Lecture — 1

ICE-3103

Books:

i) Microwave Engineering — 4th edition

David M. Pozarr

A brief introduction

→ Microwave frequency : 300 MHz — 300 GHz

Wavelength : 1 m — 1 mm

IEEE

3 — 3 GHz
and
10 cm — 1 mm

⇒ Why microwave frequencies are in interest much ?

→ One advantage is Higher frequecy :

Let/ We need to transmit 4 GHz voice signal through a wireless channel. let's assume that we have two wireless channel to chose, one operating at 500 MHz and another at 4 GHz with 10% Bandwidth.

For 500 MHz system

$$\text{Number of channel} = \frac{\text{Operating frequency} \times \text{Bandwidth Percentage}}{\text{BW per channel}}$$

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

⇒ Application of microwave (Article 1.1 – Page 3)

- Wireless Communication
- Radar system
- Wireless power transfer
- Microwave heating
- Satellite system

Note-khata Must

Sir থেকে দেখা

⇒ Lumped elements

└ Difference between input and output voltage = Negligiable (small)

⇒ Distributed elements

├ Difference of input and output voltage = Bigger

└ Isolator, Circulator, Attenuator

⇒ Microwave frequency generator ⟶ Gull Oscillator,

⇒ Microwave transmission medium ⟶ Transmission-line / Wave-line

⇒ Advantage of Antenna-size (Smaller)

1st-system:

$f = 300$ MHz.

Now, $c = f\lambda$

$$\therefore \lambda = \frac{c}{f} = \frac{3\times10^8}{3\times10^8} = 1\text{ m}$$

Beam-width, B = 100°

$$\boxed{\text{Diameter} = 140\frac{\lambda}{B}} = 140\times\frac{1\text{m}}{100^\circ} = 1.4$$

2nd System:

$f = 30$ GHz

Then, $\cancel{\lambda = \frac{30\times10^9}{3\times10^8} = 0.034}$ $\lambda = \frac{3\times10^8}{30\times10^9} = 0.003$

$$\therefore \text{Diameter} = 140\times\frac{0.0034}{100^\circ} = \cancel{0.048}\ 0.004$$

For 4 GHz system

Number of channel $= \frac{4\text{ GHz} \times 0.1}{4\text{ kHz}} = 100,000$

We see that

operating system frequency (↑)
↓
capacity (↑)

Another advantages is ~~are~~ Antenna size.

Chapter-1
Article-1.1 (table)
Figure-1.1 (Band-name)

⇒ Circuit theory vs EM Field theory

Circuit theory → Bigger wavelength, Small device structure,
✓ Lumped parameter circuit components

EM Field theory → Small wavelength, Big structure.
✓ Distributive parameter circuit components

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⇒ Application of Microwave Engineering

⇒ Disadvantages

- Voltage is not well-defined.
- More expensive component
- One must carefully choose lumped elements
- To transport electrical signal from one position to another one must use special wires.

⇒ Maxwell's Equation — Article 1.2

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

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

$$\nabla \cdot \bar{D} = \rho$$

$$\nabla \cdot \bar{B} = 0$$

$\bar{E}$ = Electric field
$\bar{H}$ = Magnetic field
D = Electric flux density
B = Magnetic flux "
M = Magnetic current "
J = Electric "
ρ = " charge

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

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

Continuity Equation

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

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

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

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

$$\nabla \cdot \bar{D} = \rho$$

$$\nabla \cdot \bar{B} = 0$$

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

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

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

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

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

Solution: $\nabla \times \bar{E}(x,y,z) = -jwB(x,y,z) - M(x,y,z)$

HW. $\rightarrow$ The importance of Maxwell equation

$\rightarrow$ Different notation of maxwell equation

or, Different representation

$\boxed{1.3,\ 1.4}$

The imaginery part ($j\epsilon''$) 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,

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

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

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

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

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

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

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

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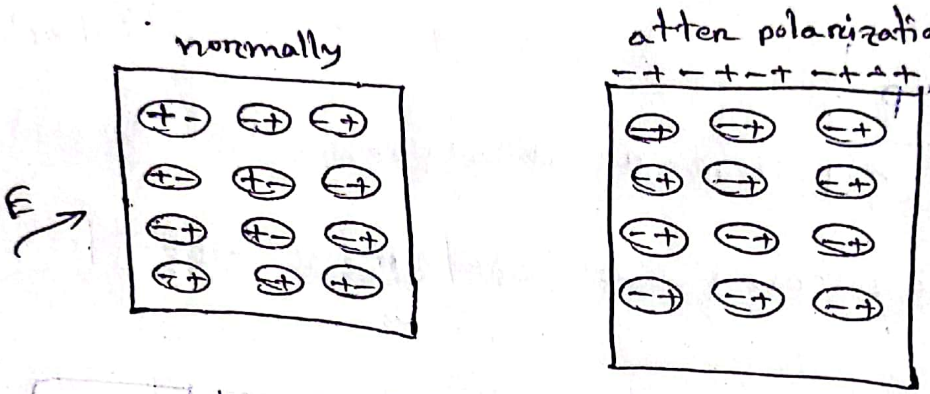
Art - 1.3

Fields in media :

Piece of dielectric material



Any piece of dielectric material has dipoles 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,

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

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

$$= \epsilon E$$

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

⇒ Two types of loss

- Conduction loss (σ)
- Di-electric loss ($j\epsilon''$)

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

Anisotropic material!

The direction of polarization is not the same as E.

example:- crystals, ionited gas } electric anisotropic material

example:- ferrites — Magnetic Anisotropic material

P_e = electric polarization
P_m = magnetic
E = Electric field
H = Magnetic

P_e, E	
Direction similar	= Isotropic
" not similar	= Anisotropic

Electric

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

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

Similarly –

Magnetic –

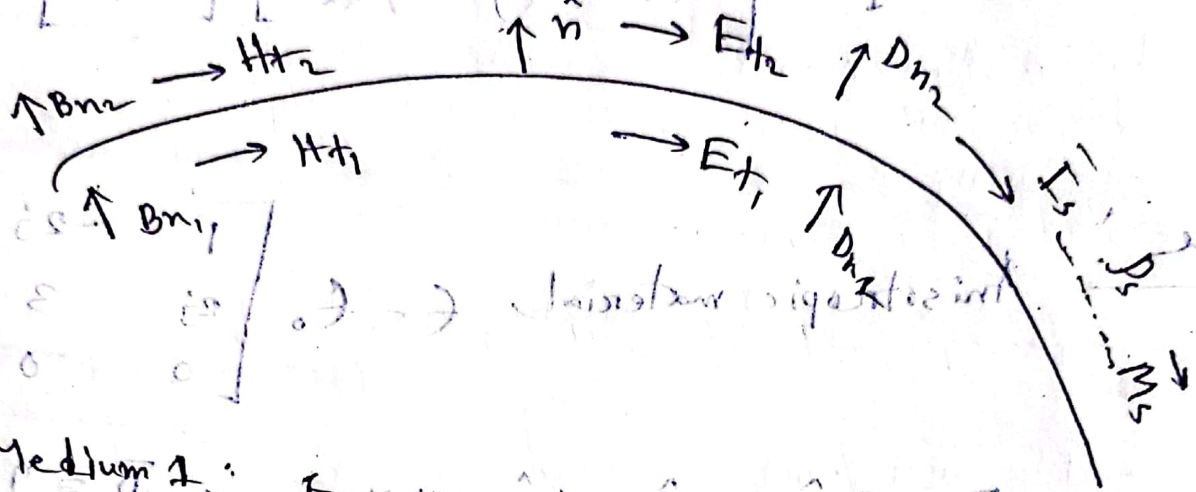
$$\begin{bmatrix} B_x \\ B_y \\ B_z \end{bmatrix} = \begin{bmatrix} \mu_{xx} & \mu_{xy} & \mu_{xz} \\ \mu_{yx} & \mu_{yy} & \mu_{yz} \\ \mu_{zx} & \mu_{zy} & \mu_{zz} \end{bmatrix} \begin{bmatrix} H_x \\ H_y \\ H_z \end{bmatrix} = [\mu] \begin{bmatrix} H_x \\ H_y \\ H_z \end{bmatrix}$$

<u>Example</u> :– Anisotropic material, $\epsilon = \epsilon_0 \begin{bmatrix} 1 & -2j & 0 \\ 2j & 3 & 0 \\ 0 & 0 & 9 \end{bmatrix}$

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

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

$$\rho_s = 0$$

$$J_s = 0$$

CamScanner

Conditions :

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

Normal flux density is continuous

$$\hat{n}\times\bar{E}_1 = \hat{n}\times\bar{E}_2$$
$$\hat{n}\times\bar{H}_1 = \hat{n}\times\bar{H}_2$$

Tangential field intensity is continuous

→ Boundary conditions at the interface with a perfect conductor

→ " " " " " magnetic wall

H.W. → (chapter 1)

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1.4 The wave equation and basic plane wave solution :

The helmholtz equation

Plane wave in a lossless medium

Example - 1.1

Plane waves in a general lossy medium

Plane waves in a good conductor

Example - 1.2

2

that of the operating ~~system~~ wavelength ($\sim \lambda/10$ to $\sim\lambda$), the simple circuit laws do not apply. In such case, the elements are called "Distributed elements".

T-lines

Lumped : Resistor, Capacitor

Distributed : T-lines

Art-2.1

⇒ TEM fields (Transverse electric-magnetic fields)

→ RLGC Model

Conduction current — R' – series resistance (Ω/m)
— L' – series inductance (H/m)

Displacement current — G' – Shunt conductance (S/m)
— C' – Shunt capacitance (F/m)

[* R' and G' represent loss in circuit]

Chapter-two

1

Transmission-line Theory

Slide- daffodil
(Johirul Islam)

Whether the simple circuit laws may be used depends on the size of our circuit in relation to the wavelength corresponding to the operating frequency.

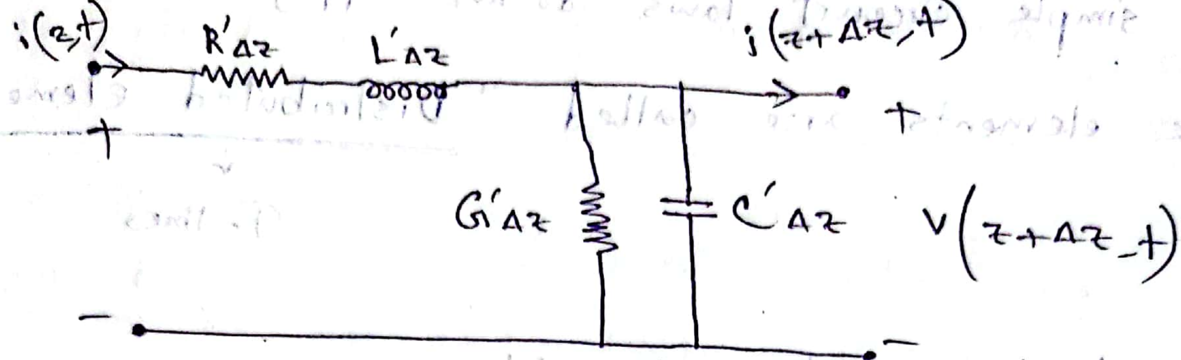
The relation between wavelength and frequency is

$$\lambda = \frac{c}{f}$$

→ If the size of the circuit (or element) is much smaller than the operating wavelength ($\sim\lambda/100$ or smaller), the simple circuit laws apply. In such case, the elements of the circuits are called "Lumped elements".

→ If the size of the circuit is comparable to

Generic equivalent circuit model :



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

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

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

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

→ for the current $i(z,t)$, apply KVL at Node A

$$i(z,t) - i(z+\Delta z,t) + v(z+\Delta z,t)\,G'\Delta z + C'_z\,\frac{\partial v(z+\Delta z,t)}{\partial t} \qquad \text{1b}$$

$\Delta i = i(z+\Delta z,$

→ divide 1a and 1b by Δz and taking limit as $\Delta z \to 0$ —

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

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

These are called "Telegrapher equations" or "T-line equations".

$\boxed{\text{Solution - 2.3 a , 2 3 b}}$ book

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→ telegraph equation simplify to —

$$\frac{dV(z)}{dz} = -(R + j\omega L) I(z)$$

$$\frac{dI(z)}{dz} = -(G + j\omega C) V(z)$$

[Article — 2.1, 2.2, 2.3]

~~CT~~

Chapter one —

Chapter two (2.1, 2.2, 2.3)