Refference : Microwave Engineering — David M Cozer 4th ed

Date – 29.02.24

Microwave frequency – [300MHz – 300GHz]
— [3GHz – 300GHz]

wavelength — [1m – 1mm]
– [3 GHz – 30 GHz]

* why are microwave frequencies are in much interest

– advantages:
  – Bandwidth and capacity
  – Antenna size.

suppose,
we need to transmit 4KHz voice signal through a wireless link.
lets assume that we have two wireless system to choose from one, operating at 500MHz and the second at 4GHz; each with a 10% bandwidth arou its capacity.

$$\text{Number of channels} = \frac{\text{operating frequency} \times \text{percent BW}}{\text{BW per channel}}$$

BW = Bandwidth

$$= \frac{0.5\,GHz \times 0.1}{4\,KHz} = 12,500$$

$$\therefore \text{Number of channels} = \frac{4GHz \times 0.1}{4KHz} = 100,000$$

· frequency বৃদ্ধি করলে capacity বাড়ে।

Another adv—

small size antenna বানাতে হলে frequency বাড়াতে হবে।

— Higher Bandwidth. [Article — 1.1 (table) fig — 1.1 (Band name)]

circuit Theory Vs EM field theory

50Hz এর frequency — device — AC current

Microwave device — structure বড়। wavelength ছোট। | Em field (microwave এর বিপরীত

lumped parameter — structure এর তুলনায় wave length বড়।

distributes parameter — structure এর সাপেক্ষে wave length ছোট, পরিবর্তিত current/voltage পাও

* General electric circuit — Transistor, FET, MOSF
* Microwave circuit element — Diode, Tunnel diode, varactor diode.
* Distributed " " " — Isolator, circulator, atunne
* Kryston Oscillator — microwave
  - Magnator "
  - TWT "
* Antenna converter.

- compare between electrical circuit and microwave circuit.

= frequency বেশি হলে transmission Line এর wavelength এর কী পরিবর্তন ঘটে?

* microwave heating কীভাবে generate করে

Adv- of ~~free~~ Antenna size (smaller)

— frequency $f = 300\,MHz$

$$\lambda = c/f$$
$$= \frac{3\times10^8}{300\times10^6} = 1\,m$$

[marconny antenna স্থাপন করেছিল]

Beamwidth $= 100^\circ$

Diameter $D = 140\times\frac{\lambda}{B}$

$$= 140^\circ \times \frac{1}{100^\circ}$$

$$= 1.4^\circ$$

second secenario

$$f = 30\,GHz$$

$$\lambda = c/f = \frac{3\times10^8}{30\times10^9} = 0.01$$

$$D = 140\times\frac{0.01}{100^\circ}$$
$$= 0.014^\circ$$

— Application of microwave (Art-1.1- Page-3)

* Microwave Engineering - কীভাবে signal generate করবে।

Lab-01

07.03.24

Ex-01: study of microwave Laboratory components

Lumped parameter

70
— Lab test — 30
— 11 Report — 20
— Quiz — 20

30
attendance — 10
viva — 20

Front page এ Ex. Name লিখবে।

— Objective হবে ৩টা

1.
2.
3.

— Theoritical background

— Apparatus required

— Experimental ~~ste~~ setup: circuit with procedure

— Experimental data

— Result analysis

— Disscussion [Objective fulfill হয়েছে কিনা]

Test Bench [NVIS 9000]

Lecture-2

07.03.24

* several application of Microwave Engineering

difficulties:

1. voltage is not well defined [electrical small circuit এর টুকরো বাদ হলে সেইম voltage পাবো]
2. More expensive components
3. One must carefully choose lumped ~~circuit~~ elements
4. To transmit electrical signals from one position to another.

* Maxwell Equation [Art-1.2]

$$\nabla \times \vec{E} = \frac{-\partial \bar{B}}{\partial t} - \bar{M} \quad \text{(i)}$$

$$\nabla \times \vec{H} = \frac{-\partial \bar{D}}{\partial t} + \bar{J} \quad \text{(ii)}$$

$$\nabla \cdot \bar{D} = \rho \quad \text{(iii)}$$

$$\nabla \cdot \bar{B} = 0 \quad \text{(iv)}$$

$\bar{M}$ - magnetic current density

$\bar{J}$ - Electric current density

$\bar{E}$ = electric field

$\bar{H}$ - magnetic field

$\bar{D}$ = electric flux density

ρ = electric charge density.

* $\boxed{\text{Adv of Maxwell Equation}}$

$\bar{B} = \mu_0 \bar{H}$

$\bar{D} = \epsilon_0 \bar{E}$

$\mu_0 = 4\pi \times 10^{-7}$ henry

ϵ_0 = permittivity

(ii) ⇒

$$\nabla \cdot \nabla \times \bar{H} = \frac{\partial}{\partial t}(\nabla \cdot D) + \nabla \cdot J$$

$$\Rightarrow 0 = \frac{\partial \rho}{\partial t} + \nabla J$$

$$\nabla \cdot J + \frac{\partial \rho}{\partial t} = 0$$

* Amphere's Law

* Stocks theory

$$\oint_c \bar{E} \cdot d\bar{l} = -\frac{\partial}{\partial t}\int_s \bar{B} \cdot d\bar{s} - \int_s \bar{M} \cdot d\bar{s}$$

$$\oint_c \bar{H} \cdot d\bar{l} = \frac{\partial}{\partial t}\int_s \bar{D} \cdot d\bar{s} + \int_s \bar{J} \cdot d\bar{s} = \frac{\partial}{\partial t}\int_s \bar{D} \cdot d\bar{s} + I$$

$$\frac{\partial}{\partial t} \to j\omega$$

time domain — frequency domain.

— $\nabla \times \bar{E} = -j\omega\bar{B} - \bar{M}$

— $\nabla \times \bar{H} = j\omega\bar{D} + \bar{J}$

— $\nabla \cdot \bar{D} = \rho$

— $\nabla \cdot \bar{B} = 0$

$$E(x,y,z,t) = Re\left[\bar{E}(x,y,z)e^{j\omega t}\right]$$

$$\nabla \times \bar{E} = \frac{-\partial\bar{B}}{\partial t} - \bar{M}$$

$$\nabla \times \bar{E}(x,y,z,t) = \frac{-\partial\bar{B}}{\partial t}(x,y,z,t) - M(x,y,z,t)$$

$$\nabla \times E(x,y,z)e^{j\omega t} = \frac{-\partial}{\partial t}\bar{B}(x,y,z)e^{j\omega t} - M(x,y,z)e^{j\omega t}$$

$$e^{j\omega t}\left[\nabla \times E(x,y,z)\right] = -\bar{B}(x,y,z)(j\omega \cdot e^{j\omega t}) - \bar{M}(x,y,z)$$

$$\nabla \times \bar{E}(x,y,z) = -j\omega B(x,y,z) - M(x,y,z)$$

Home work

— The importance of Maxwell equation
— Microwave এ equation টর কোন প্রয়োজন,
কোন wave এর ক্ষেত্রে use করাবো,
— Different notation of maxwell equation
OR, কোন কোন equation এ তা Represent করতে পারি,
Art -[1.2, 1.3- fields in media and...]

Micro lab - 2

Precaution

1. Main power supply এর আগে knob minimum position এ থাকতে হবে, 'HT' should be 'OFF' before switching 'ON' the main supply.

11. Beam knob should be anticlockwise and repeller voltage knob should be clockwise.

111. switch on the main supply and some warm up time to get current.

iv. Fans use করা হয় to make the power supply cool down.

v. ON and off button press করার পূর্বে KNOB minimum position এ রাখতে হবে,

vi. Don't increase the repeller voltage more than -70V. It should be between -70V to -270V

Ex-2:

Study of the characteristics of kryston tube and to determine its electronic tunning range.

- modulation ছাড়া signal কোন কাজের না, সেটা আমাদের বের করতে হবে,
- front panel control

objective

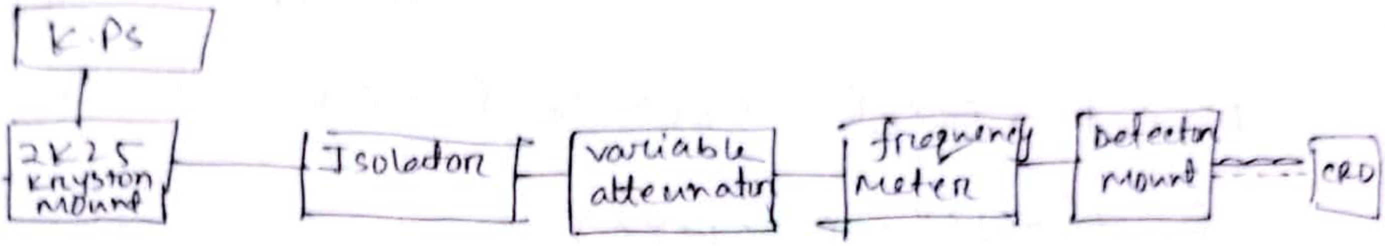
- Apparatus required
  1. kryston power supply
  2. kryston tube with kryston mount
  3. Isolator
  4. frequency meter
  5. variable attenuator
  6. Detector mount.

Theory-

Principle of operation.

— square wave operation

Experimental setup

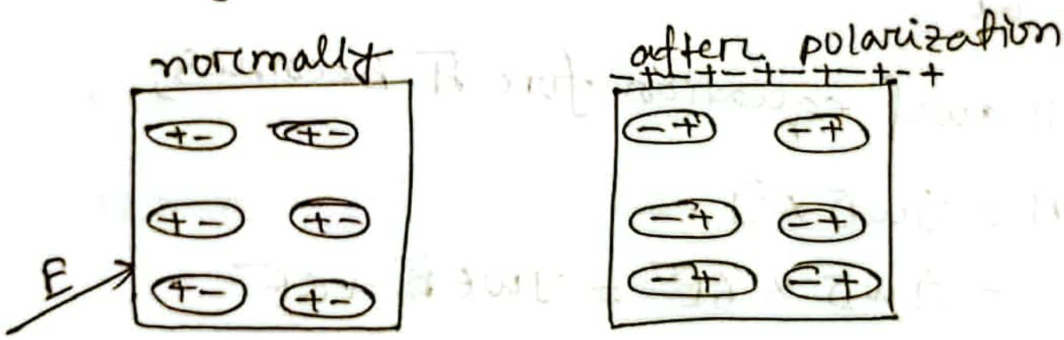


Lecture-3

21.03.24

Art-1.3 [fields in media]

Piece of dielectric material



Any piece of dielectric material has dispoles that are randomly distributed. When an electric field is passed through this material polarization occurs.

$$D = \epsilon_0 \bar{E} + \bar{P}_e \quad [\because \bar{P}_e = \text{electric polarization}]$$

In Linear medium,

$$\bar{P}_e = \epsilon_0 \chi_e \bar{E} \quad [\because \chi_e = \text{electric susceptibility}]$$

$$\bar{D} = \epsilon_0 \bar{E} + \epsilon_0 \chi_e \bar{E} = \epsilon_0 (1+\chi_e)\bar{E} = \epsilon \bar{E}$$

$$\epsilon = \epsilon' - j\epsilon'' = \epsilon_0 (1+\chi_e)$$

The imaginary part of $(j\epsilon'')$ represents loss in the medium due to damping of the vibrating dipole moments

In material with conductivity σ, a conduction current will exists.

$$\bar{J} = \sigma \bar{E}$$

From maxwell curl equation for $\bar{H}$ becomes;

$$\nabla \times \bar{H} = j\omega \bar{D} + \bar{J}$$

$$= j\omega \bar{D} + \sigma \bar{E} = j\omega\epsilon \bar{E} + \sigma \bar{E}$$

$$= j\omega\epsilon' \bar{E} + (\omega\epsilon'' + \sigma)\bar{E}$$

$$= j\omega \left(\epsilon' - j\epsilon'' - j\frac{\sigma}{\omega}\right)\bar{E}$$

$$= j\omega \epsilon_0 \epsilon_r (1 - j\tan\delta)\bar{E}$$

where, $\tan\delta = \dfrac{\omega\epsilon'' + \sigma}{\omega\epsilon'}$ represents loss tangent.

Two types of loss
- conduction loss (σ)
- Di-electric loss ($J\epsilon''$)

conductor loss, $\tan\delta = \frac{\sigma}{\omega\epsilon'}$

Anisotropic material:

The direction of polarization is not the same as E.

example:

crystals, ionized gas — electric anisotropic material

example:

ferrites — Magnetic Anisotropic material

P_e = electric polarization

P_m = magnetic "

E = Electric "

H = magnetic "

P_e, E

Direction similar — Isotropic

" not similar — Anisotropic

Electric
$$\begin{bmatrix} D_x \\ D_y \\ D_z \end{bmatrix} = \begin{bmatrix} \epsilon_{xx} & \epsilon_{xy} & \epsilon_{xz} \\ \epsilon_{yz} & \epsilon_{yy} & \epsilon_{yz} \\ \epsilon_{zx} & \epsilon_{zy} & \epsilon_{zz} \end{bmatrix} \begin{bmatrix} E_x \\ E_y \\ E_z \end{bmatrix} = [\epsilon] \begin{bmatrix} E_x \\ E_y \\ E_z \end{bmatrix}$$

$\boxed{D = \epsilon E}$ $\boxed{B = \mu H}$

Similarly,

Magnetic, $\begin{bmatrix} B_x \\ B_y \\ B_z \end{bmatrix} = \begin{bmatrix} \mu_{xx} & \mu_{xy} & \mu_{xz} \\ \mu_{yx} & \mu_{yy} & \mu_{yz} \\ \mu_{zx} & \mu_{zy} & \mu_{zz} \end{bmatrix} \begin{bmatrix} H_x \\ H_y \\ H_z \end{bmatrix} = [\mu] \begin{bmatrix} H_x \\ H_y \\ H_z \end{bmatrix}$

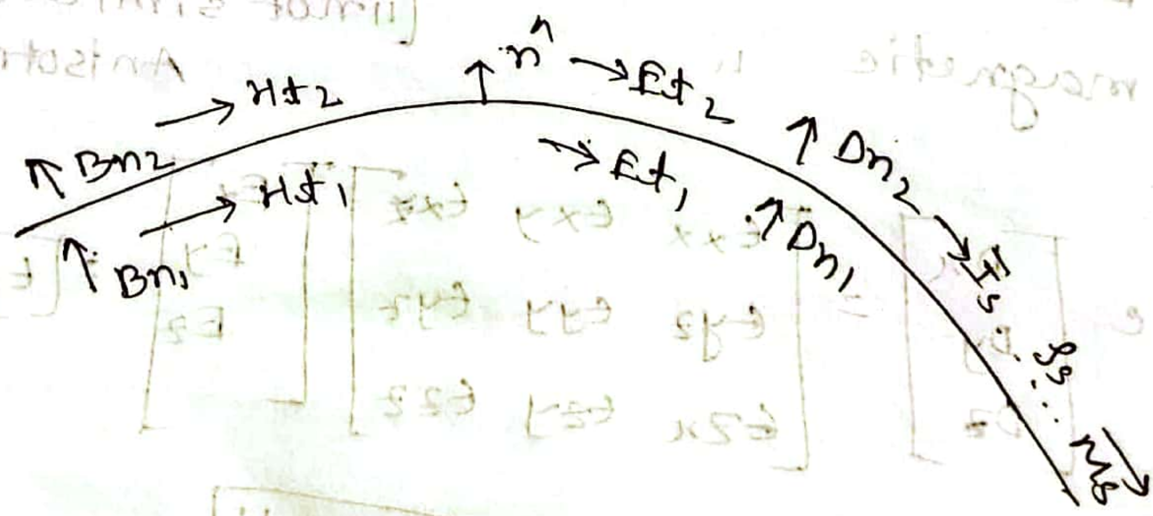
Example :

Anisotropic material, $\epsilon = \epsilon_0 \begin{bmatrix} 1 & -2j & 0 \\ 2j & 3 & 0 \\ 0 & 0 & 4 \end{bmatrix}$

$E = 2\hat{x} + 3\hat{y} + 4\hat{z}$, what is $\bar{D} = ?$

Boundary condition :

- Medium 2 : ϵ_2, μ_2



Medium 1: ϵ_1, μ_1

$$\hat{n} \cdot (\bar{D}_2 - \bar{D}_1) = \rho_s$$

$$\hat{n} \cdot \bar{B}_1 = \hat{n} \cdot \bar{B}_2$$

$$(\bar{E}_2 - \bar{E}_1) \times \hat{n} = \bar{M}_s$$

$$\hat{n} \times (\bar{H}_2 - \bar{H}_1) = \bar{J}_s$$

Boundary conditions at a dielectric interface,

$$\rho_s = 0$$

$$J_s = 0$$

Conditions:

$$\left.\begin{aligned} \hat{n} \cdot \bar{D}_1 &= \hat{n} \cdot \bar{D}_2 \\ \hat{n} \cdot \bar{B}_1 &= \hat{n} \cdot \bar{B}_2 \end{aligned}\right] \text{Normal flux density is continuous}$$

$$\left.\begin{aligned} \hat{n} \times \bar{E}_1 &= \hat{n} \times \bar{E}_2 \\ \hat{n} \times \bar{H}_1 &= \hat{n} \times \bar{H}_2 \end{aligned}\right] \text{Tangential field intensity is continuous.}$$

→ Boundary conditions at the interface with a perfect conductor.

→ Boundary conditions at the Interface with a magnetic wall.

H.W — Lecture-4 — 21.03.24

1.4

- The wave eqn and basic plane wave solution
- The helmholtz equation
- plane weave in a lossless medium.

Exp-1.1

plane waves in a general lossy medium.

plane " " " good conductor.

Example-1.2

Chap-2

- T-Line Theory

Whether the simple circuit law's may be used depends on the size of our circuit in relation to the wavelength corresponding to the operating frequency

$\lambda = c/f$

The relation between wave-length and the operating frequency.

- If the size of the circuit (or element) in question is much smaller that the operating wavelength ($\lambda/100$ or smaller), the simple circuit laws apply. In such as case, we say that the elements of the circuit are "Lumped" elements.

- If the size of the circuit question is comparable to that of the operating wavelength ($\sim \lambda/10$ to λ), the simple circuit laws do not apply. In such case, we say that the elements of the circuit are "distributed" elements.

Lumped: Resistor, capacitor

Distributed: T-lines.

Art (2.1)

- TEM fields (Transverse electromagnetic fields)

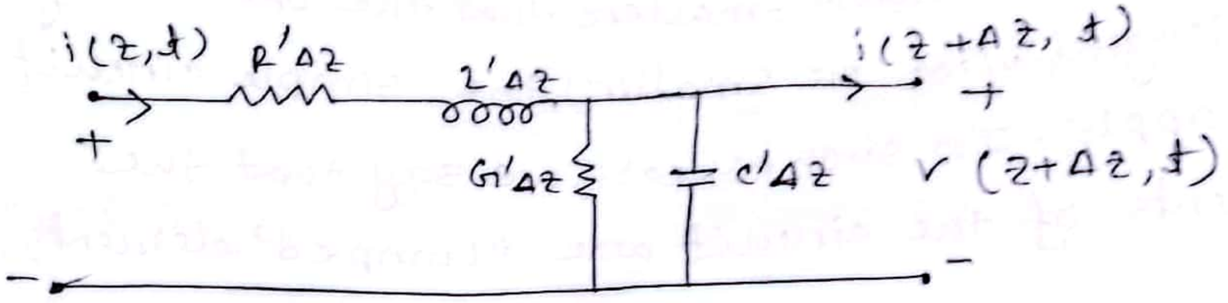
- RLGC model

conduction current
- R' - series resistance (Ω/m)
- L' - " inductance (H/m)

Displacement current
- G' - shunt conductance (S/m)
- C' - " capacitance (F/m)

[R' and G' represent loss in circuit]

Generic equivalent-circuit model:



— After applying KVL, governing equation for $v(z,t)$:

$$v(z,t) = v(z+\Delta z, t) + i(z,t)R'\Delta z + L'\Delta z\,\frac{\partial i(z,t)}{\partial t} \quad \text{— 1(a)}$$

$$\Delta v = v(z+\Delta z, t) - v(z,t)$$
$$= -i(z,t)R'\Delta z - L'\Delta z\,\frac{\partial i(z,t)}{\partial t}$$

— For current $i(z,t)$, apply KCL at Node A

$$i(z,t) = i(z+\Delta z, t) + v(z+\Delta z, t)G'\Delta z + C'z\,\frac{\partial v(z+\Delta z, t)}{\partial t} \quad \text{— 1(b)}$$

Divide 1(a) and 1(b) by Δz and taking the limits $\Delta z \to 0$

$$\frac{\partial v(z,t)}{\partial z} = -R'\,i(z,t) - L'\,\frac{\partial i(z,t)}{\partial t}$$

$$\frac{\partial i(z,t)}{\partial z} = -G'v(z,t) - C'\,\frac{\partial v(z,t)}{\partial t}$$

These are called 'Telegrapher equ...
'T-line equations'

$$\frac{\partial V z}{\partial z} = -(R + j\omega L) I(z) \quad (2.3a).$$

$$\frac{\partial I(z)}{\partial z} = -(G + j\omega C) V(z) \quad (2.3b)$$

Transmission line এর parameter দ্বারা সমন্বয়। I ও V এর মান,

[Art - 2.1, 2.2, 2.3]

CT - chap - 1

chap - 2 (2.1, 2.2, 2.3)

Lect-5 (online) 23.04.24

(2.2a) (2-2b) equation

↓

solution

(2.3a) (2.3b)

Wave propagation on a Transmission Line:

$$(2.4a) \quad \frac{d^2 V(z)}{dz^2} - \gamma^2 V(z) = 0$$

$$(2.4b) \quad \frac{d^2 I(z)}{dz^2} - \gamma^2 I(z) = 0$$

$\gamma \rightarrow$ complex propagation

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

$$V(z) = V_0^+ e^{-\gamma z} + V_0^- e^{\gamma z} \quad (2.6a)$$

$$I(z) = I_0^+ e^{-\gamma z} + I_0^- e^{\gamma z} \quad (2.6b)$$

সামনের দিকে যে wave যাবে তা forward voltage/wave — V_0^+

বিপরীত দিকে বাধাপ্রাপ্ত wave — Reflected wave — V_0^-

$$Z_0 = \frac{R + j\omega L}{\gamma} = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \quad (2.7)$$

$\downarrow$

Characteristic Impedence

The reflection co-efficient

$$(2.8) \quad \frac{V_0^+}{I_0^+} = Z_0 = \frac{-V_0^-}{I_0^-}$$

[direction বুঝাচ্ছে]

[impedence কখনো negetive হয় না]

$$(2.9) \quad v(z,t) = |V_0^+| \cos(\omega t - \beta z + \phi^+) e^{-\alpha z} + |V_0^-| \cos(\omega t + \beta z + \phi) e^{\alpha z}$$

$$(2.11) \quad v_p = \frac{\omega}{\beta} = \lambda f$$

একটি transmission line draw করা হয়,

The lossless line [transmission line absolutely lossless হয় না]

R, G → lossless কে represent করে,

attenuation const zero.

(2.13)

low loss transmission line :

condition :

Distortion less line (যেন use করবো তা জেনেও হবে)

Art - 2.7

lossy transmission line (low loss distortion)

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

Homework —

Ex - 2.6 $R/L = \frac{G}{C}$

Art - 2.88

Art - 2.7

Ex - 2.1

Next class — Art 2.2 (Field Analysis)

Art - 2.3 — The terminated lossless Transmission Line

Lect-6 24.04.24

2.2 Field Analysis of transmission line.

* telegrapher equation

(2.18)
(2.19)
(2.20)] Fig-2.3

Example-2.1

Table-2.1

How to calculate the permutance of co-axial cable

Art-2.3 The terminated lossless transmission line

Fig-2.4

β = phase constant

* Reflected wave
  Eq (2.34a) (2.34b)
  eq (2.35)

* standing still wave

Vmax, Vmin থাকবে।

matched condition
$\gamma = 0$ হলে
there is no reflected wave,
voltage এর min, max থাকে না

~~un~~ mismatche condition
$\gamma = 1$ হলে
load এর ভিতরে আসার
Z_L ও Z_0 এর মান সমান না হলে। $Z_L \neq Z_0$

(2.37), (2.38) → matched Loss পাবো,

Reflection হবেনা standing wave পাবো,

তার (2.39)

(2.40a), (2.40b), (2.41)

SWR = Min 1, max ∞

* Γ এর মান শূন্য হলে,

$\lambda/2$, two successive minimum

* SWR এর মান বেশি নাকি কম হলে ভালো?

Homework – 2.42

(2.43) (2.44)

Lec-7 25.4.24

Minimum impedence হলে max voltage পাবো,

eq (2.43) (2.44)

* Special case

* terminated in short circuit

short করলে,

$V = 0, I = \infty$

R_L, Z_L, I_L, V_L [বের করবো]

(2.45c) Fig-2.6, 2.7

transmission line in open circuit

$I = 0 \quad V = \infty \quad Z_L = \infty$

eq(2.44), (2.46c) (2.47) (2.48)

$Z_{in} = Z_L \qquad Z_{in} = \frac{Z_0^2}{Z_L}$

— Transmission co-efficient

(2.49)

(2.50b) . (2.51) (2.52)

Desible থেকে NP তে convert
vice-versa

* smith chart.

<u>Lect-8</u> 28-4.24

* construction of smith chart
* smith chart parametric Equation

বই: How this resistance circle created
" " reactance " "

* complete the smith chart

$Z_L = (300 - j25)\,\Omega$

$Z_0 = 50\,\Omega$

$Z_L' = (300/50 - j\,25/300)\,\Omega$

$= (6 - j0.5)\,\Omega$

$\uparrow_R$ $\uparrow_X$ [measurement error]

↓

মান সামান্য ভুল হলে Exm এ সমস্যা হবে না,

<u>Lec - 9</u>

<u>02.4.24</u>

- How to calculate SWR

* Reflection co-efficient

* angle of reflection

— magnitude

— angle

$3\angle 65^\circ \rightarrow$ angle

↓

magnitude

lec-10 5.5.29

Example (4.2)

load impedence

Ex-2.4

ch-3

Transmission Line and . . . .

[wave guide
→ High frequency electromagnetice way কে transmit করে যায়]

* difference between

waveguid	transmission line	co-axial
Loss কম, power বেশি, expensive	expensive নয়, TEM wave কে propagate করতে পারি।	

— Transmission line কী? কত প্রকার?
  waveguid " "

— কোন wave কোন waveguidকে support করে?

Art-3.1 ←
[Home work]