Page NO.

1. 1 to 29 – Mid Term
2. 30 to 66- Final Term


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COMPUTER AND COMMUNICATION ENGINEERING

International Islamic University Chittagong


COURSE CODE: CCE-4707

COURSE TITLE: Microwave Engineering

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ETE

# MW Frequency

⇒ Radio Frequency (RF) & MW Engineering Covers AC signals with Frequencies in the range of 100 MHz to 1000 GHz

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## Transmission Line

Generator থেকে Load পর্যন্ত power কে নিয়ে যাওয়ার কাজ যে করে তাকে tramission Line বলে।

⇒ The thing which takes power from generator to load is called as transmission Line.

**Why Transmission Line Theory:**

⇒ A transmission Line is a two Conductor system where one is used to ~~too~~ send forward current & the other one is used for bringing return current.

→ The key difference between a circuit theory & Transmission Line Theory is in their electrical size.

Circuit Analysis assumes that the physical dimensions of the networks are much smaller than the electrical wavelength.

And a transmission lines are many wavelength in size.

For Example:- For a 50000 MHz signal the wavelength is 10 km then we will have to use transmission line theory instead of circuit Theory.

(DIF) ⊛ In circuit theory we assume that the magnitude, phase ~~___~~ can't vary. And we also assume that in transmission Line Theory magnitude phase can be varied.

(DIF) ⊛ ~~Circuit~~ IF the circuit length is near to wavelength then we will use Transmission Line Theory

4

On the other hand, if the electrical length is much smaller than the wavelength then the ~~Tp~~. Circuit theory will be used.

Note:- (i) Current grow from Magnetic Field
(ii) Voltage grow from Electrical Field.

⇒ An ordinary electrical cable suffice to carry low frequency AC such as main power which reverses direction 100 to 120 times per second. However, they can't be used to carry currents in the radio frequency range above 30 KHz cause the energy tends to radiate off the cable as radio waves, causing power losses.
So to get rid of this radiation loss two conductors are used & arranged that their electromagnetic fields are in opposite direction.
To meet the requirement, the current of conductor must flow in opposite direction

that means shifted by ~~le~~ b in phase by 180 degrees.

3 types of theory:-

Circuit

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**Brief**

① why Transmission Line should be parallel?
why Two conductors are needed & closed together?

=> parallel:-

VVIM

## Why Two conductors are needed & closed:-

Generator হতে power কে Load পর্যন্ত নিয়ে যাওয়া এই কাজ যে করে তাকে Transmission Line বলে।

we need:-

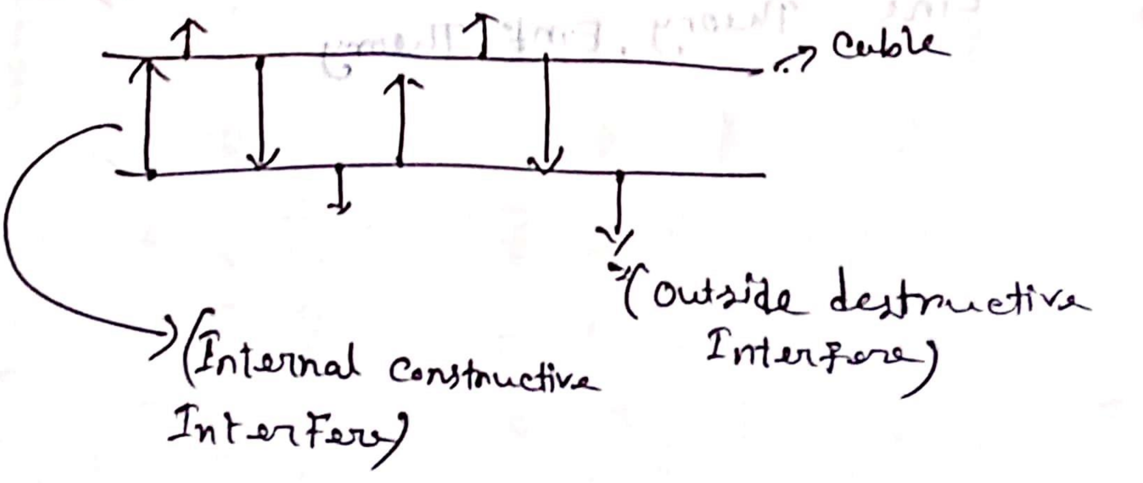
→ Two Conductors:-

(1) One conductor will take forward current

(2) Another one will ~~take~~ bring return current.

→ Two conductors will be in parallel &

→ Two conductors are very close to each other. So that the angle of path difference can't be changed.



VVIm

(1) How many Conditions are needed for TL or,
(1) when to use Transmission Line theory or,
(2) Why Transmission Line Theory is used?

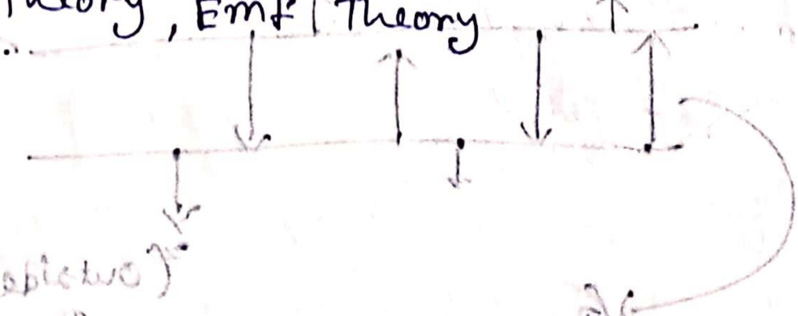
Ans:-

(1) ⇒ If the wavelength for 50,000 MHz signal is 10 km then we need to use Transmission Line Theory instead of Circuit Theory.

(2) → In Circuit Theory we assume that manghitude phase can't vary,
But, In transmission Line Theory it can be veried.

(3) → when circuit length is almost equal to wavelength then Transmission Line Theory is used.

(3) Discussion on Circuit Line Theory, Transmission Line Theory, EMF Theory



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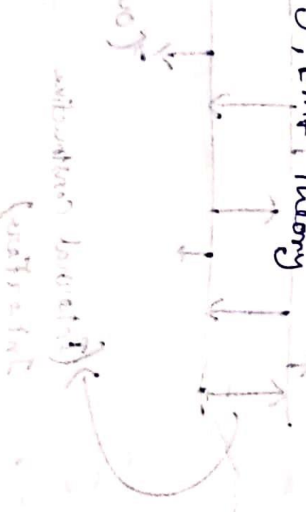
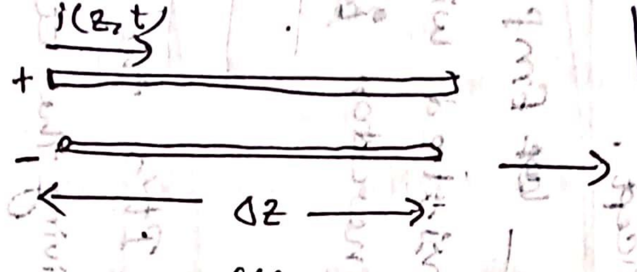


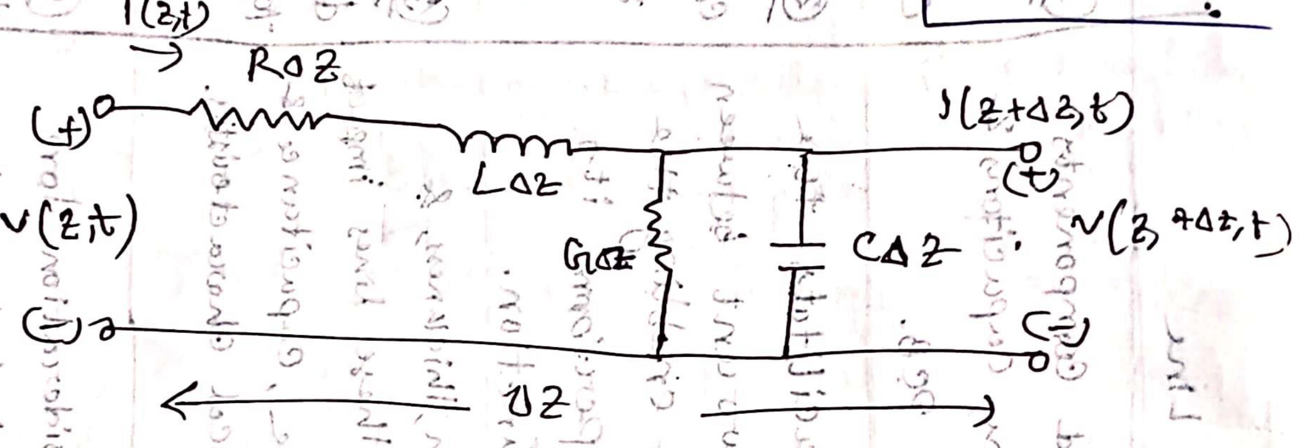
| Transmission Line | Circuit Line | EMF |
|---|---|---|
| (1) Crucial for High Frequency long distance signal Transmission | (1) Connected components like resistors, capacitors & IC etc on PCB. | (1) For Electromotive Force, is a Fundamental Concept. |
| (2) Consist of two Conductors that carry electrical signals between two points. | (2) Lines facilitats the Flow of current between Compnents & enabling the Circuit to perform its intended function. | (2) ~~loss~~ Emf are consisted with battery, generator in circuit. |
| (3) Can be thought distributed Circuits, where the Interaction between Capacitance, Inductance resistance & impedance are important. | (3) The width, thickness, & material of these lines impact their resistance, capacitance & other electrical characteristics. | (3) It's the energy driving the electric charges to move through a circuit. |
| (4) Key parameters include characteristic impedance, ~~resistance~~ propagation delay, reflection Coefficient. | (4) Design consideration for circuit lines include minimizing resistance, managing impedance & avoiding signal interference | (4) It is not a force in the mechanical sense. It's a measure of energy Conversion |

## Equivalent circuit representation : OF TL




(a)

(i) RLGC
(ii) per unit length




(b)

⇒ ① In the figure a transmission line is schematically represented as a two-wire line since transmission lines (for transverse electromagnetic [TEM] wave propagation) always have at least two conductors.

② Four fundamental parameters :-

$R$ = Series resistance per unit length, for both conductors ($\Omega m^{-1}$)

$L$ = Series inductance per unit length, for both conductors, in $Hm^{-1}$

$60^{\times}$
$60$

# (VSWR)

$100 + j150\,\Omega$, $50\,\Omega$ lossless line $\quad \frac{100 + 150\,\Omega\, j}{50} = 2 + 3j$ (resistance, reactance)

① Reflection coefficient, $\Gamma = x/y = \frac{6.2}{8.3}$

$= 0.747 \angle 27^\circ$

② S (VSWR) = 7

③ Load Admittance, $y_L = \frac{1}{2 + j3\,\Omega}$

$= 0.154 - 0.231 j\,\Omega = \frac{0.154 - 0.231 j}{50}$

$= 0.00308 - 0.00462 j$

④ $Z_{in}$ at $0.4\lambda$ from the load.

$\Rightarrow 0.213 + 0.4\lambda$

$= 0.613\lambda$

$\therefore Z_{in} = (0.24 + j0.81)\,\Omega$

$= (0.24 + j0.81) \times 50$

$= 12 + 40.5j\,\Omega$

⑤ The Vmax & Vmin with respect to the load, if the line is $0.6\lambda$ long.

$\Rightarrow 0.6\lambda$ Distance from load

$0.6\lambda + 0.213 = 0.813$

Now,

1st Vmax $= (0.25 - 0.213) = 0.037\lambda$

(VSWR)

2nd তম $V_{max} = (0.037 + 0.5)\lambda$

$= 0.537\lambda$

$V_{min} = (1st$ তম $V_{max} + 0.25)$

$= 0.037 + 0.25$

$= 0.287$

Ⓚ What is propagation constant? And how does it gives info about wave?

⇒ Propagation constant is denoted by $\gamma$. It describe the behavior of electromagnetic waves or other types of propagating waves as they travel through a medium.

It ~~is~~ has two parts:-

(i) Attenuation Constant ($\alpha$):-

This part describe the exponential decay of the wave's amplitude as it travel through medium. And also describe how much the wave's energy is lost per unit length due to absorption or scattering.

A higher value of $\alpha$ indicates greater attenuation

(2) Phase constant ($\beta$):- How much the phase of the wave changes as it propagates through the medium. It indicates the phase shift experienced by the wave per unit length of propagation. It determines wave's spatial variation along the propagation direction.

$$\gamma = \alpha + i\beta \quad \Big| \; i = \text{imaginary number}$$

→ Here $\alpha$ is responsible for attenuation of the wave's intensity, while $\beta$ is responsible for the phase shift. And together they provide information about how the wave's amplitude decreases and how its phase evolves as it travels through the medium.

Q. What is lossless line? Justify the assumption of MW Transmission Lines as lossless lines?

⇒ A Lossless Line:

It is a theoretical type of transmission line that has no resistance, conductance, dielectric loss. In other words, it is a transmission line that has zero losses and can transmit signals without any power loss.

⇒ A low lossless line is possible, when,

$R << \omega L$, & $G << \omega C$

So, we can find,

$\gamma = \alpha + i\beta = \sqrt{(R + j\omega L)(G + j\omega C)}$

$= j\omega\sqrt{LC}$

or, $\beta = \omega\sqrt{LC}$, $\alpha = 0$

The attenuation, $\alpha = 0$

Characteristic impedance, $Z_0 = \sqrt{\dfrac{R + j\omega L}{G + j\omega C}}$

$= \sqrt{L/C}$

I $V = IR$

Now, it is a real number. So the ~~solu~~ general solution of,

$V(z) =$

lossless Transmission Line (voltage)

$$V(z) = V_0^+ e^{-jBz} + V_0^- e^{jBz}$$

$$I(z) = \frac{V_0^+}{Z_0} \cdot e^{-jBz} - \frac{V_0^-}{Z_0} e^{jBz}$$

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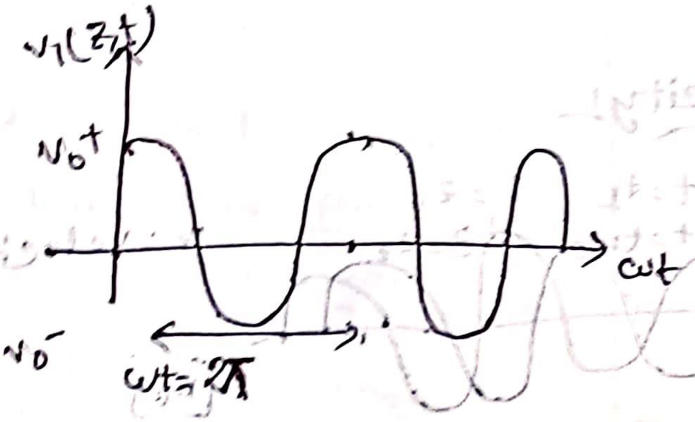
## Angular frequency, phase constant, phase velocity:

(i) Angular frequency:-

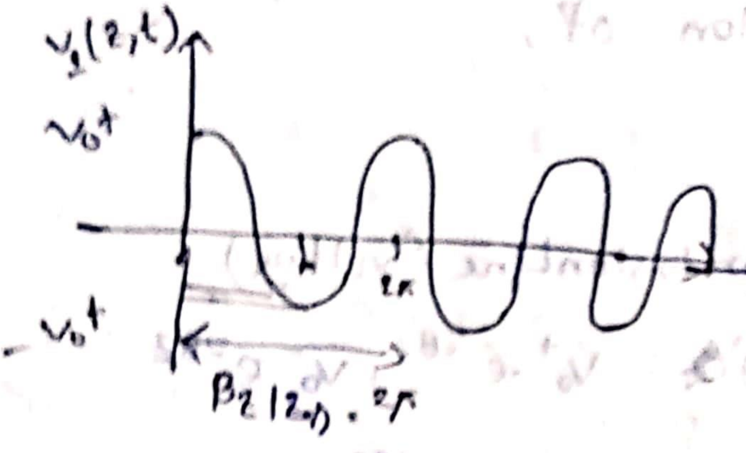
$$V_1(z,t) = V_0^+ \cos(\omega t - \beta z)$$




$\omega t = 2\pi$

$\Rightarrow T = \frac{2\pi}{\omega} = 1/f$ [T = Time period of wave]

### (ii) Phase constant :-

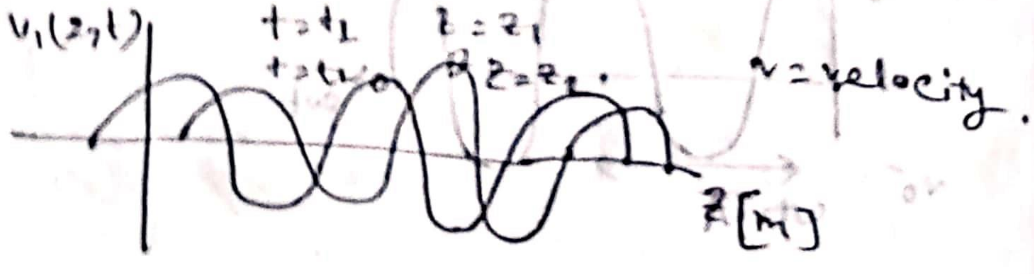



$$\beta z|_{z=\lambda} = 2\pi$$

$$\Rightarrow \lambda = \frac{2\pi}{\beta} \qquad | \lambda = \text{wavelength}$$

Distance between two consecutive equal values of the signal is ~~das~~ defined as the wavelength.

### (iii) Phase velocity :-




$$v_1(z_1, t_1) = v_2(z_2, t_2)$$

$$\Rightarrow \cos(\beta z_1 - \omega t_1) = \cos(\beta z_2 - \omega t_2)$$

$$\Rightarrow \frac{z_2 - z_1}{t_2 - t_1} = \frac{\omega}{\beta} \Leftarrow \beta z_1 - \omega t_1 = \beta z_2 - \omega t_2$$

$\Rightarrow V_p = \omega/\beta = \frac{\omega}{\omega\sqrt{LC}} = 1/\sqrt{LC}$

wavelength, $\lambda = \frac{2\pi}{\beta} = \frac{2\pi}{\omega\sqrt{LC}} = \frac{V_p}{f} = V_p T$

## Difference between characteristic impedance & Line impedance.

$\Rightarrow$

| Characteristic Impedance | Line impedance |
|---|---|
| ① Related to the physical quantities & frequency of the transmission line. Reflected voltage, current waves. | ① Varies as we go distance from load to source, characteristic impedance doesn't vary. |
| ② Important params to calculate line params & calculate impedance. | ② New combined total impedance seen at a distance from load. |
| ③ Helps to determine params of TL. | ③ Helps to determine impedance |

~~12~~ Converting a Transmission Line into an Arbitrary Load. Then what will be the reflection coefficient?

=) Converting a transmission line into an arbitrary load involves terminating the transmission line with an impedance that are not necessarily matched to the characteristic impedance of transmission line.

$$\boxed{\text{The reflection coefficient, } \Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}}$$

$Z_L$ = Load impedance

$Z_0$ = The characteristic impedance of TL

When $Z_L = Z_0$ then $\Gamma = 0$

When $Z_L$ is not equal to $Z_0$ then the $\Gamma$ is non zero

So, if converted ~~& the~~ into arbitrary load & not matched to characteristic impedance of the TL, the reflection coefficient will be non ~~zero~~ zero. That means there will be some ~~are~~ amount of signal reflection at the load interface.

V.S.M

Difference between Return Loss, VSWR; Insertion Loss

=>

| Return Loss | VSWR | Insertion Loss |
|---|---|---|
| 1) Measure of the amount of signal power that is reflected back towards the source due to impedance mismatch. | 1) Measure of how well the load is matched to the transmission line's characteristic impedance. It is a radio | 1) Reduction of signal power when a device or component is inserted into a transmission line or network. |
| (2) Expressed in dB | (2) Ratio of maximum voltage along the transmission line | (2) used to quantify the signal attenuation caused by the insertion of the device. |
| (3) $RL = -20 * \log_{10}(\Gamma)$ | (3) VSWR = $(1+\lvert\Gamma\rvert)/(1-\lvert\Gamma\rvert)$ | (3) $IL = P_{in} - P_{out}$ |
| (4) Higher return loss value indicates less signal reflection & better impedance match. A perfect match results in infinite return loss. | (4) A lower VSWR (closer to 1) return better impedance matching. | (4) Higher Insertion loss indicates greater signal attenuation caused by the insertion of the component |

Q) Calculate or & write down the formulas for Line impedance & Input impedance which are from L distance from Load of transmission.

⇒ Considering a lossless transmission line And charateristic impedance ($Z_0$) propagation Constant ($\beta$), $Z_L$ = Load impedance ($Z_L$), $Z_{in}$ = Input impedance.

So, equation for line impedance from Distance L from Load:-

$$Z_L = Z_0 \frac{Z_{in} + j Z_0 \tan(\beta L)}{Z_0 + j Z_{in} \tan(\beta L)}$$

Input Impedance ($Z_{in}$) from Distance L:-

$$Z_{in} = Z_L \frac{Z_0 + j Z_{in} \tan(\beta L)}{Z_{in} + j Z_0 \tan(\beta L)}.$$

Q) Derive the equations for Line Impedance, Reflection coefficient & Telegrapher's equation.

⇒ Line Impedance :-

$$I(z) = \frac{V^+}{Z_0} e^{-j\beta z} - \frac{V^-}{Z_0} e^{j\beta z}$$

Voltage $V(0) = V_{load}$

$$\therefore I_{load} = \frac{V_{load}}{Z_0} + \frac{V^-}{Z_0}$$

Solving for $v^-$ & substituting the difinition of $\Gamma$,

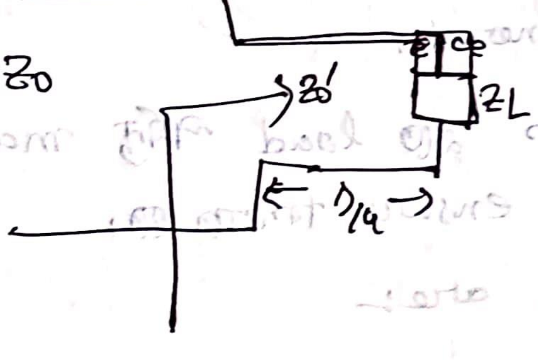
$$v^- = \frac{Z_L - Z_0}{Z_L + Z_0} v^+$$

[Telegrapher & Reflection Coefficient previous]

~~Quarter wavelength অর্থ, মূলত what is~~

WTW What is a Quarter wavelength Transformer? What is the condition of achieving impedance matching with it?

=> The $\lambda/4$ section of the transmission line is called quarter-wave length cause it is used for impedance matching like an ordinary transformer.




$Z_L = Z_0$

When $Z_0 \neq Z_L$ that means load is mismatched and a reflected wave exists on the line. The maximum power transfer can be gained when it is matched.

$Z_0 = Z_L$ so that there is no reflection.

So $Z_{in} = Z_0 \left[ \dfrac{Z_L + jZ_0 \tan \pi/2}{Z_0 + jZ_L \tan \pi/2} \right] = \dfrac{Z_0^2}{Z_L}$ — (i)

$\Rightarrow \dfrac{Z_{in}}{Z_0} = \dfrac{Z_0}{Z_L}$ — (ii)

$\Rightarrow Z_{in} = 1/Z_L$ — (iii)

From (i) $Z_0'$ is selected such that $(Z_{in} = Z_0)$

$Z_0' = \sqrt{Z_0 Z_L}$ [$Z_0'$, $Z_0$, $Z_L$ are real]

Where $Z_L$ = Load impedance

$Z_0$ = Line "

$Z_G$ = Generator "

Q. যদি Generator হতে load পর্যন্ত max power transfer হবে তা ensure করতে হবে।

Ans:- Conditions are:-

(i) $Z_0 = Z_L$

(ii) $Z_G = Z_{in}$

Load & Generator impedances are $73\Omega$ & $50\Omega$ respectively. Design a quarter wavelength transformer for proper impedance matching between them.

⇒ To design quarter wave length,

we need characteristic impedance, $Z_0 = \sqrt{Z_g \times Z_L}$

$$= \sqrt{73 \times 50}$$

$$= 60.62\Omega$$

Now, determining the electrical length of the quarter wavelength,

$$\beta L = \frac{\pi}{2}$$

β = Phase constant
L = electrical Length

The phase constant can be calculated :-

$$\beta = \frac{2\pi}{\lambda}$$

λ = Wavelength of Transmission Line.

$$\lambda = 4L$$

$\therefore$ value ⇒ $\frac{2\pi}{\lambda} \times L = \frac{\pi}{2}$

$$\therefore L = \frac{\lambda}{4} = \frac{c}{4f\sqrt{\varepsilon_r}}$$

Assuming that transmission line to be air filled,

$\varepsilon_r = 1$, plugin in the given freq. of 2.4 GHz

we get :-

$$L = \frac{c}{4f} = \frac{3\times10^8}{4\times2.4\times10^9} = 31.25\,mm$$

So the electrical length of the quarter wavelength transformer is 31.25 mm.

# Lecture -5

VVImp

## Difference between TL & waveguide.

Q =)

| Transmission Line | waveguide |
|---|---|
| ① Two separated conductors in parallel. | ① Single conductor |
| ② For low power transmission | ② For bulk power transmission. |
| ③ TEM Mode | ③ TE/TM Mode |
| ④ works for any frequency generally. | ④ works like a high pass filter. |

VVImp
AUT-22

## Difference between TEM, TM, TE

| TEM | TM | TE |
|---|---|---|
| ① Transverse Electro magnetic wave | ① Transverse magnetic | ① Transverse Electric |
| ② $E(z)=0$ | ② $E(z)!=0$ | ② $E(z)=0$ |
| ③ $H(z)=0$ | ③ $H(z)=0$ | ③ $H(z)!=0$ |
| ④ Doesn't have a cut OFF frequency. | ④ Has a cut off frequency. | ④ Has a cut OFF frequency. |

VVIm

## procedure for analyzing TEM :-

(1) Solving Laplace eqation $\nabla_t^2 \phi(x,y) = 0$,
For $\phi(x,y)$. The solution will contain several unknown constants.

(2) Find these constants by applying the boundary conditions for the known voltages on the conductors.

(3) Compute $\bar{e}$ & $\bar{E}$. Compute $\bar{h}$ & $\bar{H}$. ~~from~~

(4) Compute V & I.

(5) The propagation constant is given by $\beta = \omega\sqrt{\mu\epsilon} = k$,
and the characteristic impedance is given by $Z_0 = V/I$.

VVIm

## procedure for TM & TE :-

(1) Solve the reduced Helmholtz equation for $h_z$ or $e_z$. The solution will contain several unknown constants & the unknown cutoff wave number, $k_c$.

(2) By using,

$$E_y = \frac{j\omega\mu}{k_c^2} \cdot \frac{\delta H_z}{\delta x} \quad \text{--- (1)}$$

(24)

And also, using this equation find the transverse fields from $h_z$ or $e_z$.

(3) Apply the boundary conditions to the appropriate field components to find the unknown constant & $k_c$

(4) The propagation constant is given by

$$k_c^2 = k^2 - \cancel{\beta}\ \beta^2$$

And the characteristic impedance is given by $Z_0 = V/I$.

Parallel plate waveguide:

$$\beta = \sqrt{k^2 - k_c^2}$$

$$= \sqrt{k^2 - (n\pi/d)^2}$$

~~Observe that for n=0, $\beta = k = \omega\sqrt{\mu\epsilon}$ and that $E_z = 0$. The $E_y$ & $H_x$ fields are then constant in~~

From this equation we can see that $\beta$ is real only when $k > k_c$. Because ~~k = constant~~ $k = \omega\sqrt{\mu\epsilon}$ is proportional to frequency, the $TM_n$

modes for $(n>0)$ exhibit a cutoff frequency of the $TM_n$ mode can be found as,

$$f_c = \frac{k_c}{2\pi\sqrt{\mu\epsilon}} = \frac{n}{2d\sqrt{\mu\epsilon}}$$

## Rectangular wave Guide:

~~wave~~ guide

## Dominant Mode of ~~frequency~~ waveguide:-

Wave guide এর বিভিন্ন characteristic type,

→ $TE_{10}$ mode dominant TE mode. And the overall dominant mode of the rectangular waveguide.

→ $TE_{11}$ mode dominant mode of circular waveguide.

→ $TE_{01}$ mode to lower order propagating mode.

→ $TM_0$, Dominant mode of dielectric slab waveguide.

$\circledast$ ~~75 Ω~~ 73 Ω & 50 Ω

$$Z_c = \sqrt{73 \times 50}$$
$$= 60.42 \,\Omega$$

Electrical length of quarter wavelength,

$$\cancel{\beta l = \pi/2} \quad \beta L = \pi/2 \qquad \Bigg| \begin{array}{l} \beta = \text{phase const.} \\ L = \text{Length} \end{array}$$

The phase constant can be calculated,

$$\beta = 2\pi/\lambda$$

$$2\pi/\lambda \; L = \pi/2$$

$$L = \lambda \cdot \pi/4 = \frac{c}{4f\sqrt{\varepsilon_r}}$$

Here, in air, $\varepsilon_r = 1$ so, $L = \frac{c}{4f}$

plugin in the given Feq, $= 2.4\,GHz$ $\frac{3 \times 10^8}{}$

$$L = \frac{c}{4f} = \frac{3 \times 10^8}{4 \times 2.4 \times 10^9} = 31.25\,mm$$

## Practice

**KVL:-**

$v(z,t) + v(z+\Delta z, t)$

$= R\Delta z\, i(z,t) + L\Delta z \cdot \frac{\delta i(z,t)}{\delta t}$

$= \frac{v(z,t) - v(z-\Delta z, t)}{\Delta z}$

$= Ri(z,t) - L\frac{\delta i(z,t)}{\delta t}$

$\therefore \frac{-\delta\, v(z,t)}{\delta z} = R(z,t) + \frac{L\delta I(z,t)}{\delta t}$ $[\Delta z \to 0]$

**KCL:**

$i(z,t) - i(z+\Delta z, t)$

$= G\Delta z\, v(z+\Delta z, t) + C\Delta z \frac{\delta v(z+\Delta z, t)}{\delta t}$

$\therefore \frac{\delta I(z,t)}{\delta z} = -Gv(z,t) - C\frac{\delta v(z,t)}{\delta t}$

$[\Delta z \to 0]$

**Telegraph to wave eqn**

$dv(z) = -(R + j\omega L) \cdot I(z)$ — (i)

$\frac{d\,(I(z))}{dz} = -(G + j\omega C)\, V(z)$ — (ii)

Differentiating in both way we get,

(i) $\frac{d^2 v(z)}{dz^2} - \gamma^2 v(z) = 0$

(ii) $\frac{d^2}{dz^2} - \gamma^2 \cdot I(z) = 0$

practice

Lossless

$R << \omega L \qquad G << \omega C$

$\gamma = \alpha + j\beta$

$= \sqrt{(R+j\omega L)(G+j\omega C)}$

$= \sqrt{j^2 \omega^2 LC}$

$= j\omega\sqrt{LC}$

$\beta = \omega\sqrt{LC} \quad , \alpha = 0$

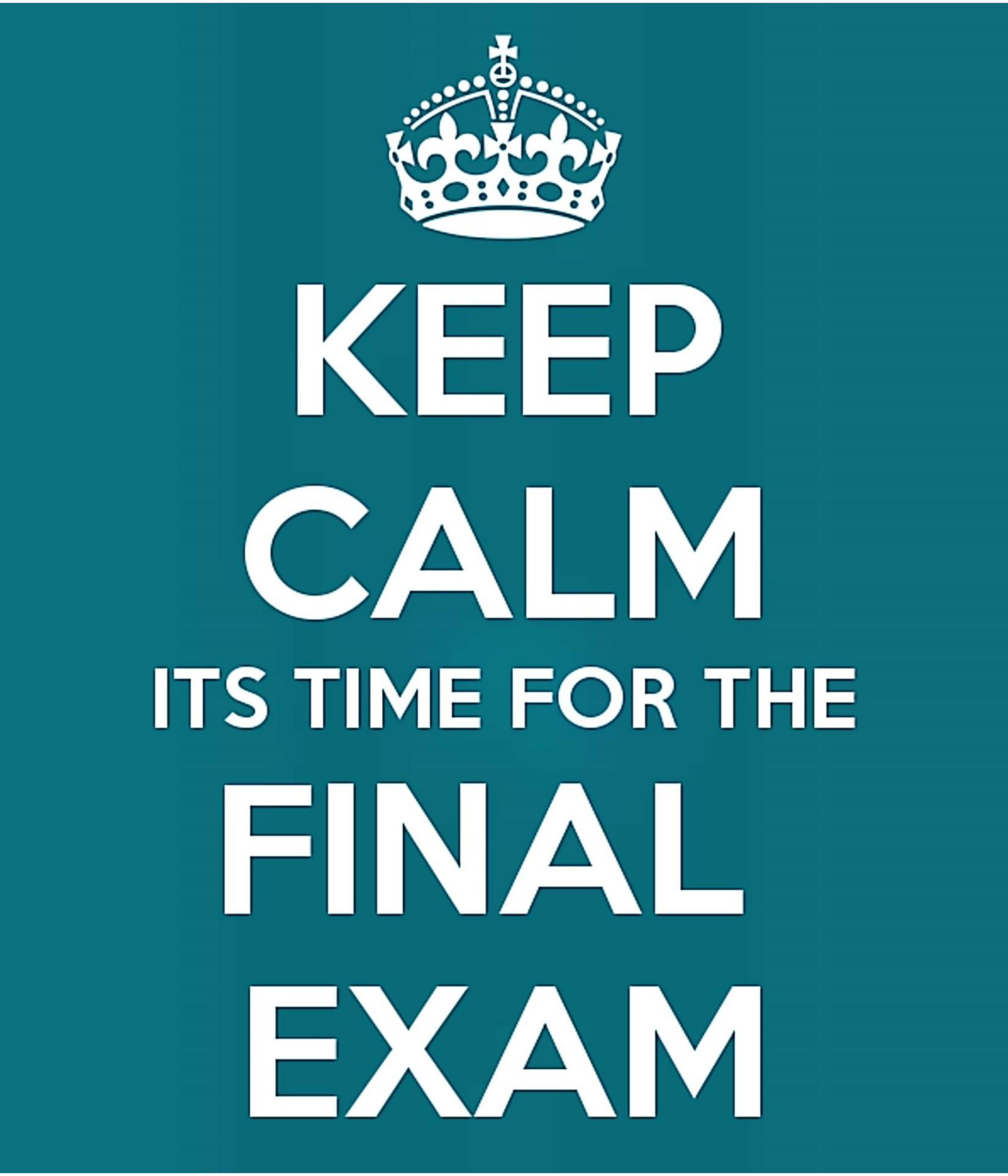
Char impedance, $Z_0 = \sqrt{\frac{R+j\omega L}{G+j\omega C}}$

$= \sqrt{L/C}$

lossless Transmission,

$I(z) = \frac{V_0^+}{Z_0} e^{-j\beta z} + \frac{V_0^-}{Z_0} e^{j\beta z}$

$V(z) = V_0^+ e^{-j\beta z} + V_0^- e^{j\beta z}$


KEEP
CALM
ITS TIME FOR THE
FINAL
EXAM

FINAL

# Network Analysis

**TE Mode:-** Transverse Electric Mode in the Content of waveguide propagation. & electromagnetic field analysis. In this mode, the electric field vector is perpendicular to the direction of wave propagation.

It implies that there is no electric field component parallel to the direction of wave propagation.

In TE $E_z = 0$

$H_z \neq 0$

**TEM Mode:-** Transverse ElectroMagnetic Mode.

Both the electric field & the magnetic field are perpendicular to the direction propagation.

In this mode, there is no ~~et~~ electric or magnetic field in the direction of propagation.

$\cancel{E_z \neq 0}$, $\cancel{H_z = 0}$

$E_z = 0, \quad H_z = 0$

TM Mode :- Transverse Magnetic Mode, is a type of electromagnetic wave propagation in which the magnetic field is perpendicular with wave propagation. And there is no electric field in this direction of propagation.

$E_z \neq 0$ $\cancel{H_z \neq 0}$ $H_z = 0$

As in TE & TM Mode, they don't have two terminal voltage & current measure can't happen in these.

But TEM mode as it has two terminal we can easily measure voltage & current from Laplace equation.

So, to get Impedance in TE & TM mode we need to find measure equivalence current or equivalance voltage.

* For microwave network analysis we need to know the impedance at every point.

In TEM Mode as we directly measure voltage & current

$V = \oint E \cdot dl$

$I = \oint H \cdot dl$

For TE & TM Mode:-

To measure equivalent current & equivalent voltage some consideration is needed:-

① voltage ∝ Tranverse electric field and
   Current ∝ Transverse magnetic field

② The equivalent voltage & currents should be defined so that their product gives the power

③ The ratio of the voltage & current should be equal to the characteristic impedance of the time.

Various types of Impedance

1] Intrinsic Impedance:- This impedance is dependent only on the material parameters of the medium and is equal to the wave impedance for the plane or TEM mode wave.

That means,

$$Z_{TEM} = \eta$$

2] Wave impedance:- The measure of the opposition that an electromagnetic wave encounters as it propagates through a medium.

$$Z_{TE} = \frac{E}{H}$$

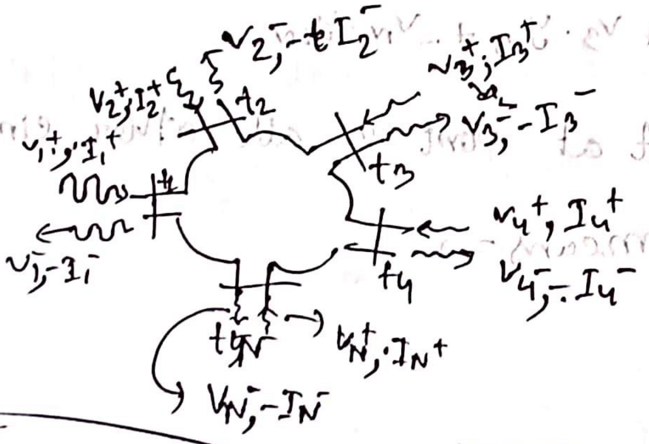
## (iii) Characteristic Impedance:-

Ratio of voltage to current for a travelling wave on a transmission line.

$$Z_0 = \frac{V^+}{I^+}$$

## Impedance & Admitance Matrices

There are nth ports.




At the Nth terminal plane, the total voltage & current is,

$$V_n = V_n^+ + V_n^- \quad \text{—(1)}$$

$$I_n = I_n^+ - I_n^- \quad \text{—(2)}$$

$V_N^+, I_N^+ \rightsquigarrow O$

$V_N^-, -I_N^- \leftsquigarrow O$

## S-Matrices (Scattering Matrices)

$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ \vdots \\ V_N \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} & Z_{13} & \cdots & Z_{1N} \\ Z_{21} & Z_{22} & Z_{23} & \cdots & Z_{2N} \\ Z_{31} & Z_{32} & Z_{33} & \cdots & Z_{3N} \\ \vdots & & & & \\ Z_{N1} & \cdots & \cdots & & Z_{NN} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_N \end{bmatrix}$$

$[V] = [Z][I]$ From this matrix $=$

$V_1 = I_1 Z_{11} + I_2 Z_{12} + \dots I_N Z_{1N}$

~~So we know,~~

So, $Z_{12} = \frac{V_1}{I_2}\Big|_{I_1, I_3 \dots I_4 \dots I_N = \text{open circuit} = 0}$

$V = I.Z$

$V = I.\frac{1}{y}$

$I = y.V$

$$\begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_N \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} & y_{13} & \dots & y_{1N} \\ \vdots & & & & \\ y_{N1} & y_{N2} & y_{N3} & \dots & y_{NN} \end{bmatrix} \begin{bmatrix} V_1 \\ \vdots \\ V_N \end{bmatrix}$$

$\Rightarrow [I] = [y][V]$

From here,

$I_1 = V_1 \cdot y_{11} + V_2 \cdot y_{12} + V_3 \cdot y_{13} + \dots V_N \cdot y_{1N}$

So, if I give current at port 2, all other circuit will be open that means $= 0$

So,

$I_1 = V_2 \, y_{12}$

$\therefore y_{12} = \frac{I_1}{V_2}\Big|_{V_1, V_3, V_4, \dots V_N = 0}$ as they are all open circuit

<u>Note:</u>- But If we have 10 port devices, there will be 100 of parameters which are unknown. As a result we need to us some techniques.

## Reciprocal Network:-

$Z_{13}$ & $Z_{31}$

$Z_{13}$ means → (i) Giving input current at port 3 &

~~$Z_{31}$ means~~ → (ii) Getting output at port 1 (voltage)

$Z_{31}$ → port -1 = Current ~~fu~~ for

port -3 = measure ~~for~~ voltage.

So, if we get such microwave device in which the path in between two path are same, then we can say that, $Z_{13} = Z_{31}$

This is called reciprocal.

## Lossless line:- If the resistance $R = 0$

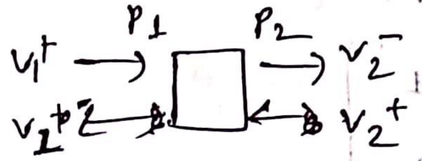
That means, $Z = R + j\omega$

$= 0 + j\omega$

$\boxed{Z = j\omega}$

## Scattering matrix:-

Forward voltage ($v^+$) & Reflected voltage ($v^-$)



S matrix:-

$$\begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix}$$

$$V_1^- = S_{11} V_1^+ + S_{12} \cdot V_2^+ \quad \text{—(i)}$$

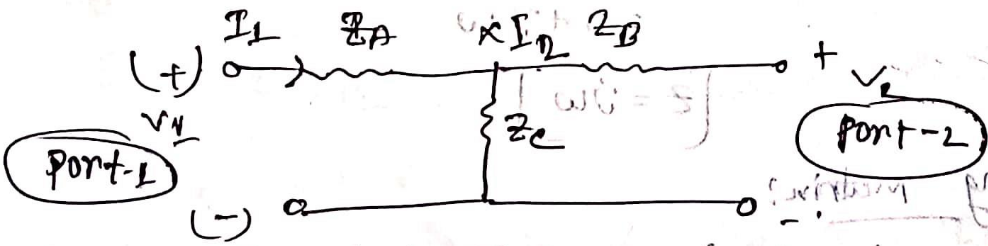
$$V_2^- = S_{21} \cdot V_1^+ + S_{22} \cdot V_2^+ \quad \text{—(ii)}$$

$$S_{11} = \frac{V_1^-}{V_1^+}\Big|_{V_2^+=0} \qquad S_{21} = \frac{V_2^-}{V_1^+}\Big|_{V_2^+=0}$$

$$S_{12} = \frac{V_1^-}{V_2^+}\Big|_{V_1^+=0} \qquad S_{22} = \frac{V_2^-}{V_2^+}\Big|_{V_1^+=0}$$

Example:-

Find the Z parameter of the Two port of T-Network:-




So, For two port Network

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

$Z_{11}^{e} =$

$V_1 = Z_{11} \times I_1 + Z_{12} \cdot I_2$

$V_2 = Z_{21} \times I_1 + Z_{22} \cdot I_2$

$Z_{11} = \frac{V_1}{I_1} \Big|_{I_2 = 0}$ | $Z_{21} = \frac{V_2}{I_1} \Big|_{I_2 = 0}$

$Z_{12} = \frac{V_1}{I_2} \Big|_{I_1 = 0}$ | $Z_{22} = \frac{V_2}{I_2} \Big|_{I_1 = 0}$

So, $Z_A$ -

So, for $Z_{11}$

$V_1 \cancel{= Z_{11} \times I_1 (Z_A + Z_e)}$

$\Rightarrow \cancel{Z_{11} = V_1 - I_1 (Z_A + Z_e)}$

$\Rightarrow \cancel{Z_{11}} =$

$V_1 = I_1 (Z_A + Z_e)$

$\Rightarrow Z_{11} \cdot I_1 = I_1 (Z_A + Z_e)$

$\Rightarrow Z_{11} = \frac{I_1 (Z_A + Z_e)}{I_1}$

$\Rightarrow Z_{11} = Z_A + Z_e$

For, $Z_{12}$

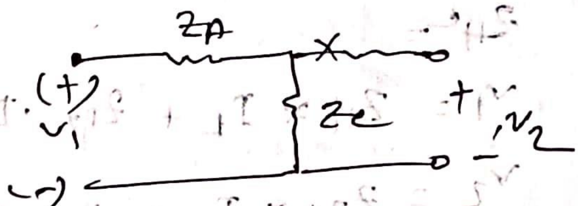
$\cancel{V_1 =}$ $Z_{12} = \frac{V_1}{I_2} \Big|_{I_1 = 0}$

$V_1 = I_2 \cdot Z_e$


$Z_{12} = \frac{I_2 Z_e}{I_2}$

$Z_{12} = Z_e$

For, $Z_{21} = \frac{V_2}{I_1}\Big|_{I_2=0}$




$V_2 = I_1 \cdot Z_c$

$Z_{21} = \frac{I_1 \; Z_c}{I_1}$

$Z_{21} = Z_c$

For, $Z_{22} = \frac{V_2}{I_2}\Big|_{I_1=0}$

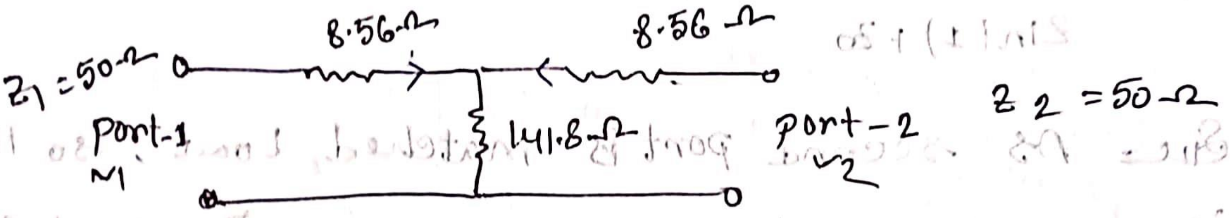
$= \frac{I_2(Z_B+Z_C)}{I_2}$

$= Z_B + Z_C$

Example - 4.4:-

Find the Scattering parameter of the 3dB antenna for circuit shown below

⇒ (Attenuator circuit means:- If we give power input at port - 1 & the output that we get at port two, the power will reduce)




∴ Ans:

$$\begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix}$$

So,

$$V_1^- = S_{11} \times V_1^+ + S_{12} \cdot V_2^+$$

$$V_2^- = S_{21} \times V_1^+ + S_{22} \cdot V_2^+$$

$S_{11} = \dfrac{V_1^-}{V_1^+} \Big|_{V_2^+ = 0}$ | $S_{21} = \dfrac{V_2^-}{V_1^+} \Big|_{V_2^+ = 0}$

$S_{12} = \dfrac{V_1^-}{V_2^+} \Big|_{V_1^+ = 0}$ | $S_{22} = \dfrac{V_2^+}{V_2^-} \Big|_{V_1^+ = 0}$

For,

$$S_{11} = \frac{V_1^-}{V_1^+}\Big|_{V_2^+=0}$$

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$$

$Z_L \rightarrow$ Load Impedance

$Z_0 \rightarrow$ Input Impedance

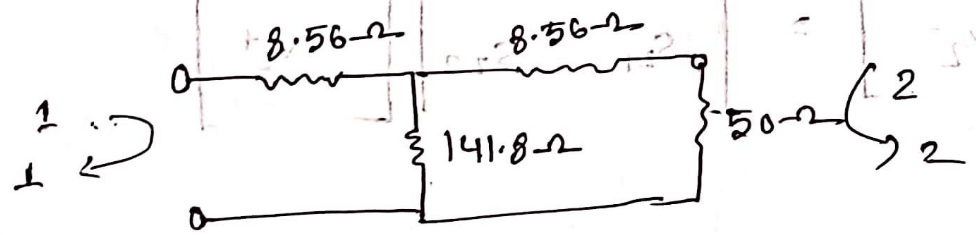
$$= \Gamma(1) \mid V_2^+ = 0$$

$S_{11} = \Gamma$ (reflection coefficient)

$$S_{11} = \frac{Z_{in}(1) - Z_0}{Z_{in}(1) + Z_0}$$

As second port is matched Load, so there is no chance to get any output from port-2

As we matched by 50 Ω load of port-2:-




$$Z_{in} = \{(50 + 8.56) \parallel (141.8)\} + 8.56$$

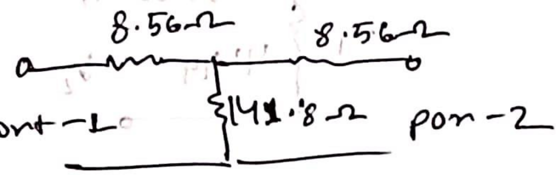
$$= [58.56 \parallel 141.8] + 8.56$$

$$= 50\,\Omega$$

$$S_{11} = \frac{50 - 50}{50 + 50} = 0$$

And also $S_{22} = 0$ (Because of the symmetry of the circuit

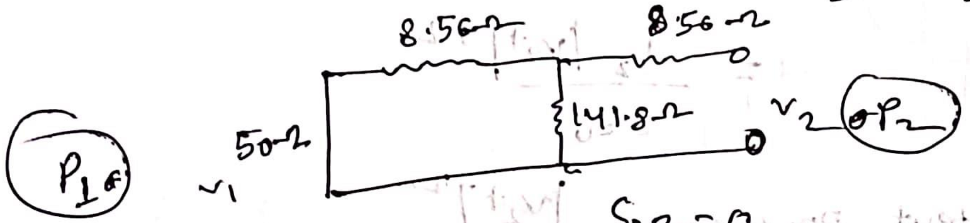
Here, we can say that the device is reciprocal. As from port-1 to port-2 which barrier will be faced from port-2 to port-1 will face the same barrier.




So, $S_{12} = S_{21}$

$$S_{12} = \left.\frac{V_1^-}{V_2^+}\right|_{V_1^+=0} \quad \because V_1 = V_1^+ + V_1^-$$
$$V_1 = V_1^-$$

$$\Rightarrow S_{12} = \frac{V_1}{V_2} \qquad \text{and } \because V_2 = V_2^+ + V_2^-$$
$$V_2 = V_2^+ \quad [\because V_2^- = 0]$$

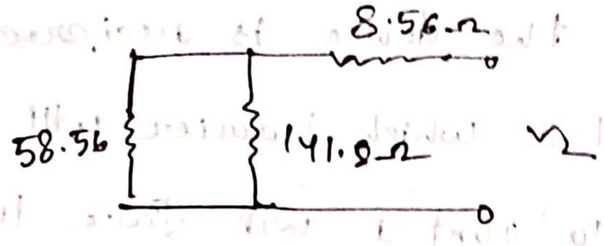


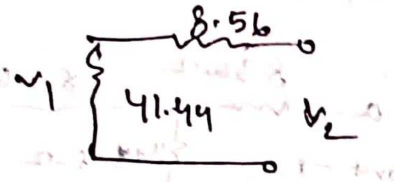

$S_{22} = 0$

As, $S_{22} = 0$ ; so, 2 নং port এ Input দিলে 2 নং পোর্টে Output পাওয়ার কোনো সম্ভাবনা নেই। তেমনি 2 নং পোর্টে ইনপুট দিলে 1 নং পোর্ট থেকে Reflected হয়ে আসারও সম্ভাবনা নাই।

$V_2^- = 0$

→ Quiz P1 → 12
P2 → 13.5




$$V_2 = \left(\frac{41.44}{41.44+8.50}\right) \times V_1 \times \frac{50}{50 \times 8.56}$$

$$V_2 = 0.707\, V_1$$

Input power $\dfrac{|V_2^+|}{2Z_0}$

Output power $= \dfrac{[V_1^-]^2}{2Z_0}$ | $\therefore S_{12} = \dfrac{V_1^-}{V_2^+}$

$V_1^- = S_{12} V_2^+$

$$= \frac{|S_{12} \cdot V_2^+|^2}{2Z_0}$$

$$= \frac{\frac{1}{2}|V_2^+|^2}{2Z_0}$$

$\therefore$ output power $= \dfrac{|V_2^+|^2}{\frac{1}{4}Z_0}$

Output power decreased by 50%

$$S \text{ matrix} = \begin{bmatrix} 0 & 0.707 \\ 0.707 & 0 \end{bmatrix}$$

Freq → min → 1 GHz

max :- 3 GHz

Time :- ns → Monitors :- E-Field, H-Field, Farfield

→ Exp Name

→ ~~Component~~

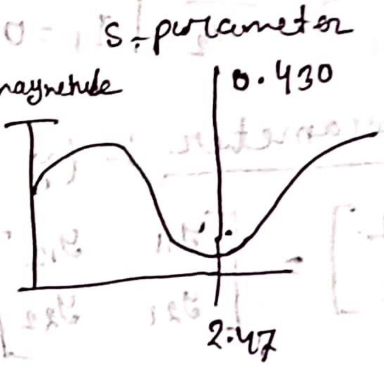
→ Calculation table L = −75   +75

r = 2.5   2.5

x → Axis → 2.5

→ Result Analysis

→ Discussion.




r = 2.5   +75  −75

+10  −10

3 GHz → design → LV → 2.472 GHz → Reflection coefficient

প্রত্যেক লেভেল উপর থাকে

Loss in metals :- 2.4 GHz Loss হয় 0.002206

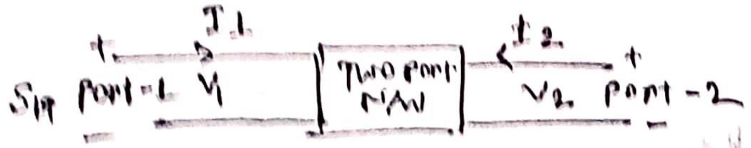
Power Acceptance :-

→ নির্দিষ্ট frequency

0.09

## Finalissima

### S- Matrix




**h-parameter :-**

$$\begin{bmatrix} V_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ V_2 \end{bmatrix}$$

$V_1 = h_{11} \cdot I_1 + h_{12} V_2$ —(1)

$I_2 = h_{21} \cdot I_1 + h_{22} \cdot V_2$ —(2)

$\therefore h_{11} = \frac{V_1}{I_1} \Big|_{V_2 = 0}$ (Short circuit)

$\therefore h_{12} = \frac{V_1}{V_2} \Big|_{I_1 = 0}$ (open circuit) [current = 0]

**y-parameter** :- (y is called as admittance)

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$

$I_1 = y_{11} V_1 + y_{12} V_2$ —(I)

$I_2 = y_{21} \cdot V_1 + y_{22} \cdot V_2$ —(II)

**Z-parameter:** (Represents Information with Impedence)

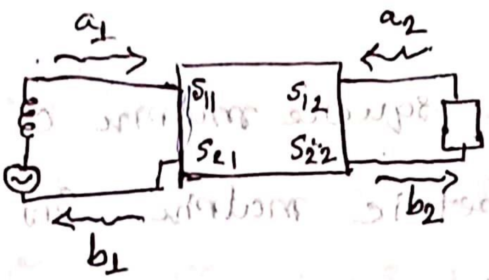
$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} z_{11} & z_{12} \\ z_{21} & z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

ABCD parameters:-

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ -I_2 \end{bmatrix}$$

Limitation of this params:-

1. Equipment is not available to stadily measure E/H instead of V/I.
2. Short circuit & open circuit very difficult to achieve.




S = Reflection coefficient
a = Incident wave
b = reflected wave

nxn port ~~dof~~ device:-

$$\begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1n} \\ S_{21} & S_{22} & \cdots & S_{2n} \\ \vdots & \vdots & & \vdots \\ S_{n1} & S_{n2} & \cdots & S_{nn} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_n \end{bmatrix}$$

(n×1) Reflected wave

(n×n) Scattering Matrix

(n×n) (Incident waves)

$\therefore b_1 = S_{11} \cdot a_1 + S_{12} \cdot a_2 + \dots + S_{1n} \cdot a_n$

$\therefore b_2 = S_{21} a_1 + S_{22} \cdot a_2 + \dots + S_{2n} \cdot a_n$

$\vdots$

$\therefore b_n = S_{n1} a_1 + S_{n2} \cdot a_2 + \dots S_{nn} \cdot a_n$

a = Input to particular port

b = output ~~to~~ from particular port

$S_{ij}$ = Scattering coefficient

(Input at ith port & ~~of~~ output taken from jth port)

$S_{ii}$ → power reflected back from junction

Properties:-

① [S] is always a square matrix of order n×n

② [S] is a symmetric matrix $S_{ij} = S_{ji}$

③ Unitary property / matrix

$$\underbrace{[S]}_{\text{Scattering Matrix}} \cdot \underbrace{[S]^*}_{\text{Complex Conjugate of } [S]} = [I] \rightarrow \text{Identity matrix}$$

Example-1:- The S-Matrix of a two-port network is given by,

$$[S] = \begin{vmatrix} 0.2\angle 0 & 0.9\angle 90 \\ 0.9\angle 90 & 0.1\angle 90 \end{vmatrix}$$

Find given network is lossless & reciprocal.

= $\boxed{\text{Reciprocal}}$ => Transpose করতে হবে [Row → Column, Column → Row] হবে

$$[S]^T = \begin{bmatrix} 0.2\angle 0 & 0.9\angle 90 \\ 0.9\angle 90 & 0.1\angle 90 \end{bmatrix} = [S]$$

As $[S]^T = [S]$ That means give network is reciprocal.

Lossless:- $(Row_{1})^2 + (Row_{2})^2 = 1$ that means lossless

[সব Row এগুলো বের করতে হবে]

we know,

So, $(S_{11})^2 + (S_{12})^2 + (S_{13})^2 + \ldots + (S_{1n})^2 = 1$

So, $(0.2)^2 + (0.9)^2 = 0.85 \neq 1$ [That means it is not lossless network. It is lossy network.

Example-2:-

The S-Matrix of a four-port network is given by,

$$[S] = \begin{vmatrix} 0.1\angle 90 & 0.8\angle 45 & 0.3\angle 90 & 0 \\ 0.8\angle 45 & 0 & 0 & 0.4\angle 45 \\ 0.3\angle 45 & 0 & 0 & 0.6\angle 45 \\ 0 & 0.4\angle 45 & 0.6\angle 45 & 0 \end{vmatrix}$$

Find given network is lossless & reciprocal.

Reciprocal:-

$$[S]^T = \begin{bmatrix} 0.1\angle 90 & 0.8\angle 45 & 0.3\angle 45 & 0 \\ 0.8\angle 45 & 0 & 0 & 0.4\angle 45 \\ 0.3\angle 90 & 0 & 0 & 0.6\angle 45 \\ 0 & 0.4\angle 45 & 0.6\angle 45 & 0 \end{bmatrix} = S$$

So, this is S-matrix. So give network is reciprocal

Lossless:-

- For first row, $(0.1)^2 + (0.8)^2 + (0.3)^2 + (0)^2 = 0.74 \neq 1$

So, the entire network is lossy. Not lossless

---

Ex:-03 The S-matrix of a two-port Network is given by

$$[S] = \begin{vmatrix} 0.15\angle 0 & 0.85\angle -45 \\ 0.85\angle 45 & 0.2\angle 0 \end{vmatrix}$$

Find, ① Network is reciprocal

② Network is Lossless

③ If port 2 is terminated with matched load, find return loss at port-1.

④ If port 2 is terminated with short circuit, find return loss at port-1.

Ans:- Reciprocal

$$[S]^T = \begin{bmatrix} 0.15\angle 0 & 0.85\angle 45 \\ 0.85\angle -45 & 0.2\angle 0 \end{bmatrix} \neq [S]$$

That means it is not reciprocal

(4.11 & 4.21)

(ii) Lossless

$(0.15)^2 + (0.85)^2 = 0.745 \neq 1$

So, this is lossy network

(iii)

Reflection coefficient, $r_1 = \frac{b_1}{a_1}$

Return Loss, $R.L = -20 \log |r_1|$

For two port network,

$b_1 = a_1 S_{11} + a_2 S_{12}$ —— (i)

$b_2 = a_1 S_{21} + a_2 S_{22}$ —— (ii)

If port 2 is terminated $a_2 = 0$,

$b_1 = a_1 S_{11}$

$\therefore S_{11} = \frac{b_1}{a_1} = r_1$

Again from matrix, $S_{11} = 0.15$

$\therefore$ return loss $= -20 \log |0.15|$

$= 16.47$ dB.

(iv) When you terminate port-2 with short circuit,

$a_2 = -b_2$

$\therefore b_1 = a_1 S_{11} \cancel{+ a_2} - b_1 S_{12}$

$\therefore b_2 = a_1 S_{11} - b_2 S_{22} \Rightarrow b_2(1+S_{22}) = a_1 S_{21}$

$\therefore b_2 = \frac{a_1 S_{21}}{1+S_{22}}$

So,

$\Rightarrow b_1 = a_1 S_{11} - a_1 \left( \frac{S_{12} \cdot S_{21}}{1 + S_{22}} \right)$

$\therefore \frac{b_1}{a_1} = S_{11} - \frac{S_{11} \cdot S_{21}}{1 + S_{22}}$

$= 0.15 - \frac{0.85 \times 0.85}{1 + 0.2}$

$= -0.45 = r_1$

$\rightarrow$ Return Loss, $R.L = -20 \log |r_1| = -20 \log |0.45|$

$= 6.93$ dB

Book ex-01 (4.2)

Consider a series RLC circuit with a current I. Calculate the power lost & the stored electric & magnetic energies, and show that the input impedance can be expressed as a

4.17 Certain three-port network is lossless & reciprocal, & has $S_{13} = S_{23}$ & $S_{11} = S_{22}$. Show that if port-2 is terminated in a reactance so that the other two ports (say port-1 & port-2) are decoupled (No power flow from port 1 to port-2, or from port-2 to port-1)

$\Rightarrow$

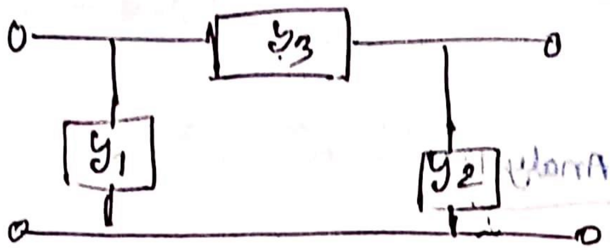
## ☐ Need of Network Analysis:-

→ To design & analyze Microwave circuit
→ To characterize Microwave devices
→ To measure the performance of MW devices
→ To troubleshoot MW problems.
→ To develop new microwave technologies.
→ Signal Integrity
→ To power Transfer
→ Frequency Domain Analysis.
→ Filter Design
→ Antenna ~~design~~ tunning.
→ System Stability & Reliability.

☐ (i) Although there are Z & Y matrices available, why do we need S-matrix?
(ii) Need of S-Matrix :-

Ans:- Z & Y matrices are used in high frequencies to calculate while the S-matrix is used to calculate the microwave Analysis.
S-matrix is also used to determine the reflection co-efficient & transmission gain from both sides of a two ~~poet~~ port network. So, we need S-matrix

## Derive ABCD Matrix:-




$$I_1 = y_{11} V_1 + y_{12} V_2$$

$$I_2 = y_{21} V_1 + y_{22} V_2$$

$$V_1 = A V_2 - B I_2$$

$$I_1 = C V_2 - B I_2$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \frac{-y_{22}}{y_{21}} & \frac{-1}{y_{21}} \\ \frac{-\Delta y}{y_{21}} & \frac{-y_{11}}{y_{21}} \end{bmatrix}$$

$$[-\Delta y = y_{12} \cdot y_{21} - y_{11} y_{22}]$$

$$A = \frac{-y_{22}}{y_{21}} = \frac{-(y_2+y_3)}{-y_3} = 1 + \frac{y_2}{y_3}$$

$$B = \frac{-1}{y_{21}} = \frac{-1}{-y_3} = \frac{1}{y_3}$$

$$C = \frac{-\Delta y}{y_{21}} = \frac{y_{12} \cdot y_{21} - y_{11} \cdot y_{22}}{y_{21}}$$

$$= \frac{(-y_3)(-y_3) - (y_1+y_3)(y_2+y_3)}{-y_3}$$

$$= \frac{y_1 y_2 + y_1 y_3 + y_2 y_3}{y_3}$$

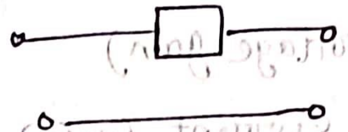
$$= \frac{y_3\left(\frac{y_1 y_2}{y_3} + y_1 + y_2\right)}{y_3}$$

$$= \cancel{y_1 + y_2 + \frac{y_1 y_2}{}}$$

$$= y_1 + y_2 + \frac{y_1 y_2}{y_3}$$

$$D = \frac{-y_{11}}{y_{21}} = \frac{-(y_1+y_3)}{-y_3} = 1 + \frac{y_1}{y_3} \text{ (Ans)}$$

Derive ABCD matrix for Fig-1



$$\Rightarrow \begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix}$$

Then, $A = \dfrac{V_1}{V_2} \Big|_{I_2 = 0}$

Which indicates that A is found by applying a voltage Vi at port-1, and measuring the open circuit voltage $V_2$ at port-2, Thus $\cdot A = 1$

Then, $B = \dfrac{V_1}{I_2} \Big| V_2 = 0 = \dfrac{V_1}{V_1/2} = Z$

$C = \dfrac{I_1}{V_2} \Big| I_2 = 0 = 0$

$D = \dfrac{I_1}{I_2} \Big| V_2 = 0 = \dfrac{I_1}{I_1} = 1$

What are the meaning of ABCD ? And how to Calculate this?

=> ABCD matrix usually refers to a mathematical representation used in electrical engineering such as two port networks.

A-Transmission (Forward voltage gain):-

B- Transmission (Reverse voltage gain)

C- Transmission (Forward current Gain)

D- Transmission (Reverse current Gain)

$\begin{bmatrix} A & B \\ C & D \end{bmatrix}$ → This is how ABCD matrix looks like.

To calculate this we use circuit Analysis techniques.

The values can depend on the specific characteristics within the network, such as resistors, capacitors & inductors.

In the content of transmission Lines, the ABCD matrix is determined by the characteristic impedance & propagation constant of the TL.

Q) Why we need ABCD matrix while we have S-matrix?

➔ Both are important. And have ~~usage~~ useage.

The use of these ~~are~~ depends on the specific characteristics of the electrical network & the nature of the analysis you are performing.

The ABCD matrix is often preferred for simpler circuit analysis & transmission line Applications while the S-matrix is powerful in the ~~context~~ content of MW Engineering & when dealing with multi-port networks.

Q) How to calculate S-Matrix value? $S_{ij}$ equation meaning?

⇒ S-matrix used to describe the relationship between the incident & reflected waves at each port of a linear network.

$$[S] = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}$$

$$S_{R} = \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_n \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1n} \\ \vdots & & & \\ & & \cdots & S_{nn} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_n \end{bmatrix}$$

$S_{ij}$ ⇒ Here i means where incident wave is originates.

Here j, ~~takes~~ means where the wave is reflected.

Examples - $S_{12}$ → Here Input is at port 1 & Output is at port 2.

[1] Reciprocal, Lossless, Matched at all ports & what does that means?

=) **Reciprocal**:- This device transmits power in both directions equally.

$$[S] = [S]^T$$

Row - column change করার পরও same থাকলে Reciprocal $S_{12} = S_{21}$ — $S_{13} = S_{31}$ - - -

**Lossless**:- Lossless হলে unitary হতে হয়। That means the device does not dissipate (বিনষ্ট) any power.

$(Row)^2 = 1$ if all values of a row in the matrix $\neq 1$ then it will be a lossy device.

**Matched**:- The impedance of each port is equal to the characteristic impedance of the transmission line that is connecting the device to the rest of the system.

# Antenna

① What is Antenna? Modes of Antenna

=> The thing which converts Radio Frequency into Electrical Energy & converts Electrical Energy into Radio Frequency. It also can transmit & Receive signals.

Mode of Antenna:-

(1) TEM Mode (Transvery Electromagnetic Mode):-

=> Both electric & magnetic fields are transverse to the direction of propagation.

(2) TE Mode (Transverse Electric Mode) & TM mode (Transverse Magnetic

(3) HE Mode (Hybrid Electric Mode)

(4) Resonant Modes

(5) Higher-order Modes.

② Losses in an Antenna:-

(i) Conductor dielectric loss:- If there are space ~~difference~~ in between two antennas that means it is dielectric loss.

(ii) Impedance mismatch Loss:- Depends on the design. Antenna এর impedance & Transmission Line এর impedence mismatch.

(iii) Material Loss:- It is material based thing, so any Loss in material will create this.

(iv) Polarization mismatch loss:- When the polarization of the transmitted & received signals does not match.

(V) Propagation & Atmospheric Losses.

(Vi) Ground & Environmental absorption.

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(3) Antenna efficiency, Total efficiency, radiation efficiency.

⇒ Antenna efficiency:- Measure of how well an antenna converts the input power from the transmitter into radiated electromagnetic waves.

$$e_0 = e_r e_c e_d$$

$e_0$ = Total efficiency

$e_r$ = Reflection (mismatch) efficiency

$e_c$ = Conduction efficiency

$e_d$ = dielectric efficiency

Total efficiency:-

It includes not only the radiation efficiency but also considers the losses in the entire communication system.

Radiation efficiency:- Specifically focuses on the losses associated with the radiation process. A measure of how effectively the antenna radiates electromagnetic waves, & often expressed as a percentage.

(4) Works of Antenna:- 3 works:-
(i) RW receive & Transmit
(ii) Freespace wave কে direction দেয়
(iii) wave কে Radiate করে

(1) Wireless Communication

(i) Cellular Networks:- Antennas used in base station

(ii) Wi-Fi Networks:- Antennas are employed in routers.

(iii) Bluetooth & Zigbee

(2) Broadcasting

(i) TV & radio

(3) (ii) Satellite Communication:-

(i) Ground Station

(4) Radar Systems:-

(i) Air Traffic Control Radar.

(ii) Automotive Radar

(5) Radio Frequency Identification

(6) Wireless Sensor Networks.

(5) Antennas parameters value depends on the application

⇒ Depends on the application. Some key parameters are given below:-

(1) Radiation pattern:- Mathematical function or graphical representation of the radiation properties of an antenna describes how it distributes radio waves in space. 3 Types

(2) Gain (i) Isotropic Antenna:- সবদিকে radiation সমান

(ii) Omnidirection Antenna:- x, y এ same। Z axis এ যত যাবে তত কমবে।

(iii) Directional pattern! - এক Direction এ ভালো বা নির্দিষ্ট লাভে ভাল ভালো কাজ করে না।

2) Gain :- Determines the antennas ability to focus or concentrate its radiation in a particular direction.

There are two types:- High distance!- use in Satellite
Low " :- Used for local wireless.

(3) polarization!- Antennas can be polarized vertically, Horizontally, circularly etc.

The polarization of antenna should match the polarization of signals.

Example!- Linear polarization is common in terrestrial wireless communication, circular polarization is used in satellite communication. (Importance)

(4) Impedance :- Antenna impedance should match the impedance of TL & to minimize the signal loss.

## (7) Half power beam width / Antenna beam width:-
(HPBW)

Antenna beam width is an angular beam width in degree measure on radiation pattern between the points where radiated power has fallen half.

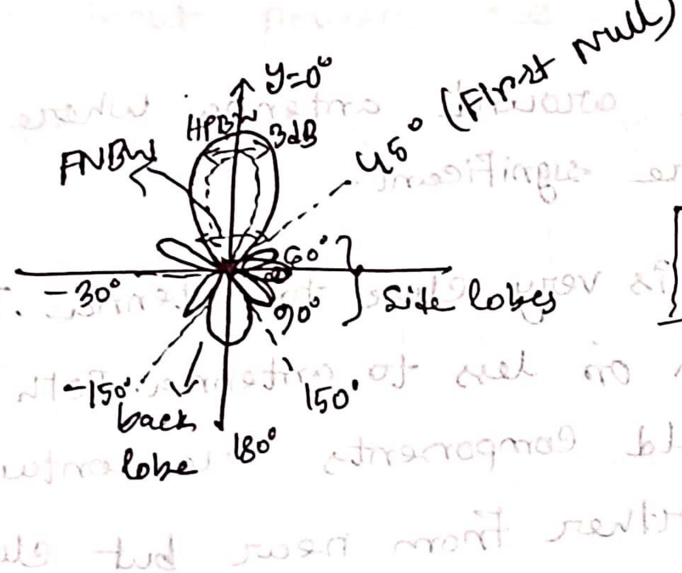
If it is directional then there will be a major lobe.

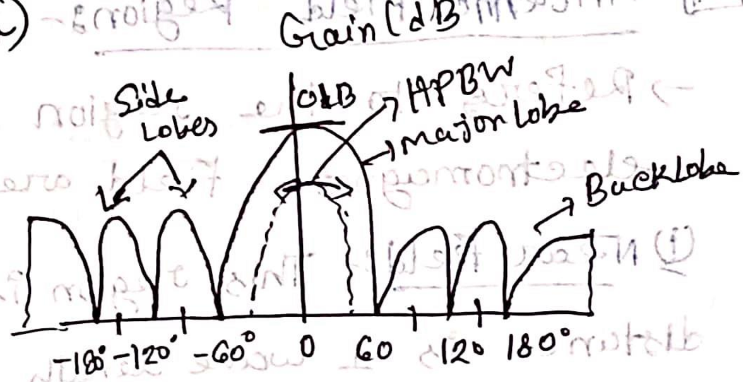
And the lobe of opposite part (180° opposite) Back lobe.

And all lobe except major lobe are minor lobe.

And the lobe inside the minor lobe which carries the most power is called as side lobe.

Side lobe needs to be reduced to forget all other minor lobe.



(8) Radiation Lobes/Antenna Lobes:-

4 types:-

(i) Main Lobe:- primary & most significant lobe. It contains highest level of radiated energy.

(2) Minor Lobe:- Any radiation lobe other than the main lobe.

(3) Side Lobe:- Additional lobes in the radiation pattern that are not as strong as main lobe. These can be uncounted for some application.

(4) Back lobe:- It is situated in the opposide (180° opposite) of the major lobe. It is called as back lobe.

[9] Antenna Field Regions:-

→ Refers to the region around antenna where its electromagnetic field are significant.

(i) Near field:- This region is very close to antenna. The distance is 1 wave length or less to antenna. Both electric & magnetic field components are contained.

(ii) Radiating Near Field:- Farther from near but closer than far field. Distance is 2 wavelength from antenna.

(iii) Far Field:- Greater than few wavelength from antenna. The field components are essentially transverse.

## (10) Directivity :-

Ratio of radiation power/ intensity in a given direction from the antenna to the radiation intensity avg over all direction.

$$D' = \frac{U_{given\ direction}}{U_{avg\ overall\ direction}}$$

Average Radiation intensity,

$$U_{avg} = \frac{P_{rad}}{4\pi}$$

Directivity, $D = \frac{4\pi U}{P_{rad}}$

max directivity ; $D_{max} = \frac{4\pi U_{max}}{P_{rad}}$

## (11) Antenna efficiency :-

~~Rea~~ Ratio of the radiated power of the antenna to the input power accepted by Antenna.

$$\text{Antenna efficiency} = \frac{\text{Radiated power}}{\text{Input power}} \times 100\%$$

Total efficiency, $e_o = e_c\, e_d\, e_r$

Radiation efficiency, $e_r = \frac{e_o}{e_c\, e_d}$

## (12) Gain of an Antenna :-

(আগে আছে)

$$\text{Efficiency} = \frac{\text{Gain}}{\text{Directivity}}$$

## (13) Difference between gain & directivity:-

| | Gain | Directivity |
|---|---|---|
| Definition | measure of an antenna's ability of how well the antenna converts input power into radio waves headed in a specific direction. | → Ability of an antenna to focus energy in a particular direction. |
| Units | Decibels over Isotropic (dBi) | Unitless |
| Relationship | Gain = efficiency × Directivity | Directivity is a component of gain. |
| | Gain is used in characterizing the effective range. | point to point communication on radar |
| | Ex:- parabolic dish antenna | Ex:- Patch antenna |

## (14) Antenna BW Classification:-

Narrow Band :-
- → Less than 3 MHz
- → High Gain
- → Narrow Beam width
- → Vertical / Horizontal polarization
- → usage in low traffic.

(2) BroadBand:-

→ 3 to 30 D MHz
→ Medium gain
→ Medium Beam width
→ vertical & Horizontal polarization
→ usage medium

(3) Widthband:-

→ 300 MHz to 3 GHz
→ Low gain
→ wide beam width
→ vertical / Horizontal polarization
→ High

(4) Ultra-wide Band:-

→ Greater than 3 GHz
→ Gain very low
→ ultra wide beam width
→ vertical / Horizontal
→ very High

pdf:- Microtubes

→ ~~7~~ (13.2) → multi cavity
→ 13.3 (Reflex Kilestone)
→ 5 No. page (Transit Time ~~point~~)
→ Magnetron (13.4)
→ TWT Foundations