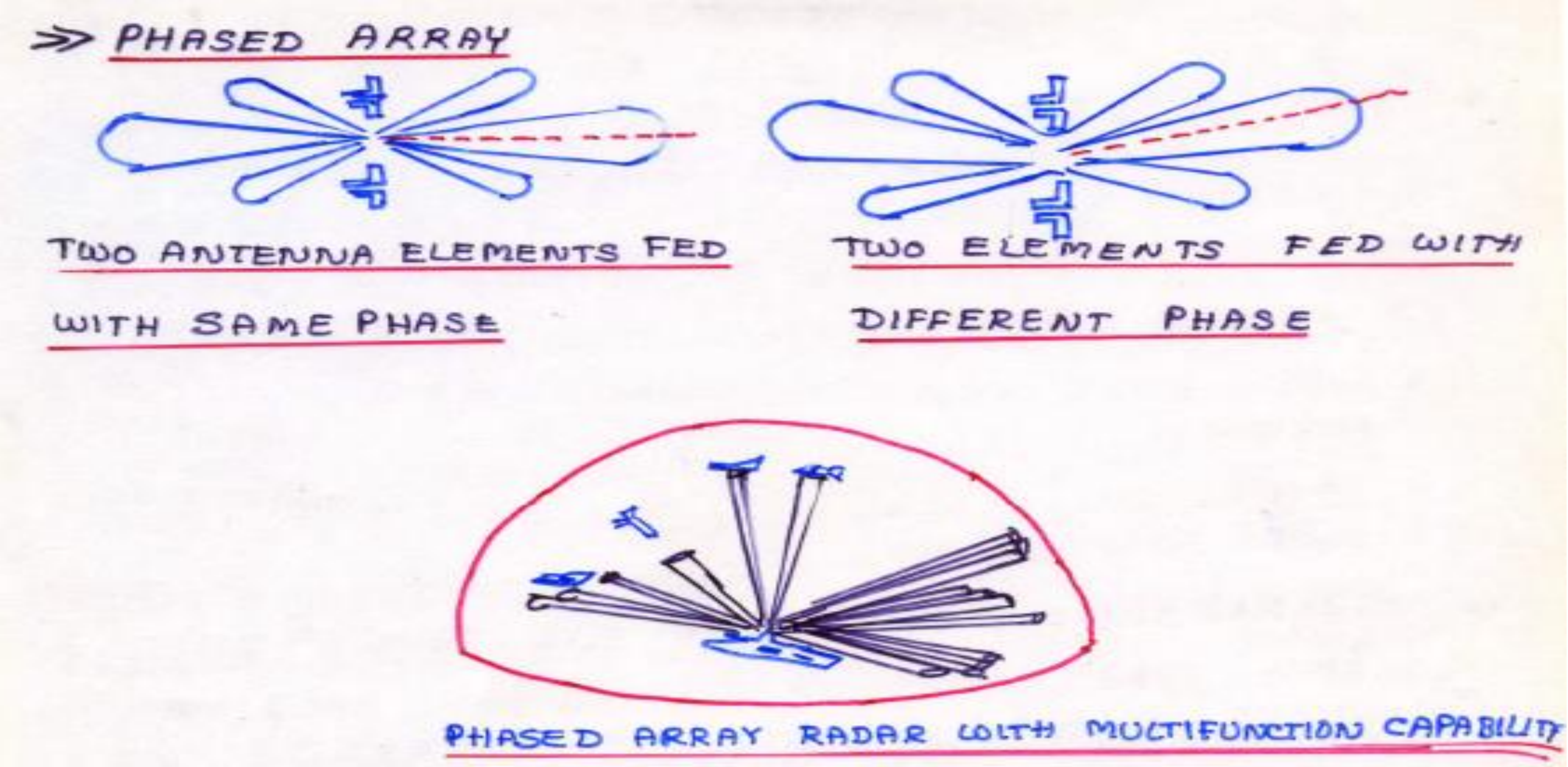
PHASE VS ANGLE ERROR (CONTD ..)

- Difference in distance travelled by the wave front to reach Antenna 2 after reaching Antenna 1.
- $R_1 - R_2 = d \sin \theta$
- But λ distance corresponds to 2π phase.
- $d \sin \theta$ distance corresponds to phase angle ψ
- $\psi = \dfrac{2\pi}{\lambda} d \sin \theta$
- $\psi = K \sin \theta$
- $\theta = \sin^{-1}\left(\dfrac{\psi}{K}\right)$

(Jntuh) **What is a Phased Array antenna and explain about its radiation pattern**

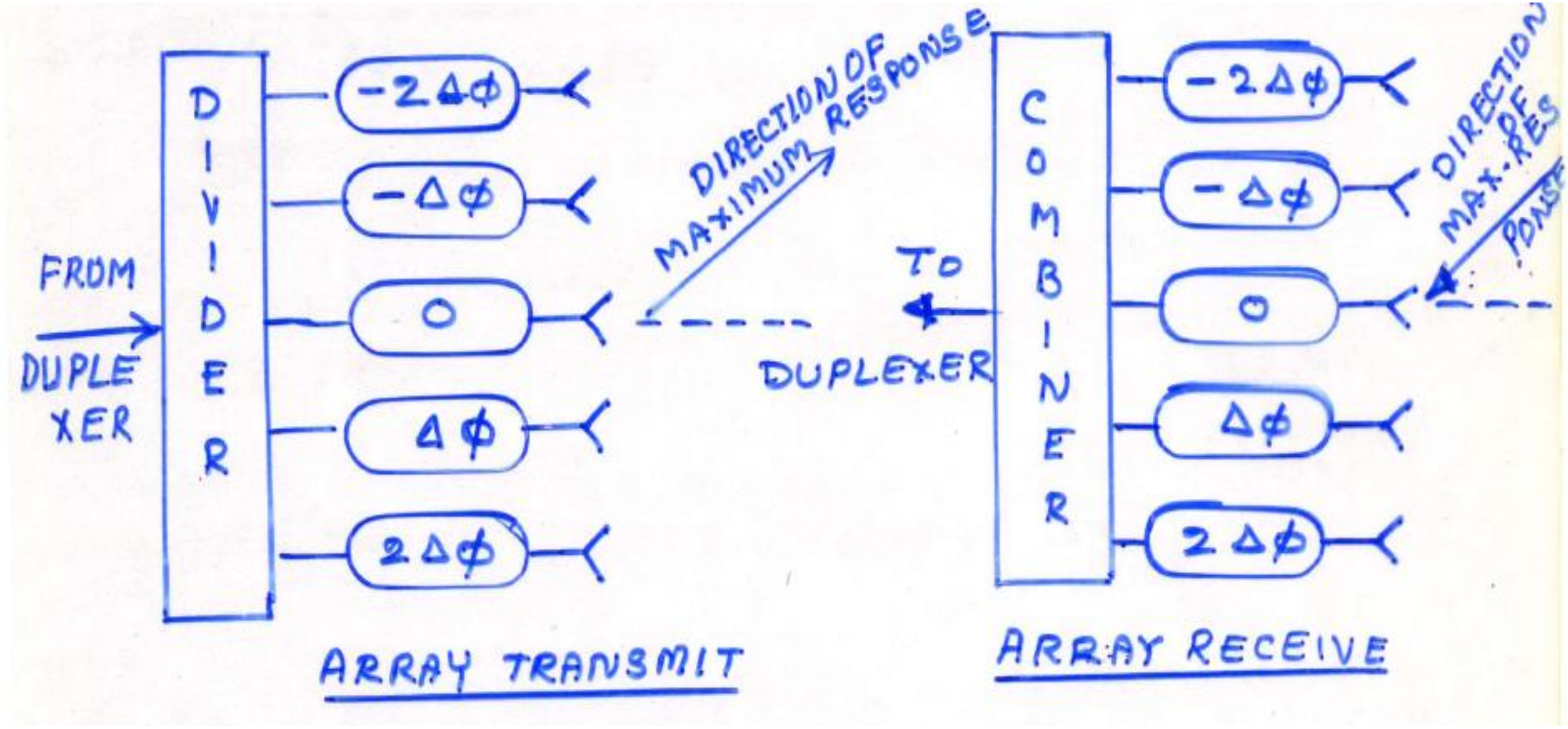
PHASED ARRAY ANTENNAS

- ## Phased Array Antennas



PHASED ARRAY ANTENNAS (CONTD..)

- **Phased Array Antennas Basics contd.**



ELECTRONIC SCANNED ARRAY

- Passive vs Active:
- PESA: In a passive electronically scanned array, the microwave feed network in the back of the antenna is powered by a single RF source (magnetron, klystron, TWT etc.) sending its waves into phase shift modules (usually digitally controlled) which in turn feed the numerous emitting elements
- AESA: An AESA, instead has individual RF source for each of its many transmit/receive elements, making them active. This provides for a graceful degradation, so that T/R modules may fail and the radar would not stop functioning.

(Jntuh) **List out the merits and demerits of Phased array antenna**

ELECTRONIC SCANNED ARRAY (contd)

- Advantages:
- Short to instantaneous (milliseconds) scanning rates
- Much higher range
- Multiple angle beams tremendous number of targets being tracked
- Desirable low probability of intercept
- Solid state devices with vastly simpler mechanical designs
- No complex hydraulics for antenna movement
- Occupies less space than a typical radar

ELECTRONIC SCANNED ARRAY (contd)

- Advantages (contd)
- Distributed transmit function eliminates most common single point failure seen in a conventional radar
- Low maintenance much more reliable
- Ability to function as a radio jammer
- High electronic counter measure (ECM) resistance
- Less susceptible to voltage failures. Very low voltage in individual elements

ESPA ANTENNAS

- **Electronically Steered Phased Array Antennas :**

- Phased Array Antenna is a directive Antenna.
- Radiation pattern is made up of number of Radiating elements.
- Shape & Direction of Radiation pattern depends on

(i) Relative phases of elements

(ii) Amplitude of currents at the elements.

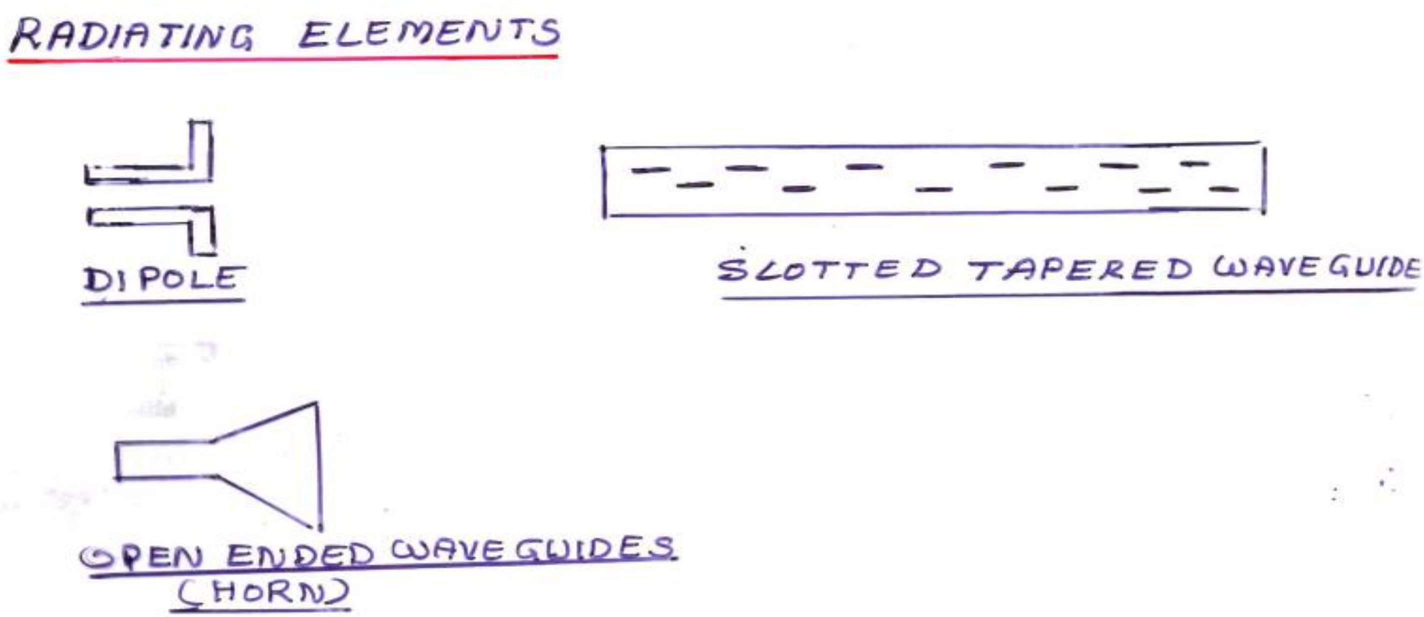
ESPA (CONTD..)

- Direction of the Radiation pattern changed by varying relative phases between radiation elements.
- Radiation Elements can be

(i) Dipoles

(ii) Open ended waveguides

(iii) Slots cut in waveguide.



ADVANTAGES OF ESPA

- **Advantages:**
- i)Beam switched from one direction to another in a few micro secs
- ii)Rapid beam steering – Rapid location of Beam in any direction
- iii)Large number of radiating elements used. Each may have its own transmitter. Large peak/

  large average power is possible. Power aperture product is large

ADVANTAGES OF ESPA (CONTD..)

- iv) Multiple target tracking is possible. Single beam is switched rapidly in any desired direction. This is done sequentially to view more than one target

OR

- Multiple simultaneous independent beams are generated to track multiple targets
- V) Solid state transmitters can be used with each radiating element. Solid state Tx power is low. But summation of number of low power beams gives large power
- Vi) Control of aperture illumination is easy & convenient

ADVANTAGES OF ESPA (CONTD..)

- Vii) Multi function is possible, like search, sector/volume, search, track, dwell etc.
- Viii) Graceful degradation of power is possible. Even if a few Txs go bad, Radar continues to function with some degradation

➢ Disadvantages of ESPA:

- i) Complex, computer required for control of phase between elements
- Ii) High cost

BASIC CONCEPTS

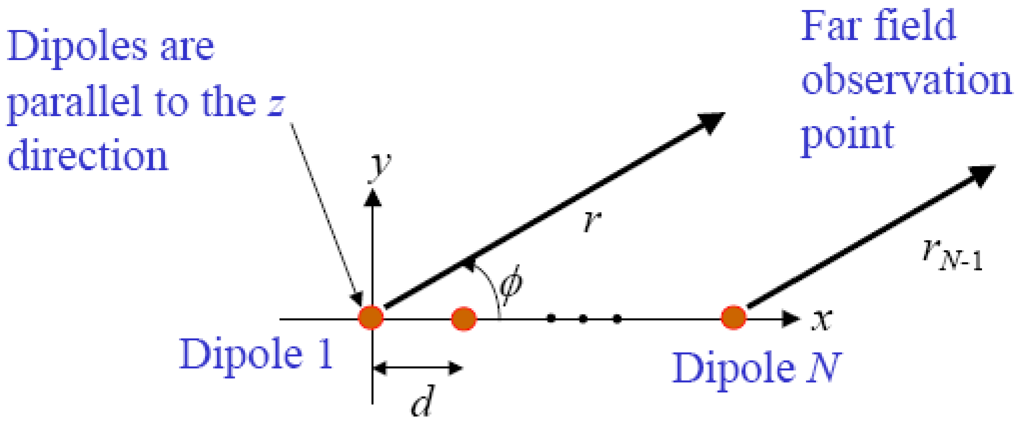
- **Array:**

- An array consists of number of antennas called Elements. They work together to form a single beam
- By controlling the amplitude and phase of signal applied to each radiating element , the radiation pattern (including direction of beam) of the combined beam is obtained
- Three types of ARRAY antennas

i) Linear array ii) Planar array iii) Conformal Array

i) LINEAR ARRAY

- **Linear Array:**
- A linear array consists of elements arranged in a straight line in one dimension

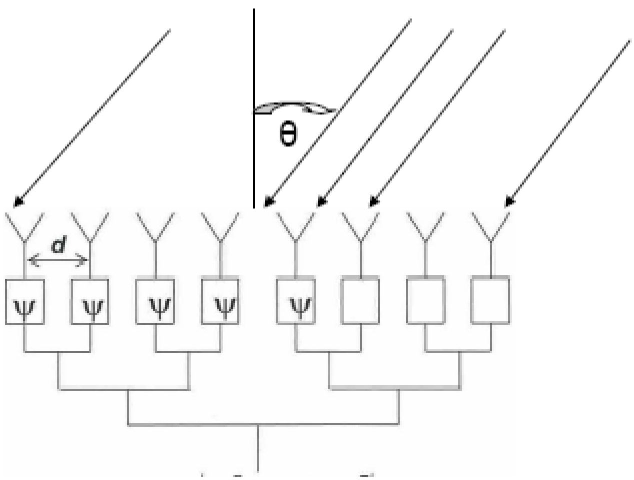


LINEAR ARRAY (CONTD..)

➢ Linear Array

Linear array radiation pattern

A linear array is made of N elements uniformly fed, spaced by a distance d



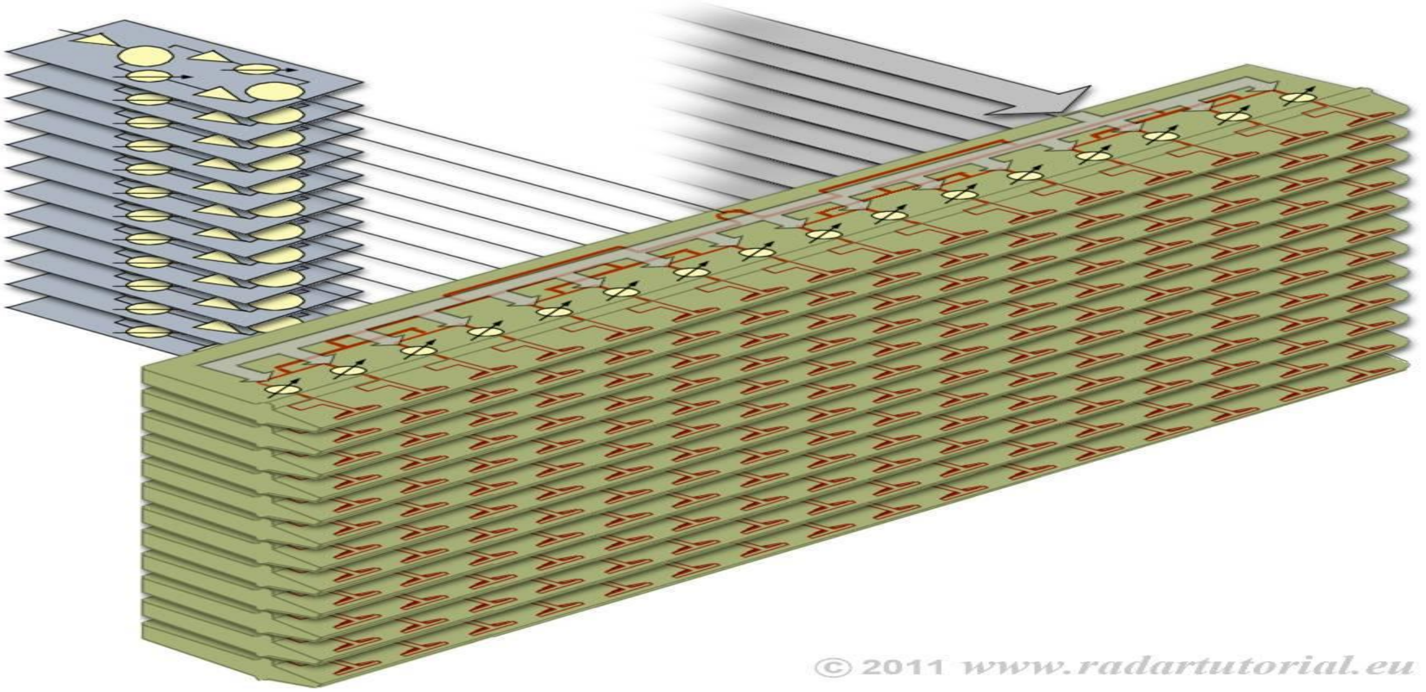
- Phase shift between adjacent sources:
  $\Psi = 2 \cdot \pi \cdot (d/\lambda) \cdot \sin\theta$
  (θ = angle of incidence)

$$|Ea(\theta)| = \left| \frac{\sin\left[N\pi\left(\frac{d}{\lambda}\right) \cdot \sin(\theta)\right]}{\sin\left[\pi\left(\frac{d}{\lambda}\right) \cdot \sin(\theta)\right]} \right|$$

$$Ga(\theta) := \frac{(|Ea(\theta)|)^2}{N^2}$$

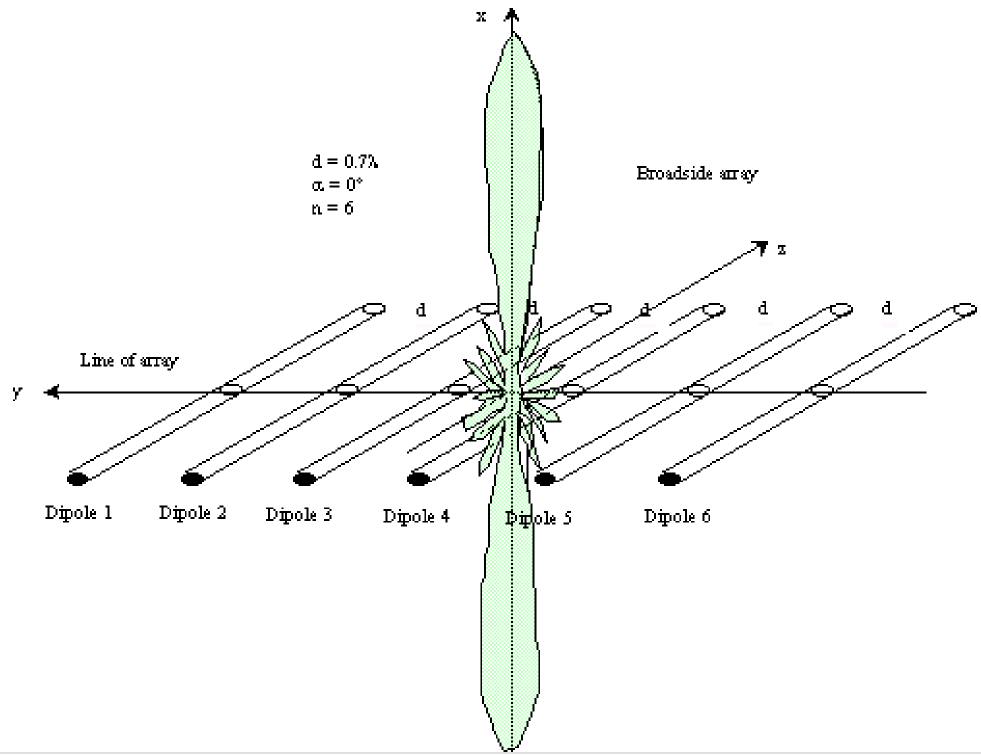
ii) PLANAR ARRAY

- **Planar array:**
- It is a 2 dimensional configuration of elements arranged to lie in a plane
- It is a linear array of linear arrays



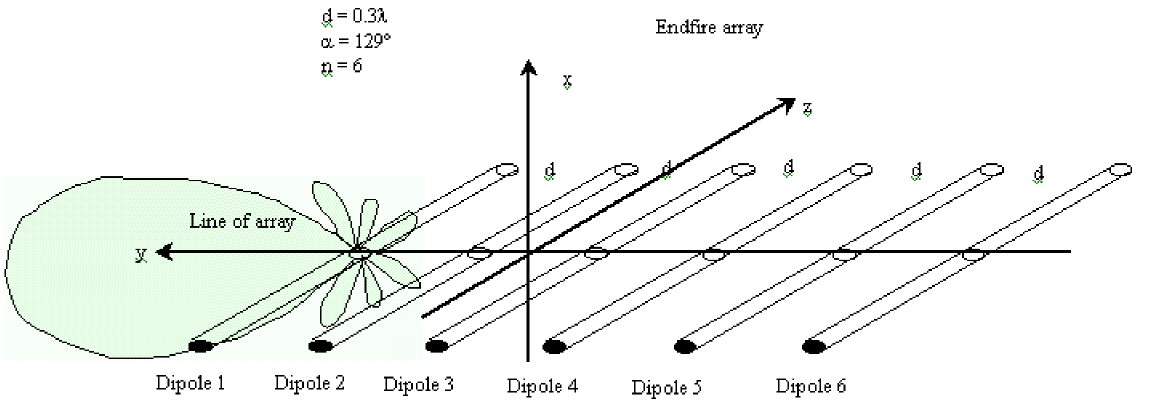
BROAD SIDE ARRAY

- Direction of maximum radiation is perpendicular to the line (or plane) of the array. Broad coverage in one direction and beamwidth in orthogonal plane



END FIRE ARRAY

- Direction of maximum radiation parallel to the array
- Beam directed along the array

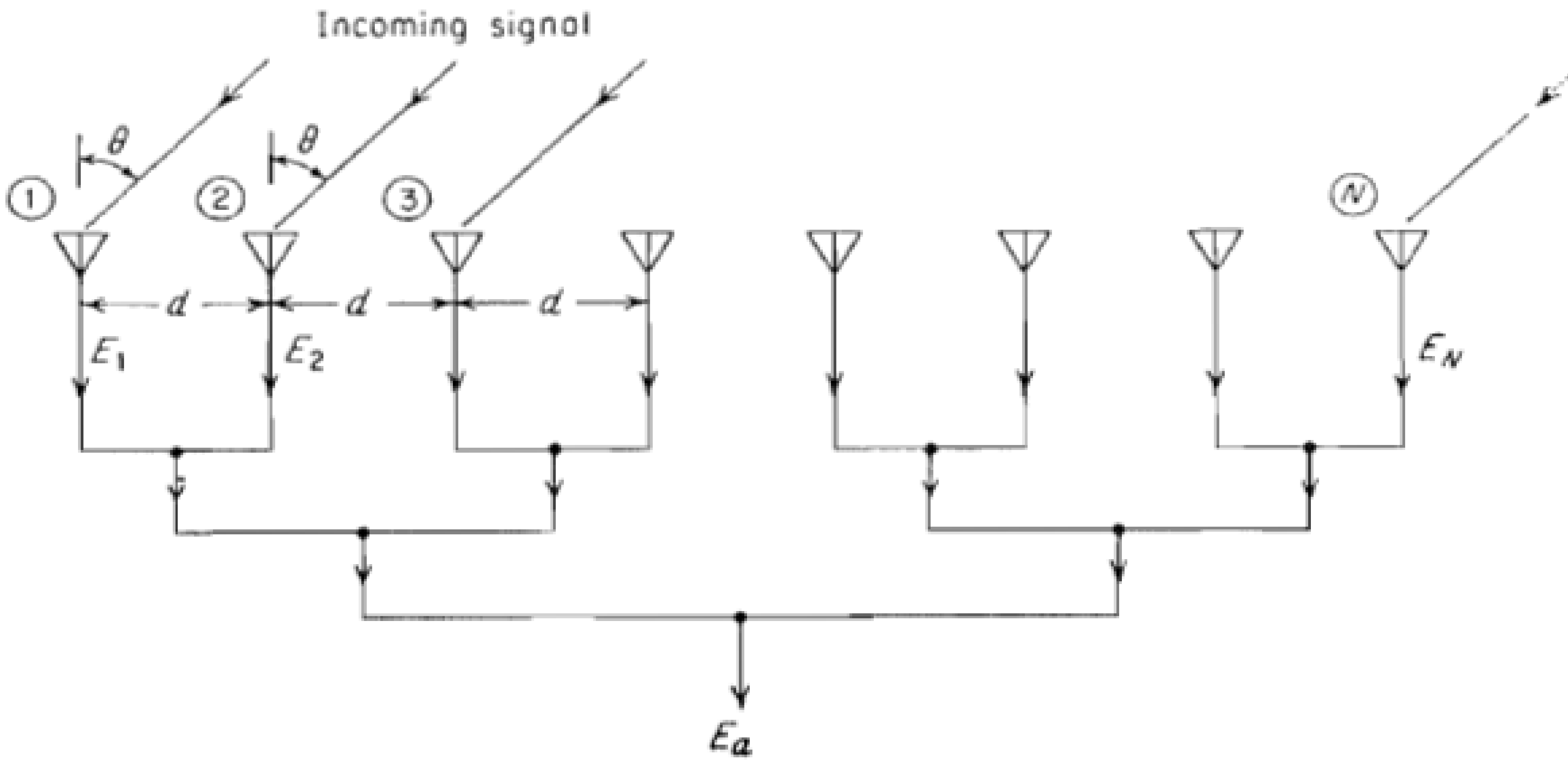


iii) CONFORMAL ARRAY

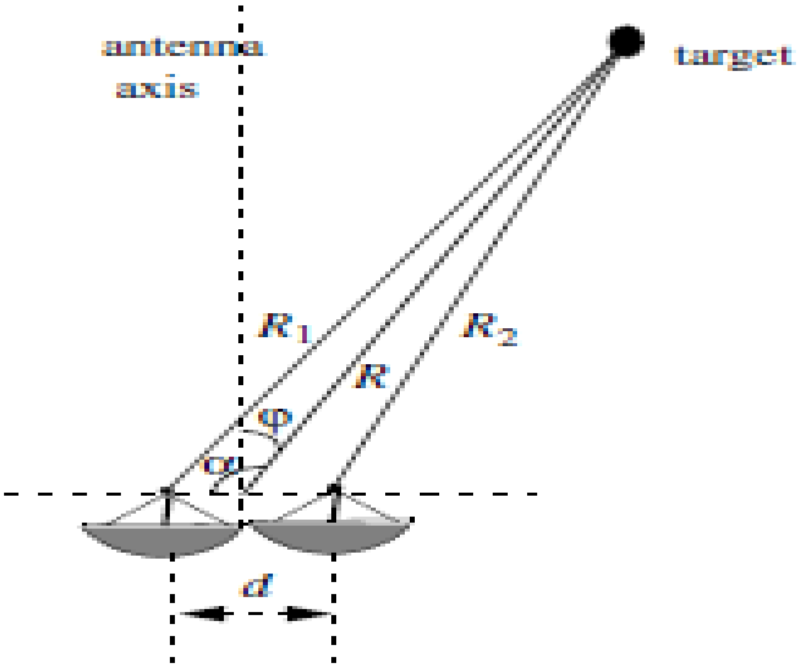
- An array whose elements are distributed on a non planar surface(such as an aircraft skin)
- Elements may be arranged on the surface of a cylinder to obtain 360^0 coverage.
- Elements may be arranged on the surface of a sphere. The phase to each element is arranged such that it gives a planewave when radiations from all elements are summed up in space.

RADIATION PATTERN

- **N- Element Linear array:**



PHASE VS ANGLE



- $R_1 = R + \frac{d}{2} \sin\theta$
- $R_2 = R - \frac{d}{2} \sin\theta$

PHASE VS ANGLE (CONTD ..)

- Difference in distance travelled by the wave front to reach Antenna 2 after reaching Antenna 1.
- $R_1 – R_2 = d \sin \theta$
- But λ distance corresponds to 2π phase.
- $d \sin \theta$ distance corresponds to phase angle $\Delta\theta$.
- $\Delta \theta = \frac{2 \pi}{\lambda} d \sin \theta$
- $\Delta \theta = \frac{2 \pi}{\lambda} d \theta$ (Since $\sin \theta = \theta$ for small angles)
- So $\Delta\theta$ is used as the error to position the antenna by servo system

N – ELEMENT LINEAR ARRAY

- Assumptions:
- (i) Elements are isotropic point sources, with equal amplitude and phase.
- (ii) Linear array made of N elements equally spaced at distance ‘d’ apart.
- (iii) Array is shown in receiving mode. Results obtained apply to transmission as well.
- O/PS are summed up via lines of equal lengths (means equal phases) to obtain a sum output voltage E_a.

N – ELEMENT LINEAR ARRAY (CONTD..)

- Let Element 1 is the reference signal with zero phase.
- Element 2 has the phase difference ψ =
  $2\pi (d/\lambda) \sin\theta$ where θ is the direction of incoming radiation.
- Amplitudes of voltage in each element are same and may be assumed to be unity for ease of analysis.
- Sum of all elements when the phase difference between adjacent element is ψ.
- $E_a = \text{Sin } wt + \sin [wt + \psi] + \sin [wt + 2\psi] +$ ----
  $+ \sin [wt + \{N-1\} \psi]$

N – Element Linear Array (contd..)

- $$E_a = \text{Sin}[wt + \{N-1\}\frac{\psi}{2}] \frac{\sin [N \psi/2]}{\sin [\psi/2]}$$

- First factor is a sine wave of frequency ω with phase shift [N-1] ψ /2
- If the reference were taken at the centre of the array, this phase shift is zero.
- The second term represents an amplitude factor of the form $\frac{\sin [N \psi/2]}{\sin [\psi/2]}$

N – ELEMENT LINEAR ARRAY (CONTD..)

- $$E_a[\theta] = \frac{\sin\ [N\ \pi\ \{d/\boldsymbol{\lambda}\}\ \sin\vartheta}{\sin\ [\ \pi\ \{d/\boldsymbol{\lambda}\}\ \sin\vartheta}$$

- When N π [d/λ] sin θ = 0, ±π , ± 2π , .. ± nπ the numerator is zero.
- Also when N [d/λ] sinθ = 0, ± π , ± 2π , .. ± nπ the denominator is zero.
- When denominator is zero, numerator also is zero. E_a (θ) = 0/0, means inderminate value.
- But using L` Hospitals rule, [E_a] is

maximum when $\sin\theta = \pm\ \frac{n\ \lambda}{d}$

N – ELEMENT LINEAR ARRAY (CONTD..)

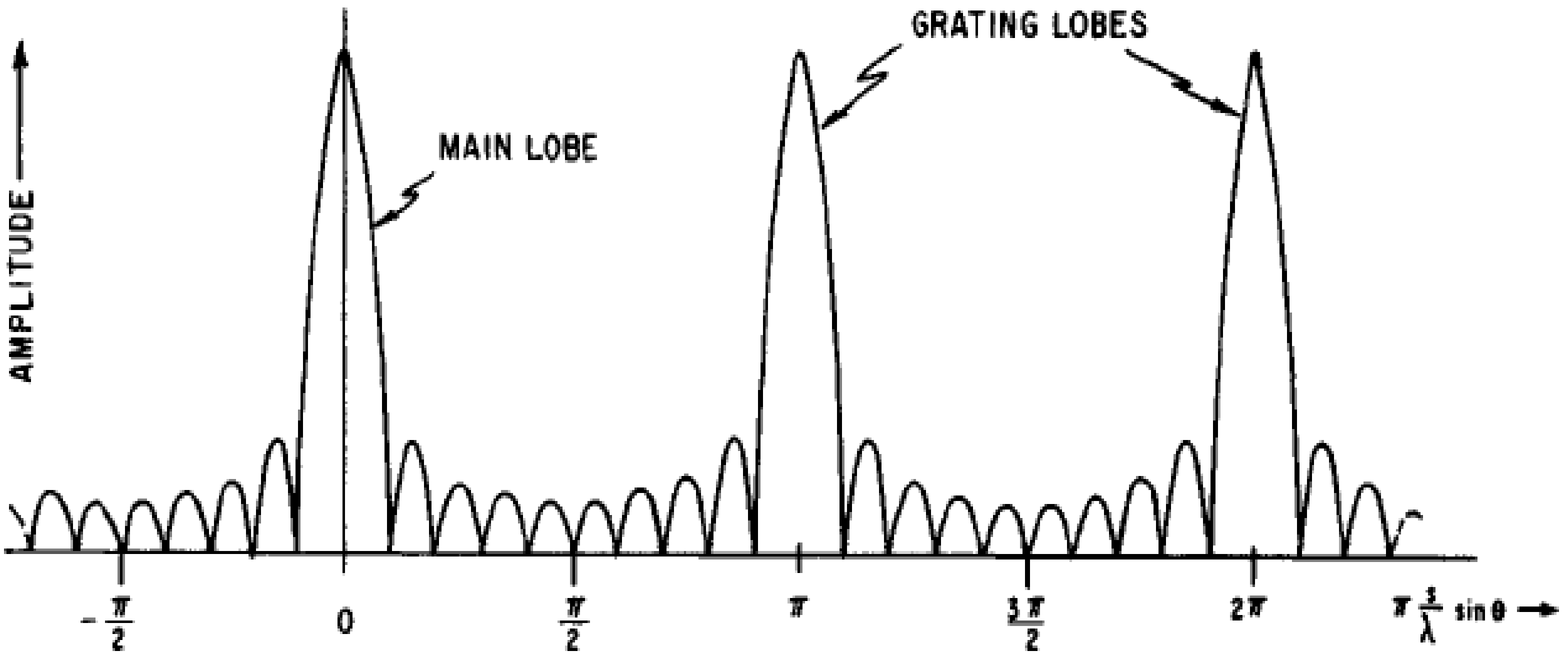
- When $\sin\theta = 0$, the $|E_a(\theta)|$ will have maximum equal N.
- Other maxima are called grating lobes and have the same maximum values and they have to be avoided.
- Let $[d/\lambda] = 0.5$, the first grating lobe ($n = \pm 1$) does not appear in real space since $\sin\theta > 1$
- If $[d/\lambda] = 1$, grating lobe appear at $\pm 90^o$
- This is satisfactory for the prevention of grating lobes.

GRATING LOBES

- Grating lobes are of the same magnitude as the main beam. They cause ambiguities. Signal received from grating lobes may be mistaken as from main lobe.
- Grating lobes are avoided by spacing elements such that $d \leq \lambda$
- When $d = \lambda$, grating lobe occurs at $\pm 90^o$. Since practical elements are not isotropic, radiation will be negligible at $\pm 90^o$.
- Since $E_a(\theta) = E_a(\pi - \theta)$, the isotropic element has a similar pattern in the rear of the antenna as in front.
- Backward radiations are suppressed by placing a reflecting screen behind the array.

GRATING LOBES (CONTD..)

- **Array Factor**



NON ISOTROPIC ELEMENTS

- **For non isotropic radiating elements, the radiation pattern is given by**

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

$G(\theta) = G_e(\theta) \times G_a(\theta)$

$G_e(\theta)$ = Element factor

$G_a(\theta)$ = Array factor = pattern with isotropic elements.

SUPPRESSION OF GRATING LOBES

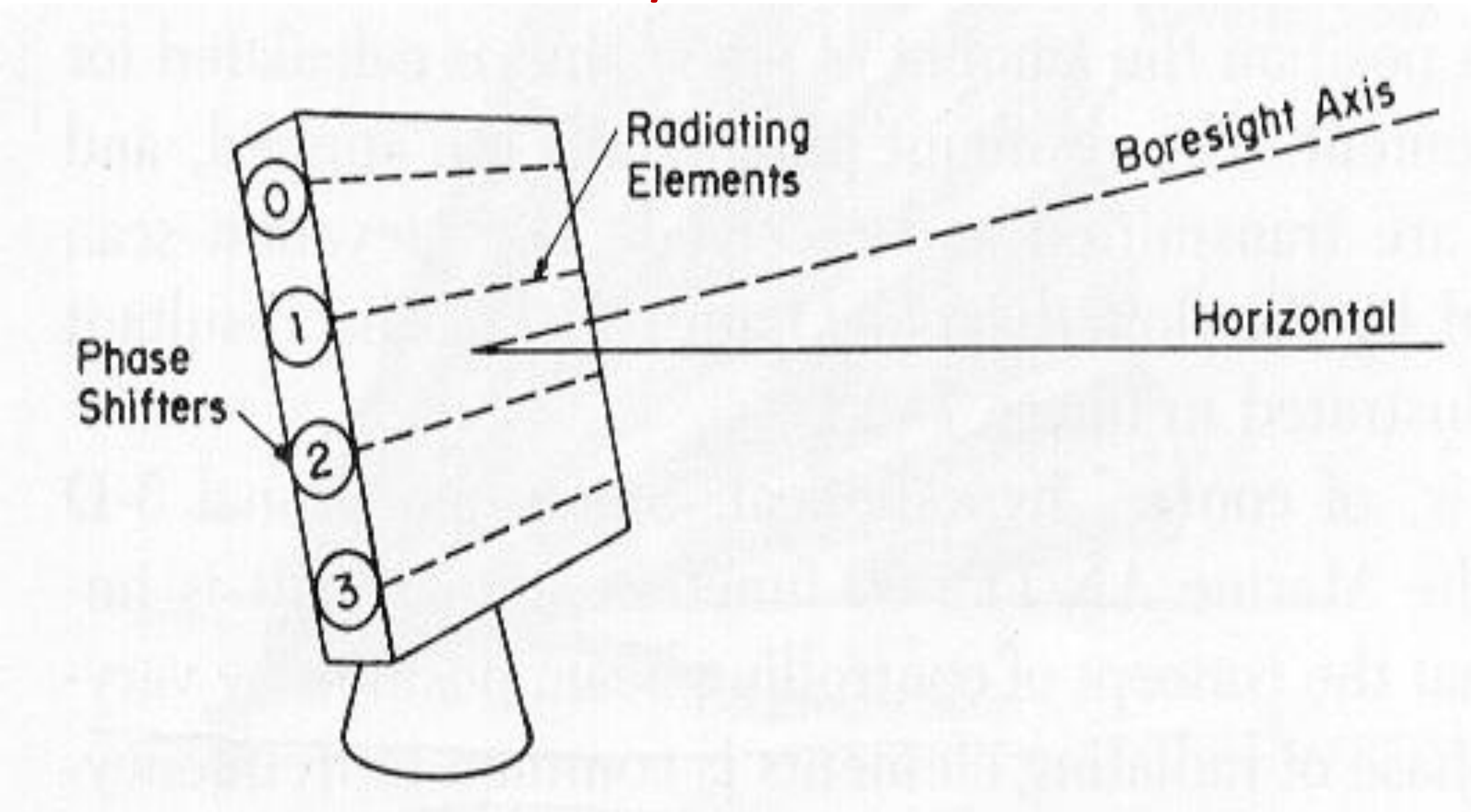
- **Example:**

- Element spacing d = 2λ, grating lobe occurs at $\pm 30^o . \pm 90^o$ In addition to main lobe at $\theta=0^o$
- If individual radial element has null width 60^o the grating lobes will be suppressed. However the antenna beam cannot be steered beyond 60^o
- In the above equation, radiation pattern of each element is assumed constant, however this is not true.
- The pattern will depend on mutual coupling of elements.
- To obtain a more practical pattern, radiation pattern of each element is measured in an Anechoic chamber in the presence of other elements.

2 DIMENSIONAL ARRAY

- 2 Dimensional Rectangular Planar Array :
- Aperture is separated into horizontal & vertical planes.
- Radiation pattern is the product of radiation patterns in 2 planes.
- $G(\theta_e, \theta_a) = 2$ Dimensional pattern
- $G_1(\theta_a)$ and $G_2(\theta_e)$ are radiation patterns in Elevation & Azimuth planes respectively

AN/SPS – 48



Radiating
Elements
Boresight Axis
Horizontal
Phase
Shifters
0
1
2
3

TWO DIMENSIONAL ARRAY (CONTD..)

- $G(\theta_e, \theta_a) =$

- $$\frac{\sin^2\{N \pi [d/\lambda] \sin \theta_a\} \times \sin^2\{M \pi [d/\lambda] \sin \theta_e\}}{N^2 \sin^2\{\pi [d/\lambda] \sin \theta_a\} \times M^2 \sin^2\{\pi [d/\lambda] \sin \theta_e\}}$$

- Where N= Number of radiating elements in θ_a
- M= Number of radiating elements in θ_e

(Jntuh) **Briefly explain the concept of beam steering Phased array antenna**

BEAM STEERING

- Beam may be rapidly steered in space without moving large mechanical pedestal on which antenna is mounted

➢ **Methods of Beam Steering - 3 kinds**

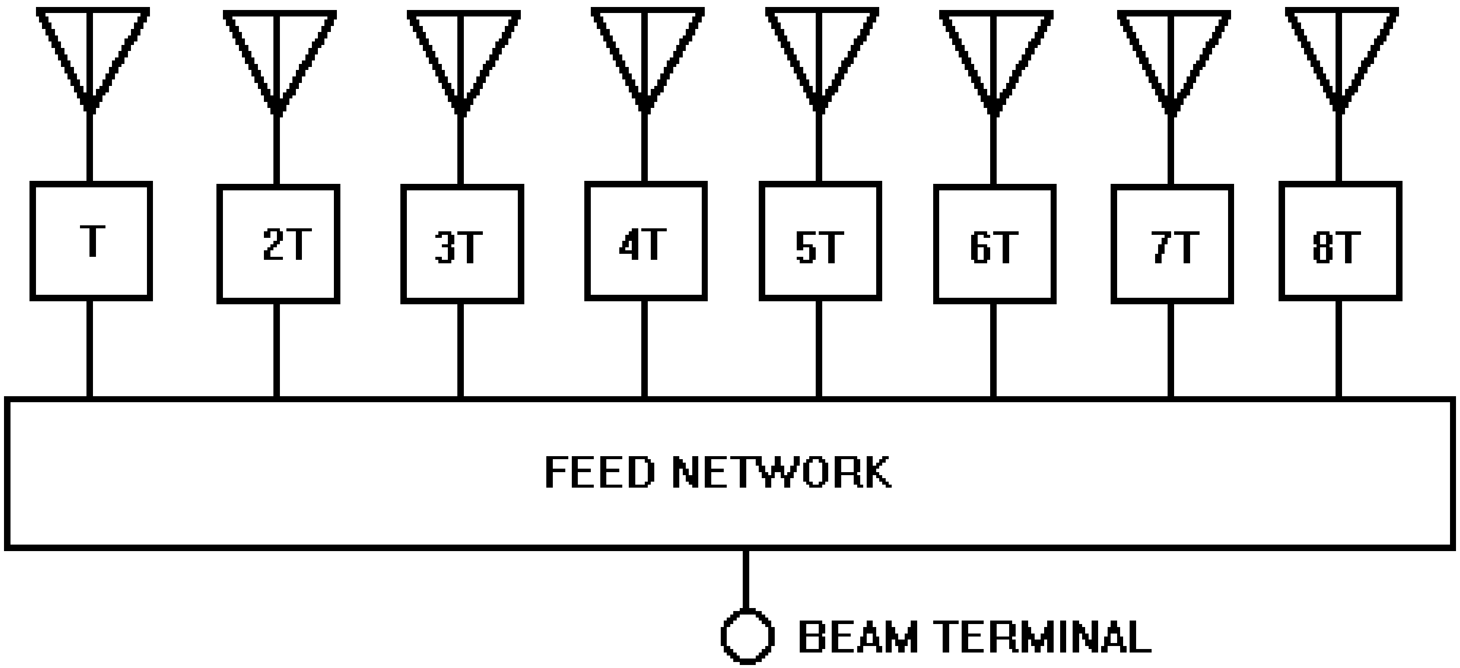
- Time delay scanning
- Frequency scanning
- Phase scanning
- The last method ie Phase scanning is very commonly used because of lesser cost & less complexity

TIME DELAY SCANNING

- **Time Delay scanning :**
- Time delay is used is used to achieve the desired phase relationship
- Time delay networks installed in front of each radiating element
- Expensive , complex & heavy

TIME DELAY SCANNING

- **Time Delay scanning :**



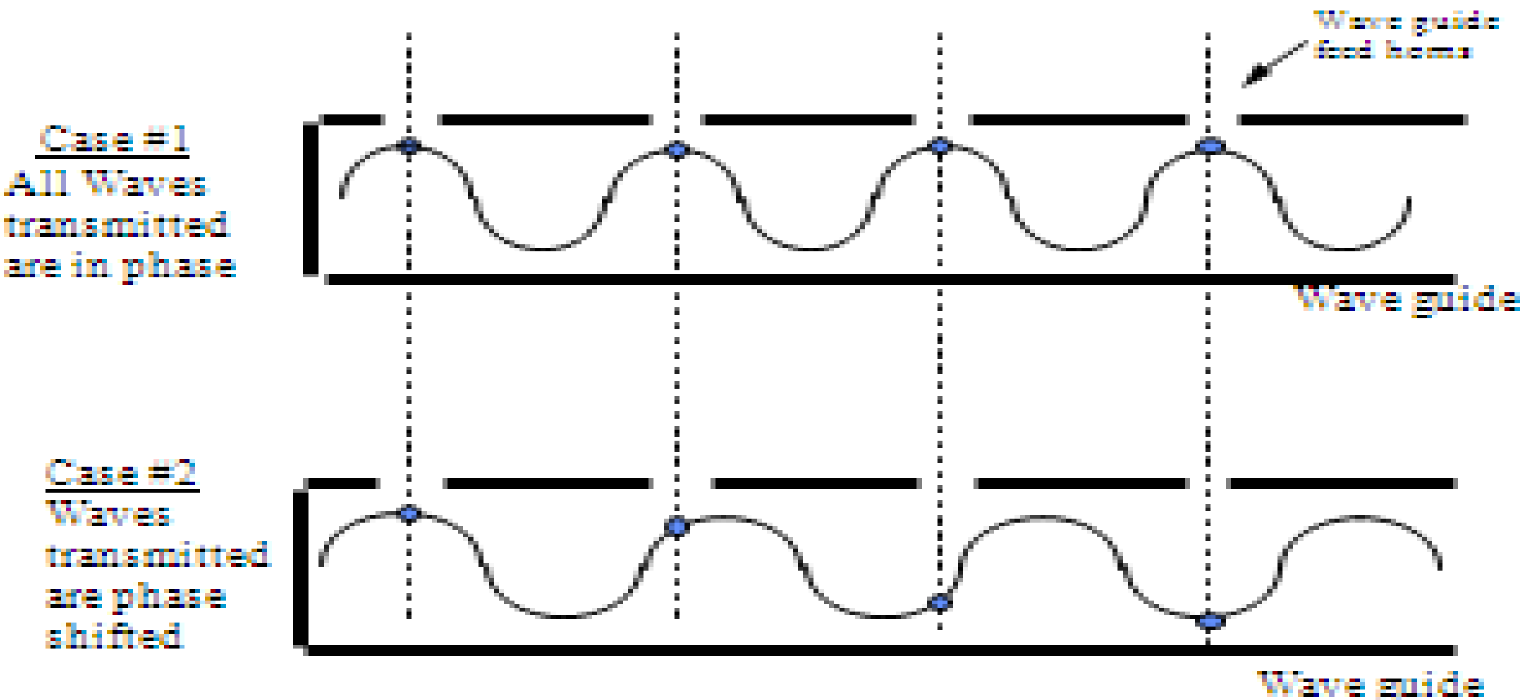
FREQUENCY SCANNING

- **Frequency scanning:**

- Physical length of waveguide is used to delay the frequency interval
- Vary the frequency about a base frequency
- Very simple and relatively less cost

FREQUENCY SCANNING

- Frequency scanning



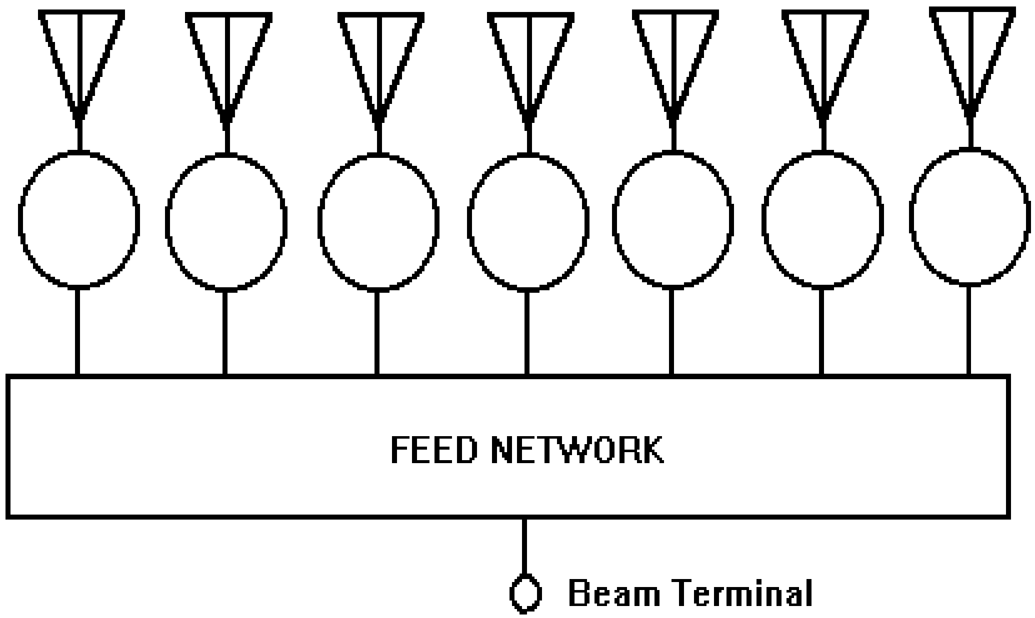
PHASE SCANNING

➢ Phase Scanning:

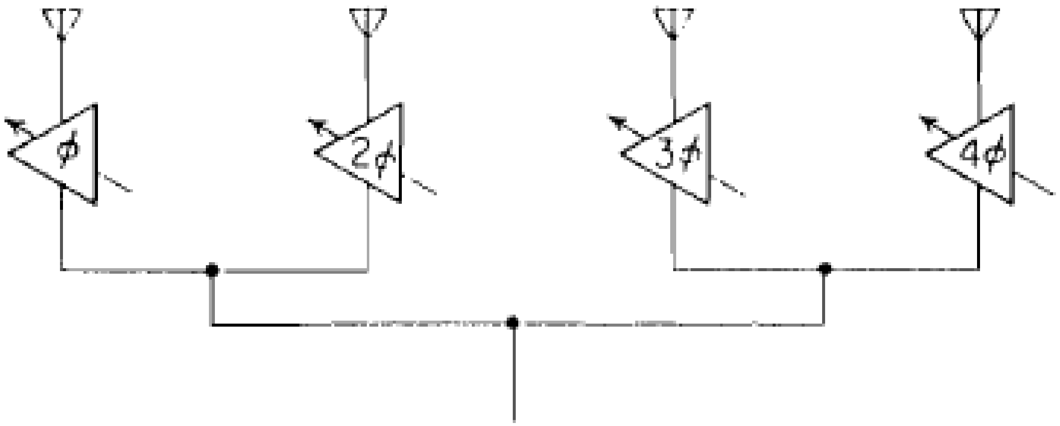
- Radiating elements fed by Phase shifters
- Phases are electronically adjusted & controlled
- More expensive than frequency scanning but cheaper than time delay

PHASE SCANNING

Phasers!!



PHASE SCANNING



- Phase of signal applied to each radiating element varied to obtain beam in desired direction
- If same phase is used in all elements the relative phase between adjacent elements is zero. The beam is at angle θ =0 to the array

PHASE SCANNING

- If phase difference between adjacent elements is not zero, the direction of beam is different from broadside
- $\Phi = 2\pi \, [d/\lambda] \, \sin\theta_0$
- Where Φ = Phase difference between adjacent elements
- θ_0 = Direction of beam
- Phase at every element is $\Phi_e + m\,\Phi$ where m = 0, 1,2 ,… (N–1)
- $$G(\theta) = \frac{\sin^2\{N\pi\,[d/\lambda][\sin\theta - \sin\theta_0]}{N^2 \sin^2\{\pi\,[d/\lambda][\sin\theta - \sin\theta_0]}$$

PHASE SCANNING

- $G(\theta) = \dfrac{\sin^2\{N\ \pi\ [d/\lambda][\sin\theta - \sin\theta_O]}{N^2\ \sin^2\{\pi\ [d/\lambda][\sin\theta - \sin\theta_O]}$
- Maximum occurs when $\sin\theta = \sin\theta_0$
- By properly inserting phase shift φ at each element , the main beam position ie θ_0 can be changed.
- For this purpose Phase shifters are used
- Grating lobes appears at angle θ_g whenever denominator is zero
- $|\sin\theta_g - \sin\theta_0| = \pm n\,[\lambda / d]$

PHASE SCANNING

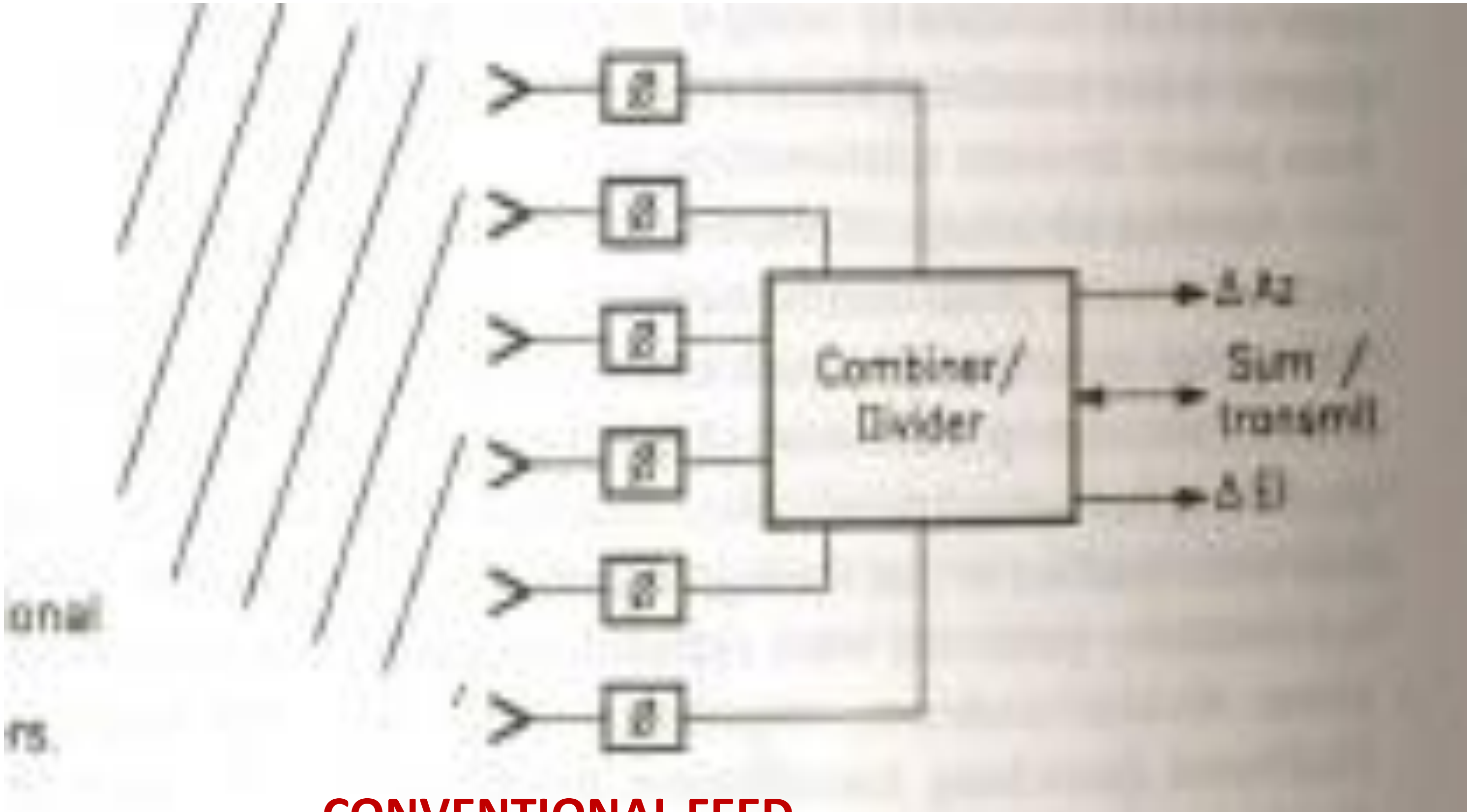
- When $d = \lambda / 2$, grating lobe appears at -90^0 when main beam is steered to $+90^0$
- Element spacing should not be larger than $\lambda / 2$ if beam is required to be steered over a wide angle
- If $d = 0.54\lambda$, the steering is limited to angle

$\pm 60^0$

(Jntuh) **Distinguish between Series and parallel feed array arrangements**

VARIOUS TYPES OF FEEDS

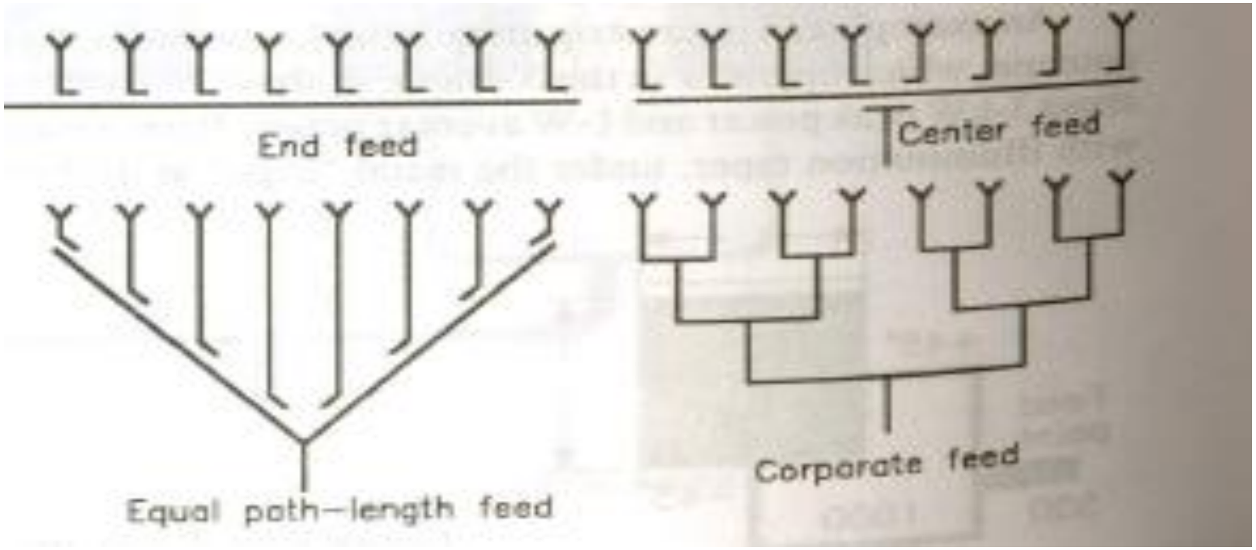
- Feeds are used to connect the antenna to Tx
- There are various types of feeds

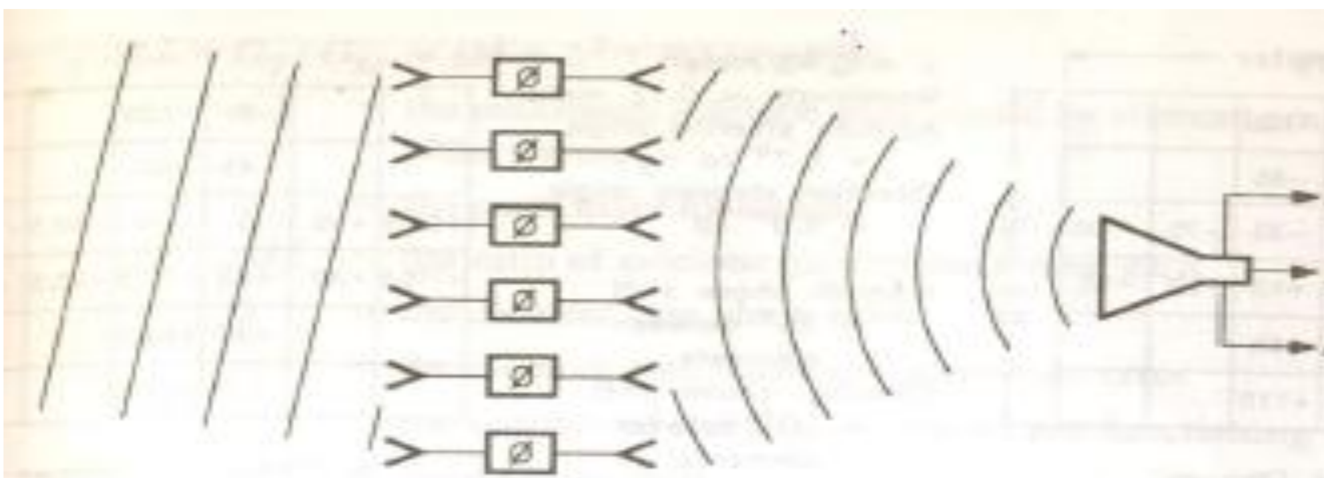


CONVENTIONAL FEED

VARIOUS TYPES OF FEEDS (CONTD..)

- **Conventional feeds:**





SPACE FED LENSE ARRAY

SERIES Vs PARALLEL FEEDS

- Relative phase shift between adjacent elements must be $\varphi = 2\pi [d/\lambda] \sin\theta_0$

- Where φ = Phase shift
- θ_0 = Position of main beam pattern

- Arrangement to get necessary phase shift

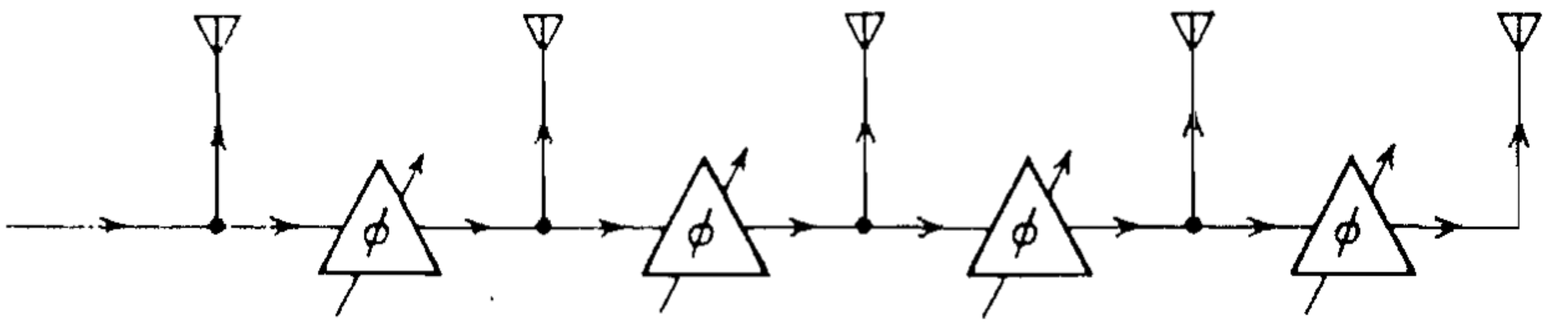
  i) Series fed feed

  ii) Parallel fed feed

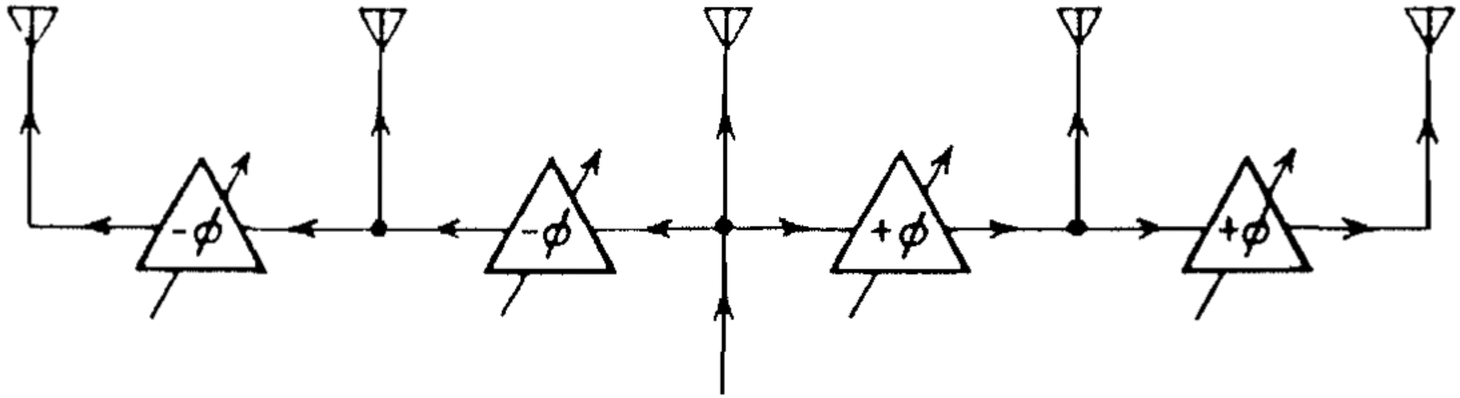
SERIES FED FEEDS

➢ Series fed feed:

- Energy transmitted i) fed from one end of the line



- Energy transmitted ii) fed from the centre to reach both ends



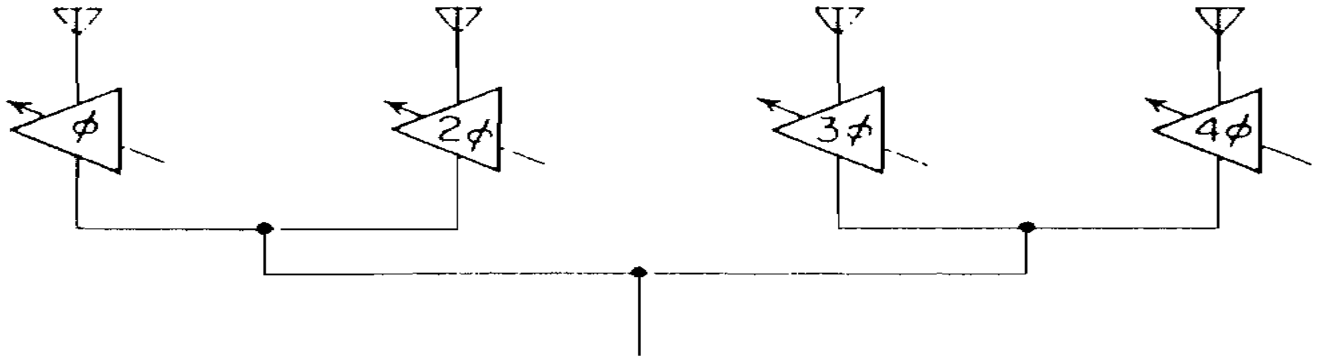
SERIES FED FEEDS

- Adjacent elements are connected by a phase shifter with phase shift of φ
- All phase shifters are identical and the phase shift is less that 2 π radians
- In series arrangement where sjgnal is fed from one end, the position of the beam will vary with frequency
- So this arrangement is limited in bandwidth
- Center fed feed does not have this problem

PARALLEL FED FEEDS

➢ Parallel feed:

- Power Splitter is used to divide the energy
- Series of power splitter are used to create a tree like structure. This is also called Corporate feed
- Equal lengths of line , transmit energy to each element so that no unwanted phase difference are introduced by lines themselves



PARALLEL FED FEEDS (CONTD..)

- The Phase shifts required in succeeding elements are φ, 2φ, 3φ, …… (N –1) φ
- Maximum phase change required for each phase shifter is many times 2 π radians
- Since phase shift is periodic with period 2π , phase shifter can have a value of maximum 2 π radians
- If the pulse width is small signal bandwidth is large compared to antenna bandwidth
- In above such case the received pulse which is the sum of number of elements gets smeared. This problem is overcome by replacing the 2 π modulo phase shifter with Delay lines

COMPARISION OF SERIES & PARALLEL FED ARRAYS

➢ Insertion Loss:

- In series fed array the insertion loss is N times the loss of a single element
- In parallel fed array the insertion loss is introduced only once
- So individual phase shifter in a Series fed array should have low insertion loss compared to that on parallel fed array. Some times Amplifiers are introduced to compensate for signal attenuation

COMPARISION OF SERIES & PARALLEL FED ARRAYS

➢ Control Signal :

- In Series fed array only one control signal is required to steer the beam since same value of phase shift is used
- In Parallel fed array (N – 1) control signals are required
- 2 Dimensional M x N array requires M + N – 2 separate control signals. A Series fed array requires only 2 control signals

END OF UNIT 5