Em energy V, I in metallic
free spa radio waves
fiber light waves

$$\cos\theta = \frac{e^{j\theta}+e^{-j\theta}}{2}$$

$$\sin\theta = \frac{e^{j\theta}-e^{-j\theta}}{2j}$$

$$\frac{\frac{\cos\theta + j\sin\theta + \cos\theta - j\sin\theta}{2}}{2}$$

low freq	comm in waves	
0.3 – 3KH	VF	
3 – 30KHz	VLF	
30K – 300K	LF	
0.3M – 3M	MF	Unit λ
3MHz – 30MHz	HF	
30MHz – 300MHz	VHF	
0.3GH – 3GH	UHF	
3GHz – 300GHz	SHF	

IR, VL, UV / X, G, C

1705 HL

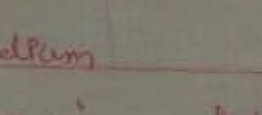
Guided – Conduct – Em energy
metallic conductive narrow
optical nonconductive
but pass the light signal

Unguided
– Vaccum, water, air

Metallic Cable — Dielectric

Longitudinal – Amp in direction of propagation
Amp = Sound waves

Transverse waves Amp $\perp$ propag



TEM – waves

TEM wave exist in dielectric medium

Tran — E V, I distribut field E and H in space quadrature

EM wave

In free space
air

of light

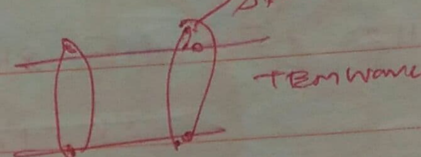
$Dis = V \times t$

$\lambda = V \times T$

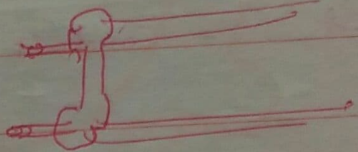
Balanced and Unbalance Transmission line

* Parallel conductor transmission line
* Co-axial transmission line

Open wire transmission line



* radiation loss more
* Twin lead



Twisted pair

characteristic of TLN determine by

spacing, Dielectric, conductivity, diameter

then define R, L, C, G - primary constants

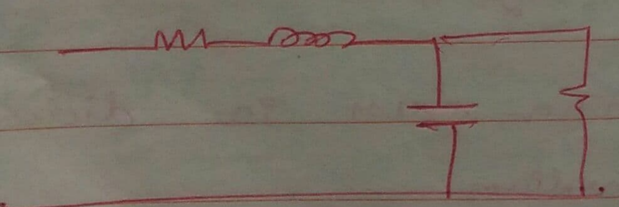
* Transmission characteristics

Z_0,

$$Z_0^2 = Z_1 Z_2 + \frac{Z_1^2}{n}$$

Infinite section $n \to \infty$

$$Z_0^2 = Z_1 Z_2$$



$Z_1 = R + j\omega L$

$\frac{1}{Z_2} = Y_2 = G + j\omega C$

$$Z = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

low fre $Z = \sqrt{\frac{R}{G}}$

High $Z = \sqrt{\frac{L}{C}}$

PART - A

from Z_0 α no reflection non resonant line

α at any point $\frac{V}{I}$ equal to Z_0

$Z_i = Z_0$

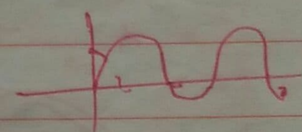
V, I inphase No reflection

max. power transferred

<u>propagation constant γ</u>

to determine signal loss and phase shift at different points

$\gamma = \sqrt{Z_1 \times \frac{1}{Z_2}}$ $\beta = \frac{2\pi}{\lambda = 4}$



$I = I_s e^{-\gamma l}$

$V = V_s e^{-\gamma l}$

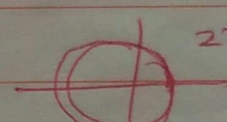
$\lambda = \frac{2\pi}{\beta}$

$= \frac{2\pi}{\pi/2}$

$\boxed{\lambda = 4}$

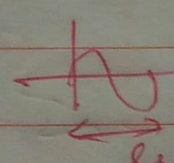
$\frac{V_f}{\text{Velocity factor}} = \frac{V_p}{c}$ propagate velocity / pry through vacuum

$V_p = \frac{1}{\sqrt{\varepsilon_r}}$ $\varepsilon_r = \varepsilon/\varepsilon_0$



L, C store energy then release

Hence Velocity depends on LC in TLoh



$V_p = \frac{D}{\sqrt{LC}}$

$V_p = \frac{1}{\sqrt{C}}$

$v = \frac{D}{T}$ $c = \nu\lambda$

$\lambda \propto$ velocity

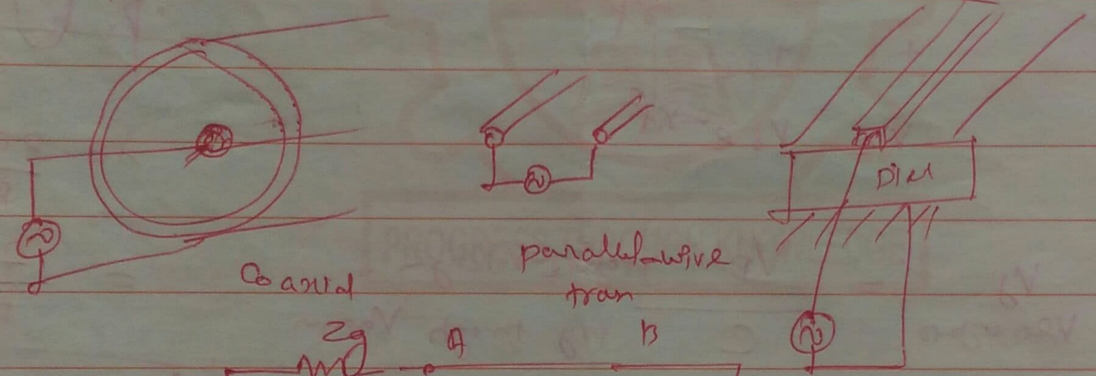
length λ $\lambda = \frac{V_p}{f} = \frac{C V_f}{f} = \frac{c}{f\sqrt{\epsilon_r}}$

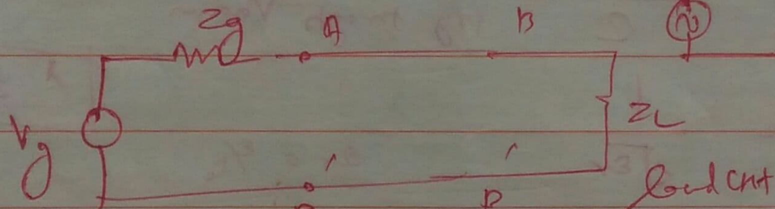
em wave vacuum 3×10^8 m/s

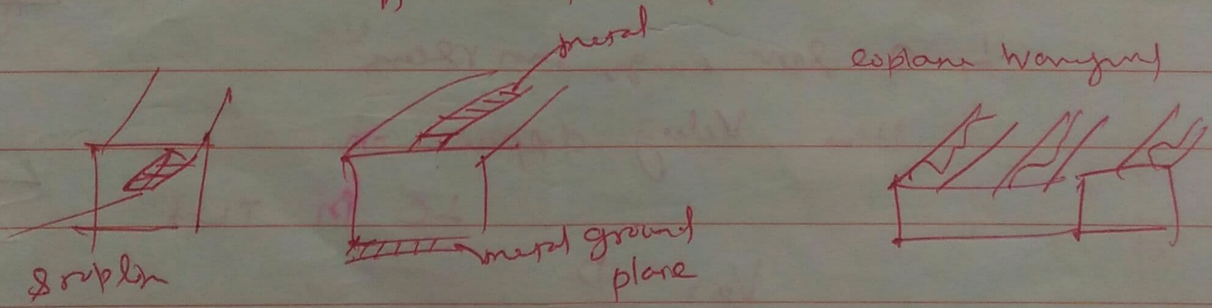
medium less

Delay line because of L, C

* energy from 1 point to another point
* TL made of 2 conductor







* info converted as em waves

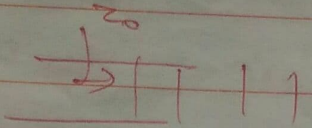
V, I, volt, signal wave

Em wave from S - load Incident wave

L - S reflected wave

$Z_0 =$ Transm line

Complex quantity

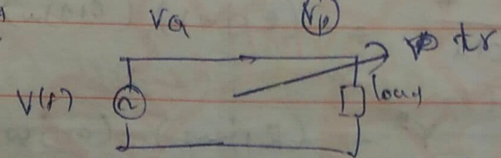


Impedn looking into a long line

Stores energy indefinitely

* Transfer energy
* Electrical Energy distributed b/w 2 conductors.

transit time effect



not instantaneously at load

take time

$t_r = \frac{l}{v}$ $\quad \frac{10^m}{10\ m/s} = 1 \quad t_r \quad$ 10m

$f > 1Hz \quad f = 2Hz \qquad \lambda = 15m$

$T \geq t_r$ assume

$1/f >> l/v$ $\quad$ V_p than V_g

$\frac{v}{f} >> l$

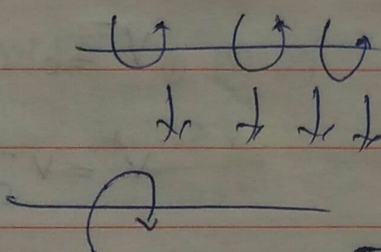
$\lambda >> l$

R = Ω/m

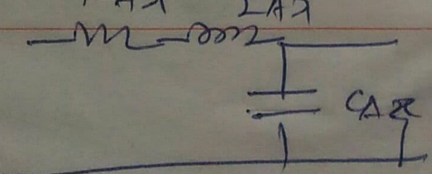
L = H/m

C = F/m

G = mho/m



Δx $\boxed{\Delta x << \lambda}$ for analysis all freq



$$\frac{\Delta v}{\Delta x} \quad \frac{dv}{dx} = (R+j\omega L)\, I$$

$$\frac{dI}{dx} = (G+j\omega L)\, V$$

$$\frac{d^2v}{dx^2} = (R+j\omega L)\, \frac{dI}{dx}$$

$$\frac{d^2v}{dx^2} = (R+j\omega L)(G+j\omega C)\, V$$

$|||^y$ $$\frac{d^2 I}{dx^2} = (R+j\omega L)(G+j\omega)\, I$$

$$\gamma^2 = (R+j\omega L)(G+j\omega)$$

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

$\gamma\,(R, L, G, C, \omega)$ complex Qty

Forward travelling wave $V^+ e^{-\gamma z}$ attenuation

Backward $V^- e^{-\gamma z}$ α N/m

$= 8.68$ dB/m

Time phase ωt Space Space $\pm \beta x$

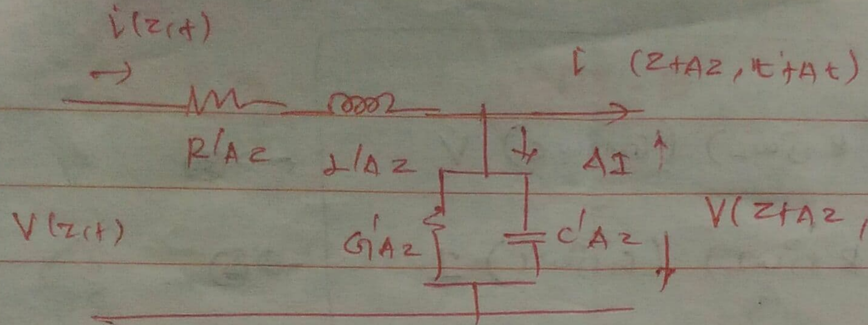
$$\beta = \frac{2\pi}{\lambda}$$

$$\frac{V^+}{I^+} = \frac{R+j\omega L}{\gamma} = \sqrt{\frac{R+j\omega L}{G+j\omega C}}$$

$\vec{Z_0}$ $\leftarrow -Z_0$

$V^- = 0$ No return

$V^+ = V^-$ full Standing wave



KVL $V(z,t) = R\,I(z,t)\,\Delta z + L\,\frac{\partial I}{\partial t}(z,t)\,\Delta + V(z+\Delta z, t)$

$$\frac{-V(z+\Delta z,t) + V(z,t)}{\Delta z} = R\,I(z,t) + L\,\frac{\partial I(z,t)}{\partial t}$$

$$-\left[\frac{V(z+\Delta z,t) - V(z,t)}{\Delta z}\right] = R\,I(z,t) + L\,\frac{\partial I}{\partial t}(z,t)$$

if $\Delta z \Rightarrow 0$ $$-\frac{\partial V(z,t)}{\partial z} = R\,I(z,t) + L\,\frac{\partial I}{\partial t}(z,t) \quad \rightarrow (1)$$

From KCL

$$I(z,t) = \Delta I + i(z+\Delta z,t)$$

$$\Delta I = G\,V(z+\Delta z,t)\,\Delta z + C\,\cancel{\Delta z}\,\frac{\partial V(z+\Delta z,t)}{\partial t}$$

$$[I(z,t) - I(z+\Delta z,t)] = G\,V(z+\Delta z,t)\,\cancel{\Delta z} + C\,\frac{\partial V(z+\Delta z,t)}{\partial t}$$

$$-\left[\frac{I(z+\Delta z,t) - I(z,t)}{\Delta z}\right] = G\,V(z+\Delta z,t) + C\,\frac{\partial V(z+\Delta z,t)}{\partial t}$$

$$-\frac{\partial I(z,t)}{\partial z} = G\,V(z+\Delta z,t) + C\,\frac{\partial V(z+\Delta z,t)}{\partial t} \quad \rightarrow (2)$$

Diff (1) & (2)

$$-\frac{\partial^2 V}{\partial z^2} = (R + j\omega L)\,\frac{\partial I}{\partial z}$$

$$-\frac{\partial I}{\partial z} = (G + j\omega)\,V$$

$$-\frac{\partial^2 I}{\partial z^2} = (G + j\omega C)\,\frac{\partial V}{\partial z}$$

$$-\frac{\partial V}{\partial z} = (R + j\omega L)\,I$$

$$\boxed{\begin{aligned} \frac{\partial^2 V}{\partial z^2} &= (R+j\omega L)(G+j\omega C)\,V \quad \rightarrow (3) \\ \frac{\partial^2 I}{\partial z^2} &= (R+j\omega L)(G+j\omega C)\,I \quad \rightarrow (4) \end{aligned}}$$

$\gamma = \alpha + j\beta$

$$\frac{\partial^2 V}{\partial z^2} = \gamma^2 V$$

$$(D^2 - \gamma^2)V = 0$$

$$D = \pm \gamma$$

$$\therefore V = a e^{-\gamma z} + b e^{\gamma z}$$

$$\boxed{\begin{aligned} V &= V_0^+ e^{-\gamma z} + V_0^- e^{\gamma z} \\ I &= I_0^+ e^{-\gamma z} + I_0^- e^{\gamma z} \end{aligned}}$$

$\cos\theta = \frac{e^{j\theta} + e^{-j\theta}}{2}$

$\sin\theta = \frac{e^{j\theta} - e^{-j\theta}}{2j}$

<u>In phasor</u>

$$V(z,t) = Re\left[V(z)\, e^{j\omega t}\right]$$

$$I(z,t) = Re\left[I(z)\, e^{j\omega t}\right]$$

$$V(z,t) = Re\left[\left(V_0^+ e^{-\gamma z} + V_0^- e^{\gamma z}\right) e^{j\omega t}\right]$$

$$= Re\left[V_0^+ e^{-(\alpha+j\beta)z} e^{j\omega t} + V_0^- e^{(\alpha+j\beta)z} e^{j\omega t}\right]$$

$$= Re\left[V_0^+ e^{-\alpha z} e^{j(\omega t - \beta z)} + V_0^- e^{\alpha z} e^{j(\omega t + \beta z)}\right]$$

$$V(z,t) = V_0^+ e^{-\alpha z}\cos(\omega t - \beta z) + V_0^- e^{\alpha z}\cos(\omega t + \beta z)$$

$$I(z,t) = I_0^+ e^{-\alpha z}\cos(\omega t - \beta z) + I_0^- e^{\alpha z}\cos(\omega t + \beta z)$$

PART - B

$$V = V_0^+ e^{-\gamma z} \rightarrow (5)$$

$$I = I_0^+ e^{-\gamma z} \quad (6)$$

$$\frac{\partial V}{\partial z} = V_0^+ e^{-\gamma z} (-\gamma)$$

$$\boxed{\frac{\partial V}{\partial z} = -\gamma V}$$

$$\frac{\partial I}{\partial z} = I_0^+ (-\gamma) e^{-\gamma z}$$

$$\boxed{\frac{\partial I}{\partial z} = -\gamma I}$$

We know

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

$$-\gamma V = (R + j\omega L) I$$

$$\gamma (V_0^+ e^{-\gamma z}) = (R + j\omega L)(I_0^+ e^{-\gamma z})$$

$$Z_0 = \frac{V_0^+}{I_0^+} = \frac{(R + j\omega L)}{\gamma} = \frac{R + j\omega L}{\sqrt{(R + j\omega L)(G + j\omega C)}}$$

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

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

$$\gamma I = (G + j\omega C) V$$

$$\gamma (I_0^+ \cancel{e^{-\gamma z}}) = (G + j\omega C) V_0^+ \cancel{e^{-\gamma z}}$$

$$Z_0 = \frac{V_0^+}{I_0^+} = \frac{\gamma}{G + j\omega C}$$

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

Expression for α / β

$$\gamma = \alpha + j\beta$$

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

$$\gamma^2 = (R+j\omega L)(G+j\omega C)$$

$$= (RG - \omega^2 LC) + j(R\omega C + G\omega L)$$

$$\gamma^2 = (\alpha + j\beta)^2 = \alpha^2 - \beta^2 + 2j\alpha\beta$$

$$(\alpha^2 - \beta^2) + 2j\alpha\beta = (RG - \omega^2 LC) + j\omega(RC + GL)$$

$$\alpha^2 - \beta^2 = RG - \omega^2 LC \rightarrow (1)$$

$$2\alpha\beta = \omega(RC + GL)$$

$$\beta = \frac{\omega}{2\alpha}(RC + GL)$$

$$\Rightarrow \alpha^2 - \frac{\omega^2}{4\alpha^2}(RC + GL)^2 = RG - \omega^2 LC$$

$$4\alpha^4 - 4\alpha^2(RG - \omega^2 LC) - \omega^2(RC + GL)^2 = 0$$

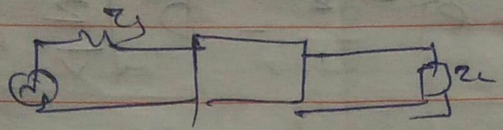
$$\alpha^2 = \frac{4(RG - \omega^2 LC) \pm \sqrt{16(RG - \omega^2 LC)^2 - 4(4)(-\omega^2)(RC+GL)^2}}{2(4)}$$

$$\alpha^2 = \frac{(RG - \omega^2 LC) \pm \sqrt{(RG - \omega^2 LC)^2 + \omega^2 (RC + GL)^2}}{2}$$

$$\text{Ily } \alpha = \sqrt{\frac{(RG - \omega^2 LC) \pm \sqrt{(RG - \omega^2 LC) + \omega^2 (RC + GL)^2}}{2}}$$

$$\beta = \sqrt{\frac{(\omega^2 LC - RG) \pm \sqrt{(RG - \omega^2 LC) + \omega^2 (RC + GL)^2}}{2}}$$

Transmission line eqn with hyperbolic fn.



$V = V_0^+ e^{-\gamma z} + V_0^- e^{\gamma z}$

$I = I_0^+ e^{-\gamma z} + I_0^- e^{\gamma z}$

Consid

$V = Ae^{\gamma z} + Be^{-\gamma z} \rightarrow (3)$

$I = Ce^{\gamma z} + De^{-\gamma z} \rightarrow (4)$

At $z=0$

$\left.\begin{aligned} V_R &= A+B \\ I_R &= C+D \end{aligned}\right\} \rightarrow (5)$

(3) $\boxed{V = Ae^{\sqrt{ZY} z} + Be^{-\sqrt{ZY} z}}$

(4) $\boxed{I = Ce^{\sqrt{ZY} z} + De^{-\sqrt{ZY} z}}$

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

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

Diff $\frac{dV}{dz} = A\sqrt{ZY} e^{\sqrt{ZY} z} - B\sqrt{ZY} e^{-\sqrt{ZY} z}$

$ZI = A\sqrt{ZY} e^{\sqrt{ZY} z} - B\sqrt{ZY} e^{-\sqrt{ZY} z}$

$\boxed{I = A\sqrt{\frac{Y}{Z}} e^{\sqrt{ZY} z} - B\sqrt{\frac{Y}{Z}} e^{-\sqrt{ZY} z}} \rightarrow (6)$

diff (4)

$\frac{dI}{dz} = C\sqrt{ZY} e^{\sqrt{ZY} z} - D\sqrt{ZY} e^{-\sqrt{ZY} z}$

$YV = C\sqrt{ZY} e^{\sqrt{ZY} z} - D\sqrt{ZY} e^{-\sqrt{ZY} z}$

$$V = C\sqrt{\frac{Z}{Y}}e^{\sqrt{ZY}z} - D\sqrt{\frac{Z}{Y}}e^{-\sqrt{ZY}z} \rightarrow (7)$$

At $z = 0$

$$I_R = A\sqrt{\frac{Y}{Z}} - B\sqrt{\frac{Y}{Z}}$$

$$V_R = C\sqrt{\frac{Z}{Y}} - D\sqrt{\frac{Z}{Y}}$$

(5) $V_R = A + B$

$I_R = C + D$

$$I_R\sqrt{\frac{Z}{Y}} = A - B$$

$$V_R = A + B$$

$$2A$$

$$2A = V_R + I_R\sqrt{\frac{Z}{Y}}$$

$$\boxed{A = \frac{V_R}{2} + \frac{I_R}{2}\sqrt{\frac{Z}{Y}}}$$

$$B = V_R - A$$

$$= V_R - \left(\frac{V_R}{2} + \frac{I_R}{2}\sqrt{\frac{Z}{Y}}\right)$$

$$\boxed{B = \frac{V_R}{2} - \frac{I_R}{2}\sqrt{\frac{Z}{Y}}}$$

$$V_R\sqrt{\frac{Y}{Z}} = C - D$$

$$I_R = C + D$$

$$2C = I_R + V_R\sqrt{\frac{Y}{Z}}$$

$$\boxed{C = \frac{I_R}{2} + \frac{V_R}{2}\sqrt{\frac{Y}{Z}}}$$

$$D = I_R - C$$

$$= I_R - \frac{I_R}{2} - \frac{V_R}{2}\sqrt{\frac{Y}{Z}}$$

$$\boxed{D = \frac{I_R}{2} - \frac{V_R}{2}\sqrt{\frac{Y}{Z}}}$$

$$\cancel{A = \frac{V_R}{2}\left(1 + \frac{Z_0}{Z_R}\right)}$$

$$\cancel{B =}$$

$$A = \frac{V_R}{2} + \frac{I_R}{2}\sqrt{\frac{Z}{Y}}$$

$$= \frac{1}{2}\left(V_R + \frac{V_R}{Z_R} Z_0\right)$$

$$\boxed{A = \frac{V_R}{2}\left(1 + \frac{Z_0}{Z_R}\right)}$$

$$B = \frac{V_R}{2} - \frac{I_R}{2}\sqrt{\frac{Z}{Y}}$$

$$= \frac{1}{2}\left(V_R - I_R\sqrt{\frac{Z}{Y}}\right)$$

$$= \frac{V_R}{2}\left(1 - \frac{V_R}{Z_R}\sqrt{\frac{Z}{Y}}\right)$$

$$\boxed{B = \frac{V_R}{2}\left(1 - \frac{Z_0}{Z_R}\right)}$$

$$C = \frac{I_R}{2}\left[1 + \frac{Z_R}{Z_0}\right]$$

$$D = \frac{I_R}{2}\left[1 - \frac{Z_R}{Z_0}\right]$$

$$V = \frac{V_R}{2}\left(1+\frac{Z_0}{Z_R}\right)e^{\sqrt{ZY}\,z} + \frac{V_R}{2}\left(1-\frac{Z_0}{Z_R}\right)e^{-\sqrt{ZY}\,z}$$

$$I = \frac{I_R}{2}\left(1+\frac{Z_R}{Z_0}\right)e^{\sqrt{ZY}\,z} + \frac{I_R}{2}\left(1-\frac{Z_R}{Z_0}\right)e^{-\sqrt{ZY}\,z}$$

$$V = \frac{V_R}{2}\left(\frac{Z_R+Z_0}{Z_R}\right)e^{\sqrt{ZY}\,z} + \frac{V_R}{2}\left(\frac{Z_R-Z_0}{Z_0}\right)e^{-\sqrt{ZY}\,z}$$

$$= \frac{V_R}{2Z_R}\left[(Z_R+Z_0)e^{\sqrt{ZY}\,z} + (Z_R-Z_0)e^{-\sqrt{ZY}\,z}\right]$$

$$\boxed{V = \frac{V_R\,(Z_R+Z_0)}{2Z_R}\left[e^{\sqrt{ZY}\,z} + \left(\frac{Z_R-Z_0}{Z_R+Z_0}\right)e^{-\sqrt{ZY}\,z}\right]}$$

V_0' $\qquad$ V_0^+

$$I = \frac{I_R}{2Z_0}\left[(Z_0+Z_R)e^{\sqrt{ZY}\,z} + (Z_0-Z_R)e^{-\sqrt{ZY}\,z}\right]$$

$$\boxed{I = \frac{I_R\,(Z_0+Z_R)}{2Z_0}\left[e^{\sqrt{ZY}\,z} - \left(\frac{Z_R-Z_0}{Z_0+Z_R}\right)e^{-\sqrt{ZY}\,z}\right]}$$

I_0^+

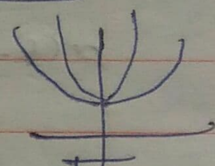
I_0'

$$V = \frac{V_R}{2}\left(1+\frac{Z_0}{Z_R}\right)e^{\sqrt{ZY}\,z} + \frac{V_R}{2}\left(1-\frac{Z_0}{Z_R}\right)e^{-\sqrt{ZY}\,z}$$

$$= \frac{V_R}{2}\left[e^{\sqrt{ZY}\,z} + \frac{Z_0}{Z_R}e^{\sqrt{ZY}\,z}\right] + \frac{V_R}{2}\left[e^{-\sqrt{ZY}\,z} - \frac{Z_0}{Z_R}e^{-\sqrt{ZY}\,z}\right.$$

$$= V_R\left[\left(\frac{e^{\sqrt{ZY}z}+e^{-\sqrt{ZY}z}}{2}\right)+\frac{Z_0}{Z_R}\left(\frac{e^{\sqrt{ZY}z}-e^{-\sqrt{ZY}z}}{2}\right)\right]$$

$$\boxed{V = V_R\left[\cosh\sqrt{ZY}\,z+\frac{Z_0}{Z_R}\sinh\sqrt{ZY}\,z\right]}$$



$$I = \frac{I_R}{2}\left(1+\frac{Z_R}{Z_0}\right)e^{\sqrt{ZY}z}+\frac{I_R}{2}\left(1-\frac{Z_R}{Z_0}\right)e^{-\sqrt{ZY}z}$$

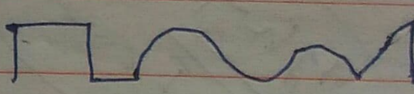
$$= I_R\left[\left(\frac{e^{\sqrt{ZY}z}+e^{-\sqrt{ZY}z}}{2}\right)+\frac{Z_R}{Z_0}\left(\frac{e^{\sqrt{ZY}z}-e^{-\sqrt{ZY}z}}{2}\right)\right]$$

$$\boxed{I = I_R\left[\cosh\sqrt{ZY}\,z+\frac{Z_R}{Z_0}\sinh\sqrt{ZY}\,z\right]}$$

Waveform Distortion

$$\alpha = \sqrt{\frac{(RG-\omega^2LC)+\sqrt{(RG-\omega^2LC)^2+\omega^2(LG+CR)^2}}{2}}$$

Voice compsitsigna



Diff freq Componuts.

× All freq are not attenuated equaly

Recived freq Compon (cons signal) not same as send such Distortion

freq Distion.

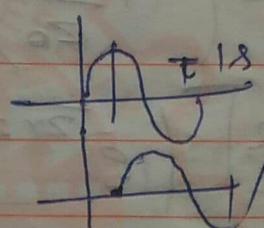
$$\beta = \sqrt{\frac{(\omega^2 LC - RG) + \sqrt{(RG-\omega^2 LC)^2 + \omega^2 (LG + CR)^2}}{2}}$$

$x(t) = A\cos(\omega t + \theta)$ $\quad \cancel{(t - T/4)}$

$x(t - T/4) = A\cos(\omega t - \omega \frac{T}{4} + \theta)$ $\quad \omega \frac{T}{4}$

$= A\cos(\omega t + \theta - \pi/2)$

$= \pi/2$ phase shift $\quad \frac{\omega}{d4}$ $\quad \frac{2\pi f}{d4}$



Some freq components delay more than others such

Delay Distortion (or) Phase Distortion.

Distortion avoid by using Equilizers at line terminals

(freq,)

ω, ϕ are adjusted $\quad$ 7600 9600 1500 600 800

Delay Distortion

minor for voice

· Important Image

Overcome by Coaxial

Skin effect $\quad$ L low at High

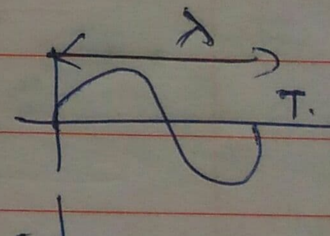
Skineffect

$\sqrt{\frac{1}{LC}}$

$\sqrt{\frac{2\beta}{\omega\mu}}$ $\quad V_p =$

$\lambda = 1$

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



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