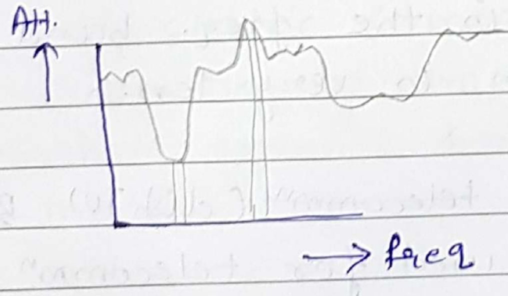
Date: 11 | 7 | 2017

Microwave engineering

- 300 MHz – 300 GHz
- $\lambda = \frac{c}{f}$ 1 m – 0.1 cm

- Micro means small not the 10^{-6}
- when the size of component is less compared to wavelength, the phase change is negliable.
- So in microwave, bcoz wavelength is less So we can't neglect the phase change.
- in free space air is fully dilectric.
- ionosphere as reflector – for microwave

charc : – Heat is ~~produced~~ genr by the MW
- size of antenna is small
- Propagate through dilectric
- reflected from conductor (due to that Microwave used in RADAR)



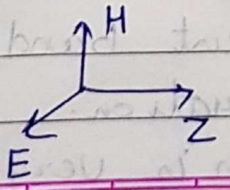
Ku band (12 & 17)
K band (18 & 24)

- L-Band (1.5 GHz)
- C-Band (6 & 3 GHz) for satellite commn its very popular. for voice & messages commn from satellite.
- we are using different bands of freq. because of attenuation.
- freq. where attenuation is very high

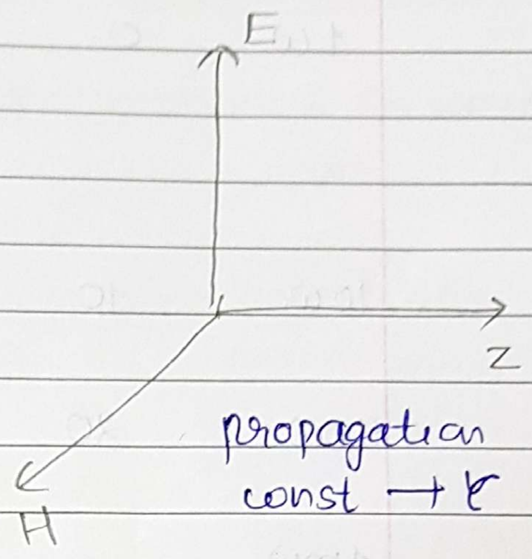
they can't used for the long distance commⁿ i.e. Bluetooth, wifi → small distance commⁿ – 2.4GHz (free band) attenuation is high.

- if Microwave focused at a point, it will genʳ heat → so can be used in medical area
- lumped — distributive
  - capacitor, inductor etc.
  - element consists of L, C, HPF, LPF based on frequency
- tubes generate high power at Microwave frequency.
- reverse recovery time
- semiconductor (III-V class)
  GUN, PIN, MESFET, HEMT
- waveguide handles high power
- licensed band is the freq. band in which attenuation is very less.
- Ka → digital ~~telecommⁿ~~ (dish TV) Broadcasting
- C → band is used for telecommⁿ
- Electromagnetic wave :

TEM mode : if E, H and direction of propagation are mutually ~~per~~ perpendicular than its TEM mode.



$E_z = 0 \; ; \; H_z = 0$



TE mode :

$$E_z = 0$$
$$H_z \neq 0$$

TM mode :

$$E_z \neq 0$$
$$H_z = 0$$

propagation const $\rightarrow \gamma$

$\gamma = \alpha + j\beta$

α : attenuation constant ; β : phase

HE mode :

$$E_z \neq 0 \; ; \; H_z \neq 0$$

- dimension, wavelength and based on the boundary conditions modes is decided.
- In wave guide (hollow cylinderical pipe) TEM is not possible.
- Mode is the defined as the orientation of electric & magnetic field and the direction of propagation.
- when signal is transmitted in the medium, then signal having the $\alpha \rightarrow$ attenuation const. & $\beta \rightarrow$ Phase shift const.
- $$\alpha = \omega \sqrt{\frac{\mu \varepsilon}{2} \left(1 + \frac{\sigma^2}{\omega \varepsilon^2} - 1 \right)}$$

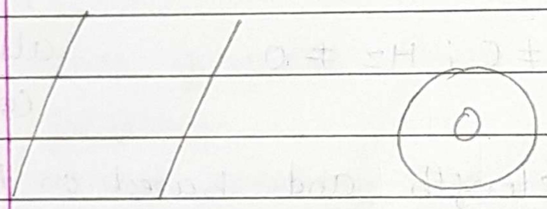
μ : permeability (indicates the ability to gen^r the flux when energised)

ε : Permittivity (ability to gen^r the electric field)

⇒

Power	dBw	dBm	dBμ
1W	0	$10\log\left(\frac{1}{10^{-3}}\right)$ $= 30$	60
10W	10	40	70
100W	20	50dBm	80
1mW		0	

⇒

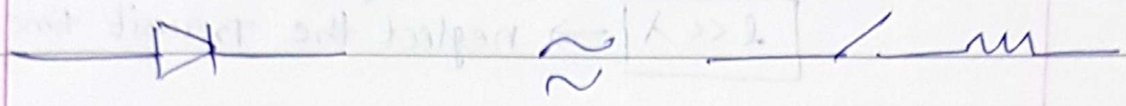


Two wire Parallel 500MHz | Coaxial | wave guide | Striplines

When High power is involves ⟶ waveguide
when low " " " ⟶ Striplines

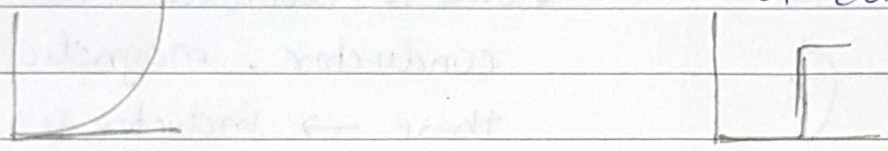
Transmission lines fundamentals

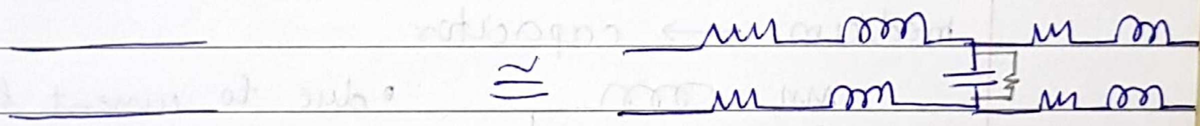
- Reference : NPTEL Lect. " Transmission line & EM waves "



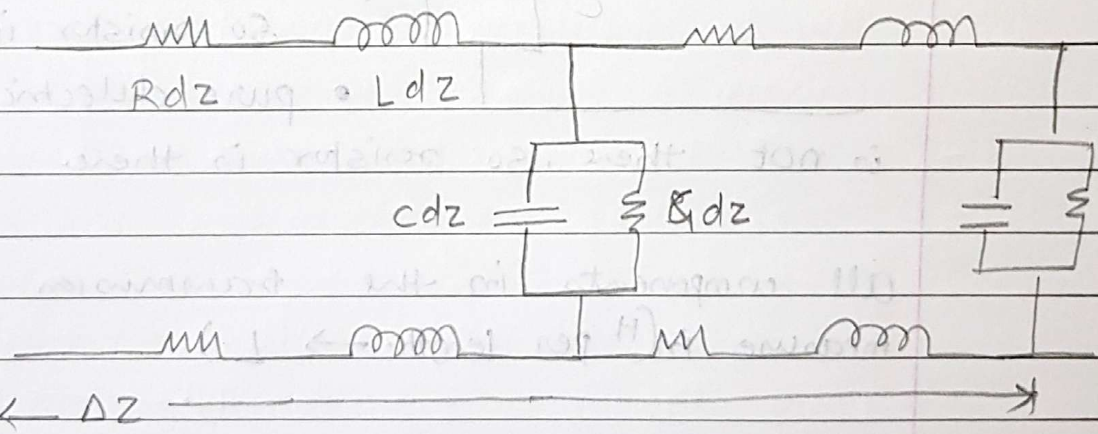
diode

equivalent ckt. of diode (5Ω with series R)



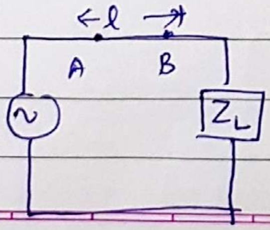
- 

Tx lines

- 

- at high freq. space dimensions are also considered.
- dimensions are not affected at low freq.
- $t_r \rightarrow$ transit time

  (time required for A to B)



$t_r <<< T_0$

$\frac{l}{v} << \frac{1}{f}$

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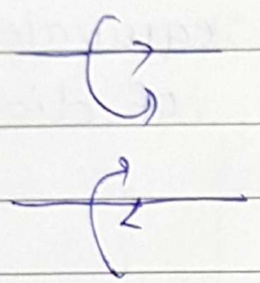
$$l << \frac{v}{f}$$

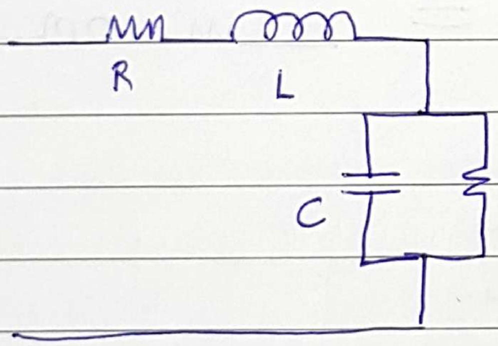
$v \rightarrow$ wave velocity

$\boxed{l << \lambda} \rightarrow$ neglect the Transit time effect

-



- due to current flow in conductor, magnetic field is there $\rightarrow$ inductor (L) will be there.
- b/w two conductor lines, dielectric medium $\longrightarrow$ capacitor



- due to current flow in the conductor and conductor is not pure so resistor is there.
- pure dielectric medium is not there, so resistor is there.

all components in the transmission lines are measure in (H per length. $\rightarrow$ L) due to impedence im-matching $\rightarrow$ reflected wave is there.

- incident & reflected waves are cosine wave
- for lossless transmission line

$$\alpha = 0$$
$$\beta = \omega\sqrt{L'C'}$$
$$\gamma = \alpha + j\beta$$

velocity $v_p = \frac{\omega}{\beta} = \frac{1}{\sqrt{L'C'}}$

independent of frequency

$$\boxed{v_p = \frac{1}{\sqrt{\mu\epsilon}}}$$

lossless lines are called non dispersive lines bcoz velocity is independent of freq

Ex 8 $R' = 0.404 \, (m\Omega/m)$

$L' = 2.0 \, \mu H/m$

$G' = 0$

$C' = 5.56 \, pF/m$

for operation at 5 KHz, determine

(i) attenuation constant

$$\alpha = \text{Real}(\gamma) = R\left[\sqrt{(R'+j\omega L')(G'+j\omega C')}\right]$$

(ii) Phase constant β

$$\beta = \text{imag}\,\boxed{\sqrt{(R'+j\omega L')(G'+j\omega C')}}$$

(iii) phase velocity v_p

(iv) the characteristic impedence Z_0

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

Voltage standing wave ratio (VSWR):

Reflection coefficient:

$$\tilde{V}(z) = V^+ e^{-\gamma z} + V^- e^{\gamma z}$$

at load end $(z = 0)$

$$\tilde{V}_L(0) = V_0^+ + V_0^-$$

$$\tilde{I}_L = \frac{V_0^+}{Z_0} - \frac{V^-}{Z_0}$$

$$Z_L = \frac{\tilde{V}_L}{\tilde{I}_L}$$

$$Z_L = \left(\frac{V_0^+ + V_0^-}{V_0^+ \cancel{+} V_0^-}\right) Z_0$$

incident wave

reflected wave

reflection coefficient Γ $Z_0 > Z_L$

$$\boxed{V_0^- = \left(\frac{Z_L - Z_0}{Z_L + Z_0}\right) V_0^+}$$

$Z_L = 0 \longrightarrow$ short ckt. $(V_0^- = -V_0^+)$

$Z_L = Z_0 \longrightarrow$ no reflection $(V_0^+ x_0 = V_0^- = 0)$ matching line

$Z_L = \infty \longrightarrow$ open ckt. $(V_0^- = V_0^+)$

reflection coefficient varies from 0 to 1 and (−) sign indicates the phase change.

$Z_L / Z_0 \longrightarrow$ normalised load impedence (means divide by its char imp)

~~z_L~~ $z_L = \frac{Z_L}{Z_0}$

$$V_0^- = \left(\frac{z_L - 1}{z_L + 1}\right) V_0^+$$

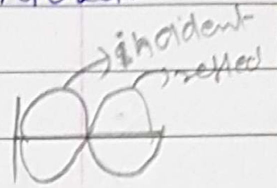
- if lossless

reflection coeff.

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

- at load end standing wave is considered.

  If standing wave magnitude = 0
  → short ckt



  if standing wave having max. magnitude
  → open ckt.

Ex:- 100 Ω transmission line is connected to a load consist of 50 Ω resistor with 10 pF capacitor. find the reflection coeff. at the load for a 100 MHz signal.

Sol:

$$Z_L = R_L - \frac{j}{\omega C_L}$$

$$= 50 - \frac{j}{2\pi\, 100 \times 10 \times 10^{-6}}$$

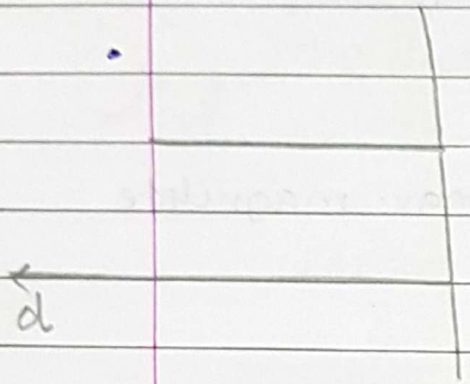
$$z_L = \frac{Z_L}{Z_0} = \frac{1}{100}(Z_L)$$

$$\text{reflection coefficient} = \frac{z_L - 1}{z_L + 1}$$

Standing wave :

Standing wave is created due to inteface b/w travelling waves (incident & reflected)

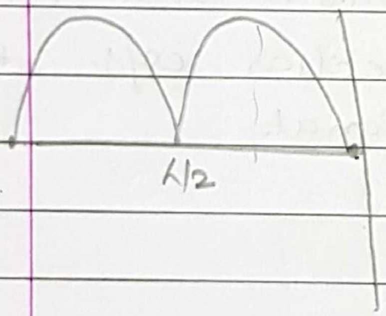
- when reflection coff is zero $\rightarrow$ no standing wave



matching line

$Z_L = Z_0$

$z=0$ at load point

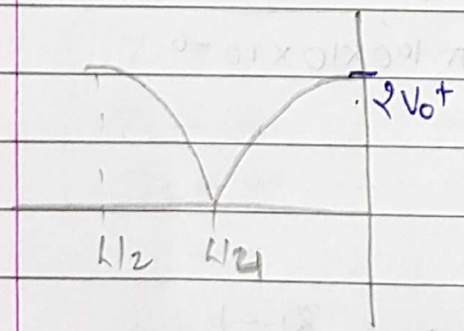


(at the load end, signal is reflected with the 180° phase shift)

short ckt. line

$Z_L = 0$

$z=0$



(at the load end signal is reflected with the 0° phase shift)

open ckt. line

$Z_L = \infty$

$z=0$

- $|\tilde{V}(z)| = \left[\tilde{V}(z) * \tilde{V}^*(z)\right]^{1/2}$

- $$\boxed{|\tilde{V}(d)| = |V_0^+|\left[1 + |\Gamma|^2 + 2|\Gamma| \cos(2\beta d - \theta_r)\right]^{1/2}}$$

- for maxima

$$2\beta d_{max} - \theta_r = 2n\pi$$

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

$$2 \times \frac{2\pi}{\lambda} d_{max} - \theta_r = 2n\pi$$

$$d_{max} = \frac{\lambda 2n\pi}{4\pi} + \frac{\theta_r \lambda}{4\pi}$$

- for minima

$$2\beta d_{min} - \theta_r = (2n+1)\pi$$

$$d_{min} = \frac{\lambda}{4}\left(1 + \frac{\theta_r}{\pi}\right)$$

max value $|\tilde{V}(d)_{max}| = V_0^+ (1+\Gamma)$

$$|\tilde{V}(d)_{min}| = V_0^+ (1-\Gamma)$$

Voltage standing wave ratio (VSWR) $= \frac{|\tilde{V}_{max}|}{|\tilde{V}_{min}|}$

$$\boxed{S = \frac{(1+|\Gamma|)}{(1-|\Gamma|)}}$$

- for a matched load $|\Gamma| = 0$
  $S = 1$

- $S = \infty$; $|\Gamma| = 1$

- reflection cofficient depends on the impedence

input impedence:

at input $d = l$;

$$Z_{in} = Z_0 \left(\frac{Z_L + j \tan \beta l}{1 + j Z_L \tan \beta l} \right)$$

Z_0 → charc impedence

for short ckt:

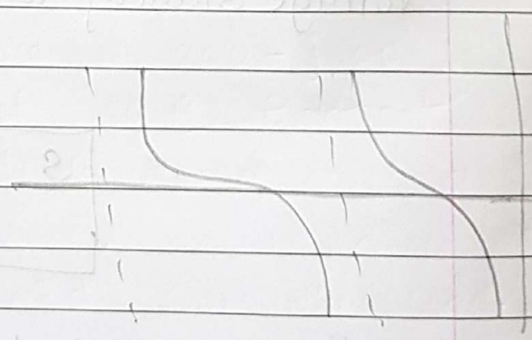
$j Z_0 \tan \beta l = j \omega L_{eq}$ if $\tan \beta l \geq 0$

$j Z_0 \tan \beta l = \dfrac{1}{j \omega C_{eq}}$ if $\tan \beta l \leq 0$

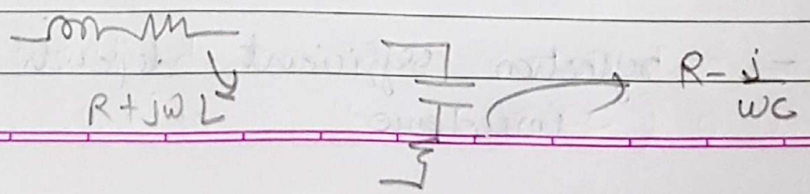
- $Z_L = 0$
  $l = 0$
  $Z_{in} = 0$

for open ckt:

- $Z_L = \infty$
  $l = 0$
  $Z_{in} = \infty$



max. Power transmitted theorem states that Z_L is the complex conjugate of the Z_{in}.



- distance is the normalised with the wavelength.

(Doubt) ? ZL is the normalised with the Zo

- in smith chart
  if we are at centered, $S = 1 \rightarrow$ Impedence matching

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Smith Chart

Ex: $\tilde{Z}_L = 1.0 + j1.0\ \Omega$, $l = 0.148\lambda$

find out the input impedence of a TL terminated in a load impedence Z_L.

* Direction clockwise $\longrightarrow$ towards generator
* if distance is in meter, then convert into λ mean divide by λ.

- find the SWR, Voltage max. & min
in the case of open circuit (max and min)
in the case of short circuit (min and max.)

(Vmin) SC ———— OC(Vmax)

- max and min $\lambda/4$ apart

Ex: The load impedence is $200 + j100$, $Z_0 = 50$. find out SWR, find out admittance, distance of max. and min. from load line, i/p impedence at distance of 0.25λ from the load.

$$\tilde{Z}_L = \frac{200 + j100}{50}$$

$$= 4 + 2j$$

- normalised impedence is plotted on Smith chart.
- SWR is on the (0 to OC) 0 line.

- at $\lambda/2$ max and min are repeated.

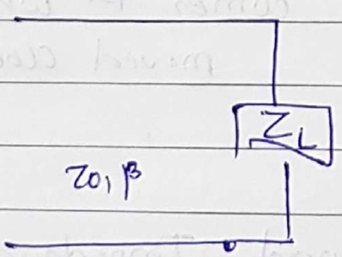
Smith chart :

- Graphical representation tool that represents a mapping b/w impedence and reflection coefficient.
- Completing 1 round on Smith chart $= \lambda/2$
- clockwise → towards generator / source
- Smith chart :
  - helps to measure 1st maxima and 1st minima
  - helps to find impedence at a certain point from the load.
- all circles have 1 common point → from there radius rises

  normalised distance, normalised values → plotted
- Stub: piece of line which is connected in transmission line for impedence matching

  it is connected in parallel mostly.

Ex:- find I/P impedence of TL terminated in load impeda. Z_L.



$z = l$ $\qquad$ $z = 0$

$\bar{Z}_L = 1 + j1$

$l = 0.148\lambda$

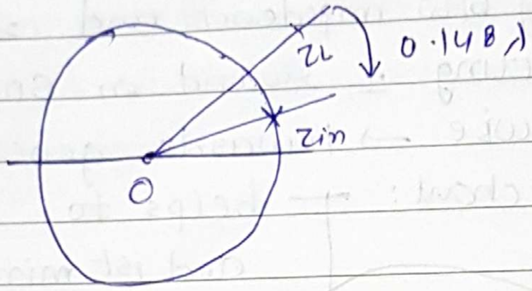
- move clockwise as we move from load to generator
  (1) Taking $O\bar{Z}_L$ as radius draw a circle with center at O.

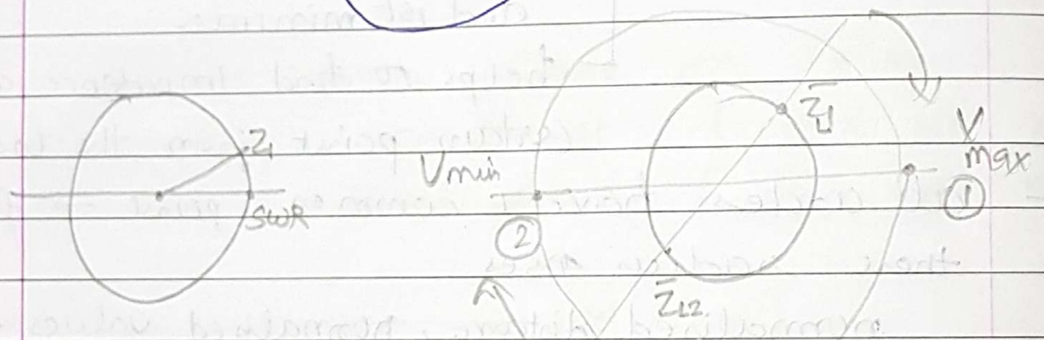
(2) extend $O\bar{z}_L$ line in the same direction till outer circle.

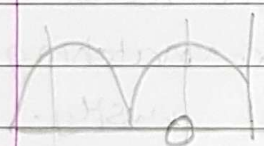
(3) Then move the line 0.148λ

(4) Draw a line from that point till O.

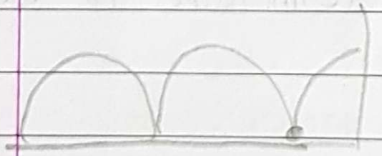
(5) The intersection of circle and line in zin.







For $\bar{Z}_{L1} \rightarrow$ we get V_{max} as Point-1 comes 1st when moved clockwise



For $\bar{Z}_{L2} \rightarrow$ we get V_{min} as Point 2 comes 1st when moved clockwise

Determine of unknown load Impedence from SWR

(1) Draw the circle of SWR

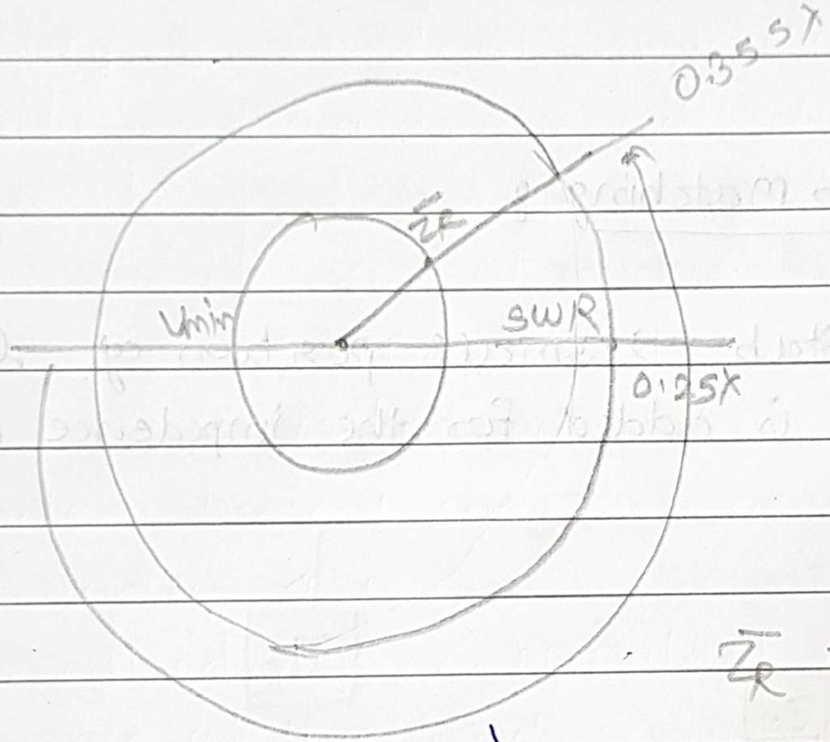
$Z_0 = 50\,\Omega$

$SWR = 3$

$\lambda/2 = 20\,cm$

$d_{min} = 14.2\,cm = 0.355\,\lambda$

$\bar{Z_R} = ?$



$\bar{Z_R} = 50\,(\bar{z_R})$

as load is to be found → so move anticlock wise

Date: 10 | Aug

Nela Potapenko

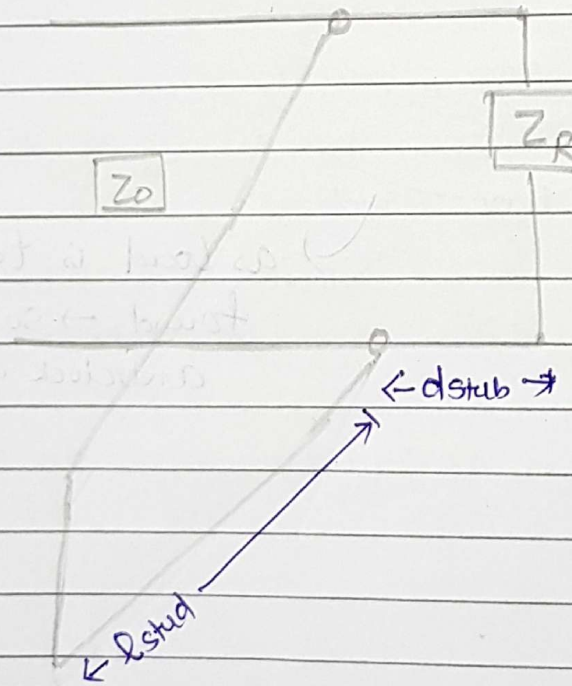
Quarter wave ($\lambda/4$) transformer :

- Impedence matching is only for a particular frequency.
- any char^c impedence of line is taken

$$Z_{0x} = \sqrt{RZ}$$

Single Stub matching :

Stub → small portion of line is added for the impedence matching.



- Coaxial cable.

Short ckt stub } — SC stub is perferred
Open ckt stub
(Keep as its)
(By conducting material is added)

- In planer, OC stub is perfered
- In coaxial, Tx line, SC " " ".

$Z_R = R + jX$

We need to match the ~~reactive part~~ resistive part R and opposite to the X reactive Part.

$R - jX'$ = stub) resistance

dstub ⟶ for the resistive part
lstub ⟶ " " reactive Part

- Stub is series or shunt
- shunt is perfered, bcoz its easy
- SD in transmission line shunt, SC stub is used.

Series ⟶ impedence
shunt ⟶ admittance

Exg $Z_L = 75 + j50$
$Z_0 = 25\Omega$
find dstub & Lstub

Sol: nomalised $z = 3 + j2$

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