05.08.25

UNIT- I

S-parameter

N port network

→ Incident sgl ⇒ V_n^+

→ Reflected sgl ⇒ V_n^-

$$\begin{bmatrix} V_1^- \\ V_2^- \\ \vdots \\ V_N^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1N} \\ S_{21} & S_{22} & \cdots & S_{2N} \\ \vdots & & & \\ S_{N1} & S_{N2} & \cdots & S_{NN} \end{bmatrix} \begin{bmatrix} V_1^+ \\ V_2^+ \\ \vdots \\ V_N^+ \end{bmatrix}$$

For 2 port network

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

Impedance is characterised to Z_0 then

$V = P$

$$P = \frac{V^2}{R} = VI = V\left(\frac{V}{R}\right)$$

$$\frac{P_1}{P_2} = \frac{V_1^2}{V_2^2}$$ provided same R (Impedance)

$$[V_n^-] = [S][V_n^+]$$

$$S_{ij} = \frac{V_i^-}{V_j^+}$$

observed port (i), Incident port (j)

$$S_{ij} = \frac{V_i^-}{V_j^+}\Bigg|_{V_k^+ = 0;\ k \neq j}$$

Means Terminated with Z_0, no reflection back

Eg: $S_{12}|_3$ (Terminated) Z_0

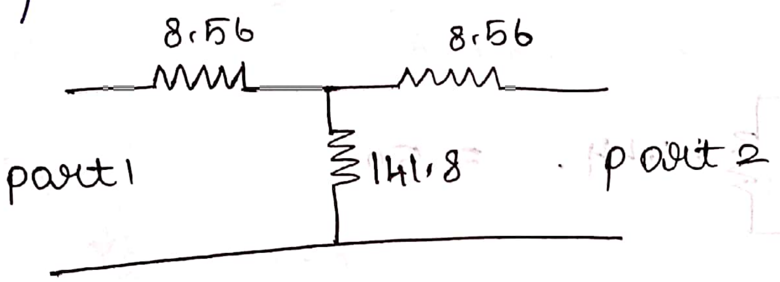
Incident port

Reflected port

port 1 → port 2 port 3 terminated.

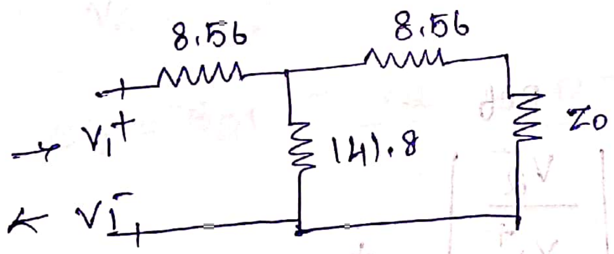
superheterodyne principle & ports at idle with termination for directional coupler

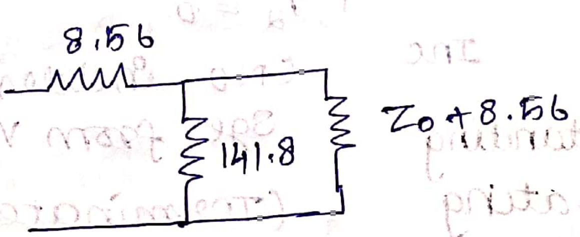
1.

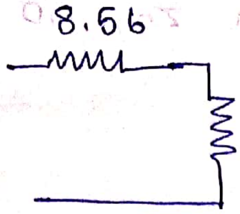


For $S_{11} = \left.\frac{V_1^-}{V_1^+}\right|_{V_2^+=0} = |\Gamma| =$ Reflection coefficient

$$\Gamma = \left.\frac{Z_{in}^{(1)} - Z_0}{Z_{in}^{(1)} + Z_0}\right|_{Z_2 \text{ terminated with } Z_0}$$







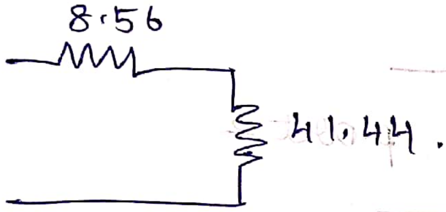
$$\frac{(141.8)(Z_0+8.56)}{141.8+Z_0+8.56}$$

$$\frac{141.8\times Z_0+141.8\times 8.56}{150.36+Z_0}=\frac{141.8\,Z_0+1213.808}{150.36+Z_0}$$

$$Z_0=50\,\Omega$$

$$=\frac{7090+1213.808}{200.36}=\frac{8303.808}{200.36}$$

$$=41.444.$$



$=50$

$$Z_{in}^{(1)}=50$$

$$S_{11}=\frac{Z_{in}^{(1)}-Z_0}{Z_{in}^{(1)}+Z_0}=0.$$

$S_{11}=S_{22}=0$ (Linear network)

<u>S_{12} (or) S_{21}</u>

$$S_{21}=\cancel{\frac{V_1^+}{V_2^-}}\left|\frac{V_2^-}{V_1^+}\right|_{V_2^+=0}$$

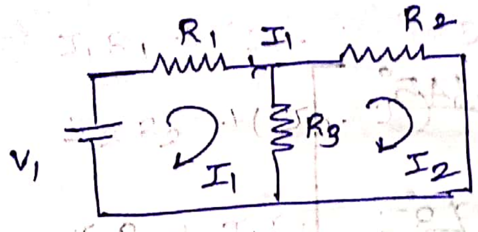
Ref

Inc

mismatch from load produce standing waves terminating sgl will not reflect back

(No incident sgl from V_2) (Terminated with Z_0)

$V_1^+ = V_1 \; , \; V_2^- = V_2$



current division

$$I_2 = \frac{I_1 R_3}{R_3 + R_2}$$

Voltage division

$$V_{R_2} = \frac{V_1 R_2}{R_2 + R_3}$$

S_{21}

$$V_2 = \frac{V_1 R_2}{R_2 + R_3}$$

$$V_2 = \left(\frac{41.44}{41.44 + 8.5}\right)\left(\frac{50}{50 + 8.5}\right) V_1$$

$$V_2 = 0.707 V_1$$

$$S_{12} = S_{21} = \frac{V_2}{V_1} = \frac{0.707 V_1}{V_1} = 0.707$$

$$S_{12} = S_{21} = -3\,dB \quad , 20 \log (0.707)$$

Hence it is a 3dB attenuator

Linear N/W $= |S_{11}|^2 + |S_{22}|^2 = 1$

If (3dB for $S_{12}, S_{21} \Rightarrow$ Amplifier)

2. The Network has S parameter value of

$$S = \begin{bmatrix} 0.15 \angle 0^\circ & 0.85 \angle 45^\circ \\ 0.85 \angle 45^\circ & 0.2 \angle 0^\circ \end{bmatrix}$$

i) Determine whether linear or not

ii) If port 2 is terminated with matched load what might be its return loss.

iii) If port 2 is shorted what will be the impact of return loss on port 1

iii) $V_2^+ = -V_2^-$ (standing wave will generate)

ii) $RL = -20 \log (\Gamma)$

$= -20 \log (S_{11})$

i) Linear Network $|S_{11}|^2 + |S_{22}|^2 = 1$

i) $|S_{11}|^2 + |S_{22}|^2 = 1$

$(0.15)^2 + (0.2)^2 = 0.0225 + 0.04$

$= 0.0625$

$\neq 1$

Hence not linear system

ii) $RL = -20 \log (\Gamma)$

$= -20 \log (S_{11})$

$= -20 \log (0.15)$

$R_L = 16.478$ dB.

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

$$V_2^+ = -V_2^-$$

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

$$V_1^- = S_{11} V_1^+ - S_{12} V_2^- \quad \text{—— (1)}$$

$$V_2^- = S_{21} V_1^+ - S_{22} V_2^- \quad \text{—— (2)}$$

From (2)

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

$$V_2^- (1+S_{22}) = S_{21} V_1^+$$

$$V_2^- = \left(\frac{S_{21}}{1+S_{22}} \right) V_1^+$$

In (1)

$$V_1^- = S_{11} V_1^+ - S_{12} \left(\frac{S_{21}}{1+S_{22}} \right) V_1^+$$

$$V_1^- = S_{11} V_1^+ - \frac{S_{12} S_{21}}{1+S_{22}} V_1^+$$

$$\frac{V_1^-}{V_1^+} = S_{11} - \frac{S_{12} S_{21}}{1+S_{22}}$$

Scanned with CamScanner

$$= (0.15\angle 0^\circ) - \frac{(0.85\angle 45^\circ)(0.85\angle 45^\circ)}{1+0.2\angle 0^\circ}$$

$$= (0.15\angle 0^\circ) - \frac{0.7225\angle 90^\circ}{1.2\angle 0^\circ}$$

$$= 0.15\angle 0^\circ - 0.602\angle 90^\circ$$

$$= 0.15 - 0.602j$$

$$\Gamma = 0.620$$

$$-20\log(0.620) = 4.152\,dB.$$

06.08.25

signal Flow Graph

→ primary components:

- Nodes

port i has 2 nodes a_i & b_i

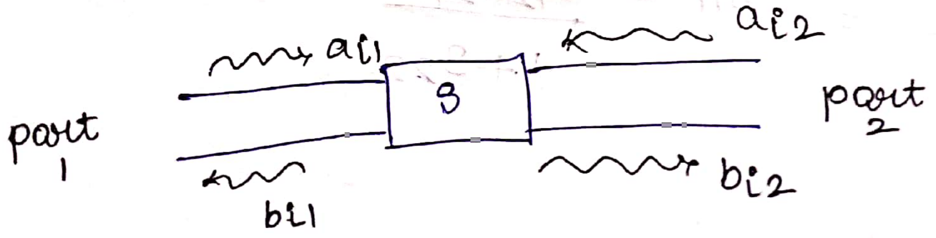
→ Node a_i (wave entering port i)

→ Node b_i (wave reflected from port i)

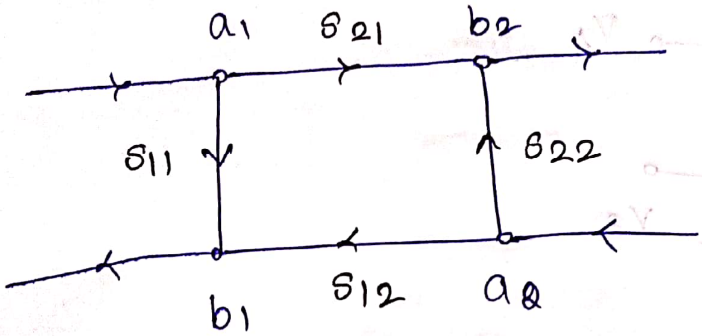
→ voltage at a node equal to sum of signals entering node

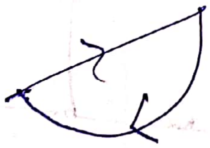
- Branch

Directed path between two nodes



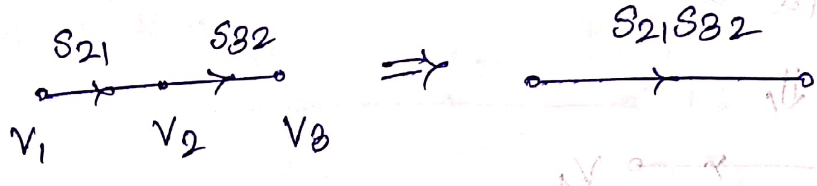
In SFG of 2 port network.



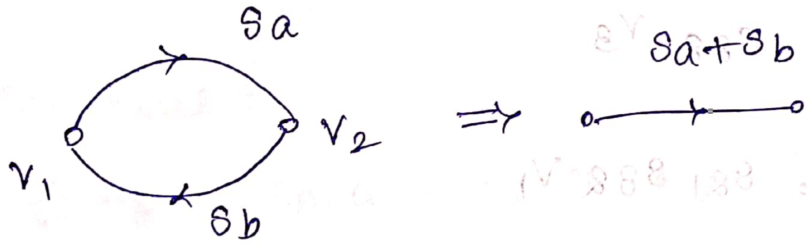


Mason's Rule

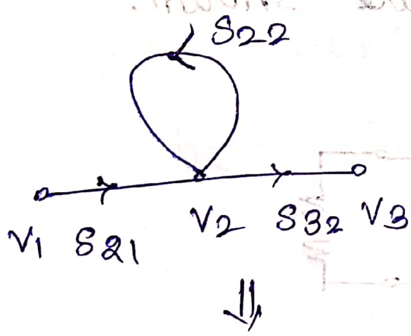
Rule: 1 series Rule



Rule: 2 parallel Rule



Rule: 3 self loop Rule.



$$V_2 = S_{21}V_1 + S_{22}V_2 \quad \text{—(1)}$$

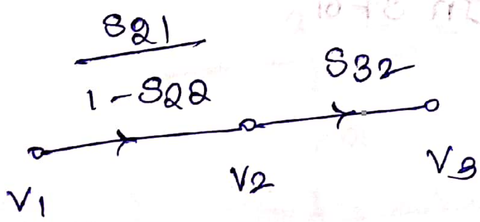
$$V_3 = S_{32}V_2 \quad \text{—(2)}$$

In (1)

$$V_2 - S_{22}V_2 = S_{21}V_1$$

$$V_2(1-S_{22}) = S_{21}V_1$$

$$V_2 = \frac{S_{21}V_1}{1-S_{22}}$$

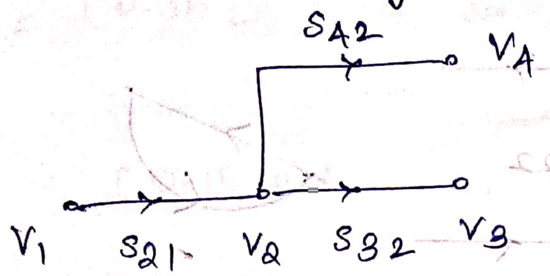


In (2)

$$V_3 = \frac{S_{32}\,S_{21}V_1}{1-S_{22}}.$$

Scanned with CamScanner

Rule 4 : Splitting Rule

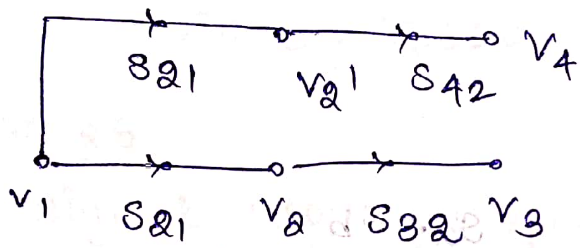


$V_4 = S_{42} V_2$

But $V_2 = S_{21} V_1$

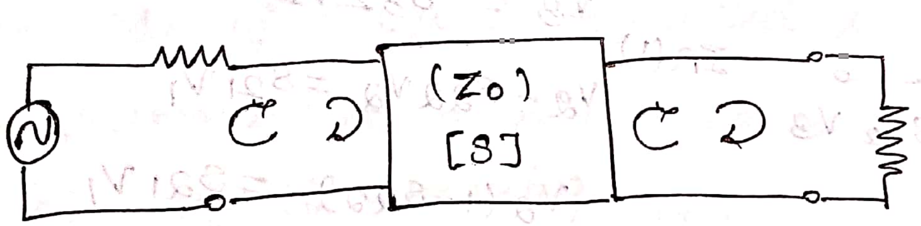
$V_4 = S_{42} S_{21} V_1$

$\Downarrow$

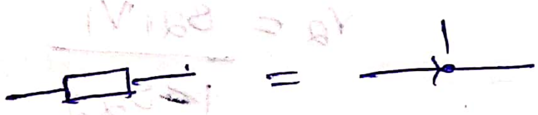


$V_3 = S_{21} S_{32} V_1$

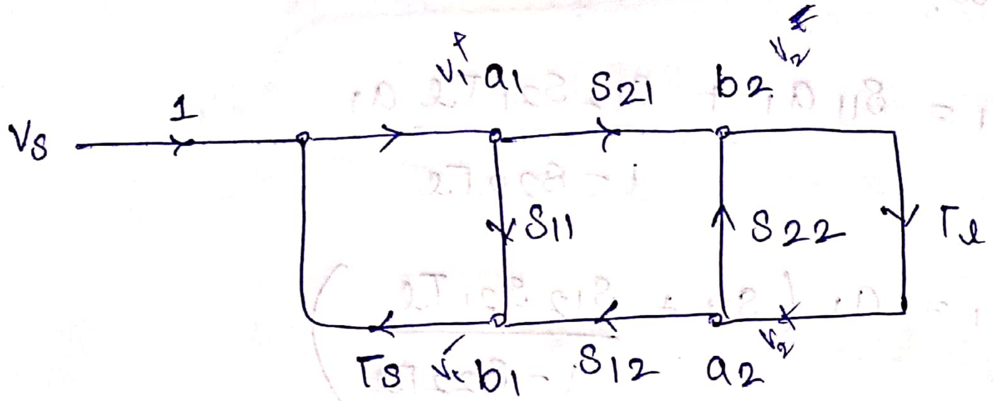
1. Use SFG to derive expressions for Γ_{in} & Γ_{out} for MW network shown.



In SFG

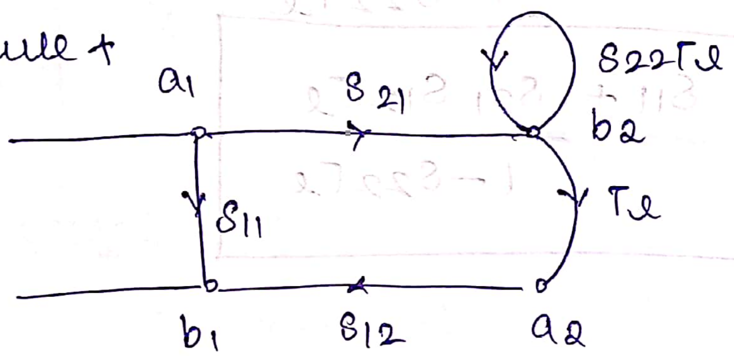


The SFG is given as follows.



$$\Gamma_{in} = \frac{b_1}{a_1} \quad \& \quad \Gamma_{out} = \frac{b_2}{a_2}$$

By Rule 4
~



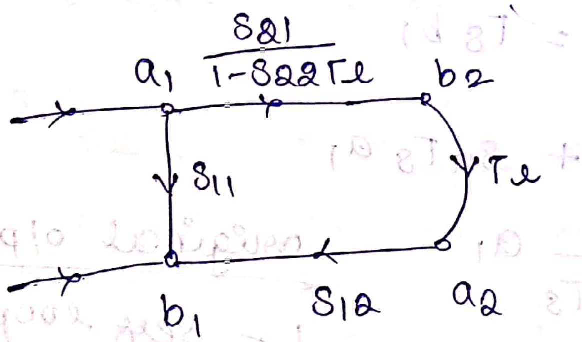
By Rule 3

$$b_2 = S_{21} a_1 + S_{22} \Gamma_L b_2$$

$$b_2 - S_{22} \Gamma_L b_2 = S_{21} a_1$$

$$b_2 (1 - S_{22}\Gamma_L) = S_{21} a_1$$

$$b_2 = \frac{S_{21} a_1}{1 - S_{22}\Gamma_L}$$



Now:

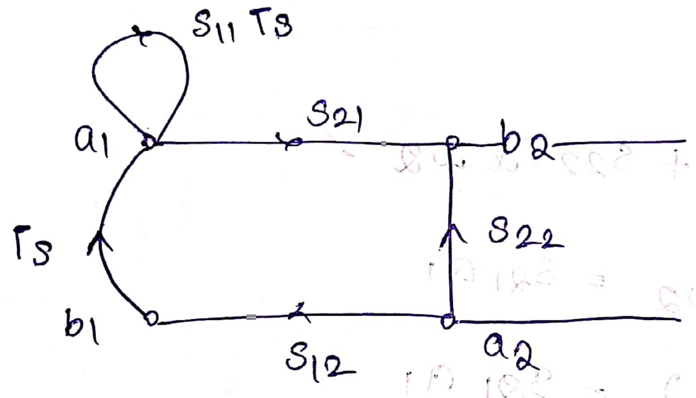
$$b_1 = S_{11} a_1 + \frac{S_{12} S_{21} \Gamma_L a_1}{1 - S_{22}\Gamma_L}$$

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

$$\frac{b_1}{a_1} = S_{11} + \frac{S_{21} S_{12} \Gamma_L}{1 - S_{22}\Gamma_L}$$

$$\boxed{\Gamma_{in} = S_{11} + \frac{S_{21} S_{12} \Gamma_L}{1 - S_{22}\Gamma_L}}$$

For Tout:



$$a_1 = \Gamma_S b_1 + S_{11}\Gamma_S a_1$$

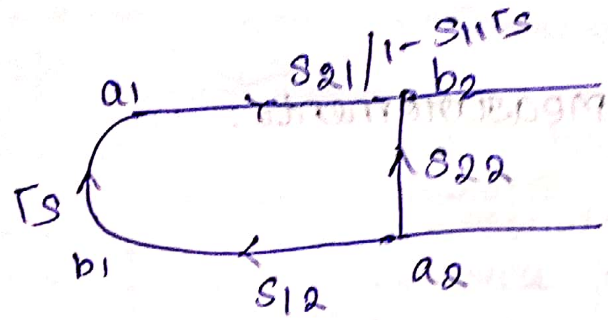
$$a_1 - S_{11}\Gamma_S a_1 = \Gamma_S b_1$$

$$a_1 (1 - S_{11}\Gamma_S) = \Gamma_S b_1$$

$$b_2 = S_{21} a_1 + S_{11}\Gamma_S a_1$$

$$b_2 = \frac{S_{21}}{1 - S_{11}\Gamma_S} a_1$$

$\frac{\text{original o/p}}{1 - \text{self loop gain}}$



$$b_2 = S_{22}\, a_2 + \frac{S_{21} S_{12} \Gamma_S}{1 - S_{11}\Gamma_S}\, a_2$$

$$\boxed{\frac{b_2}{a_2} = S_{22} + \frac{S_{21} S_{12} \Gamma_S}{1 - S_{11}\Gamma_S}}$$

TX coefficient

$$\frac{b_2}{a_1} \text{ (or) } \frac{b_1}{a_2}$$

$$\left.\frac{b_2}{a_1}\right|_{a_2=0} \quad \text{hence} \quad = \frac{S_{21}}{1 - S_{22}\Gamma_L}$$

$$\left.\frac{b_1}{a_2}\right|_{a_1=0} \Rightarrow b_1 = S_{11}\Gamma_S b_1 + S_{12} a_2$$

$$b_1 (1 - S_{11}\Gamma_S) = S_{12} a_2$$

$$\boxed{b_1/a_2 = S_{12}/1 - S_{11}\Gamma_S}$$

$$b_1 = S_{11} a_1 + S_{12} a_2 \quad \text{——— (1)}$$

$$b_2 = S_{21} a_1 + S_{22} a_2 \quad \text{——— (2)}$$

(2) $b_2 = S_{21} a_1 + S_{22} \Gamma_L b_2$

$$b_2 (1 - S_{22}\Gamma_L) = S_{21} a_1$$

$$\boxed{\frac{b_2}{a_1} = \frac{S_{21}}{1 - S_{22}\Gamma_L}}$$

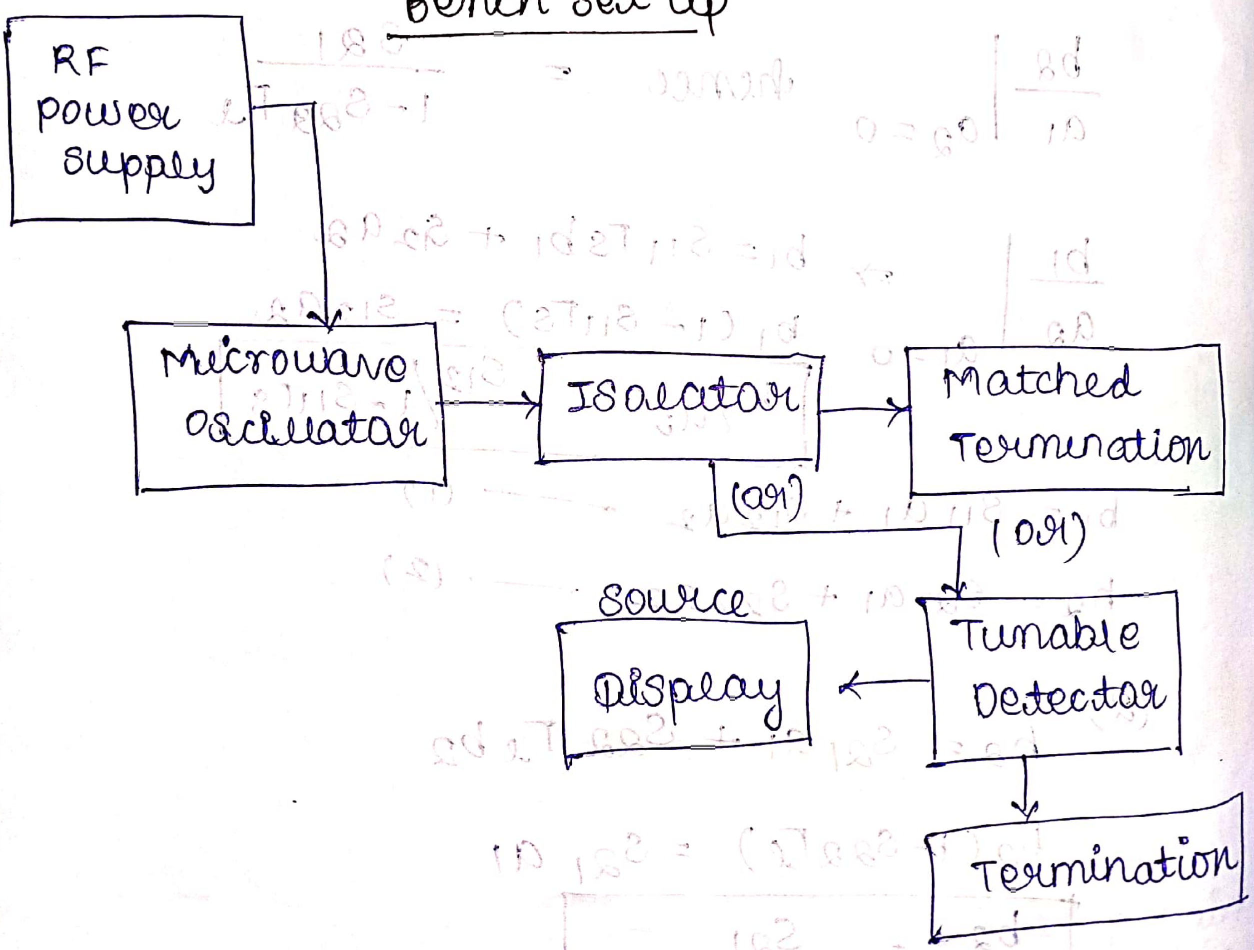
12.08.25

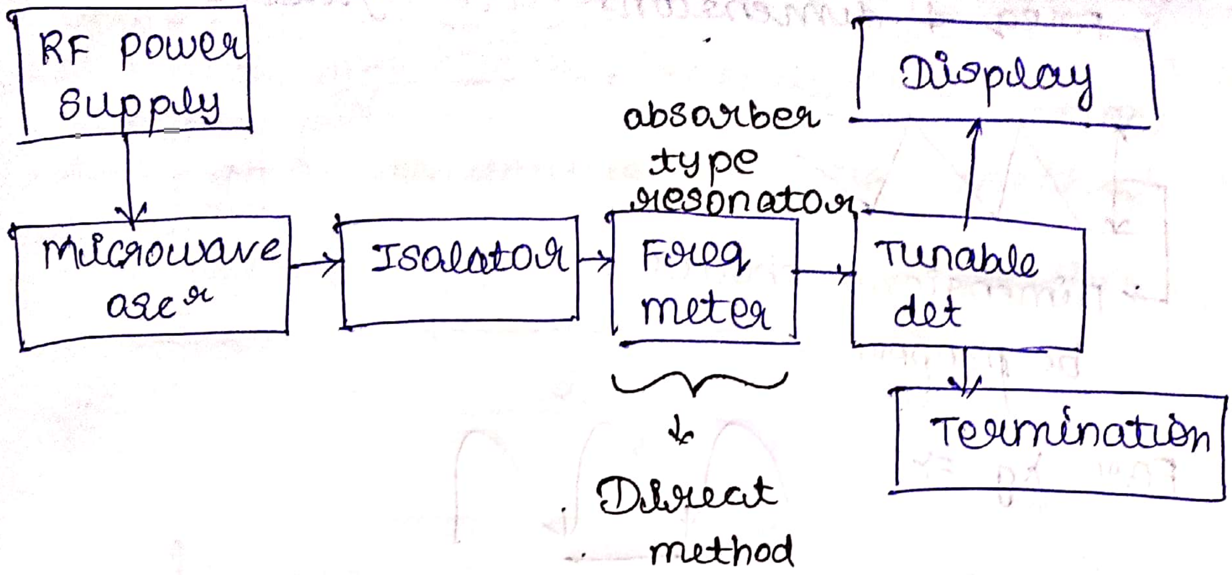
Microwave Measurements:

→ Frequency
→ Wavelength
→ VSWR
→ Impedance
→ power

Reflex Klystron or any μW Osc^{r} → Isolator (safe from Reflections) [stops one way only I/p → O/p] → Detector

Bench set up



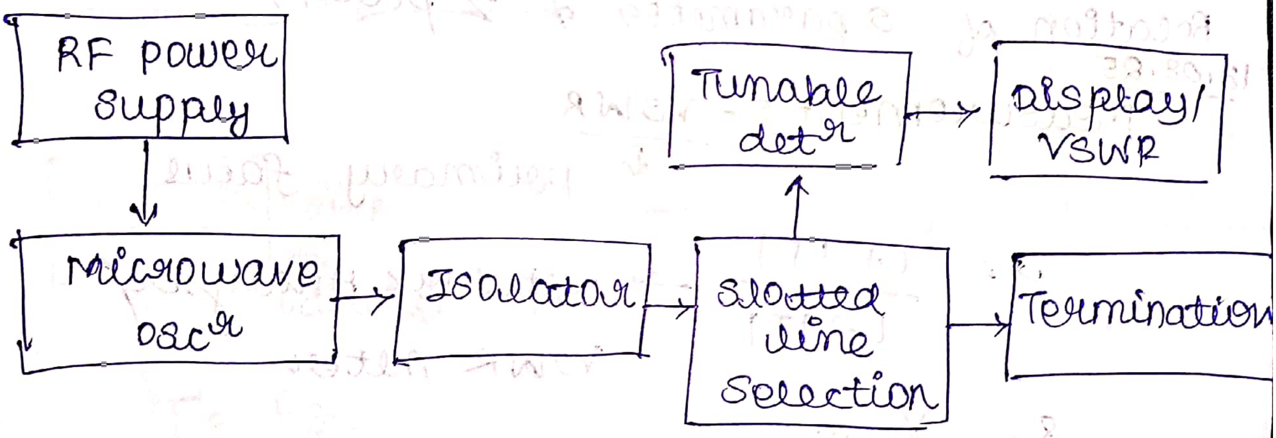


Indirect method:

$$\lambda_0 = c/f_0$$

$c = 3\times10^8$ m/s

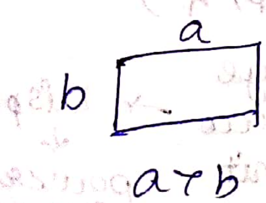
Indirectly measuring λ_0 we will get f_0.



$$\frac{1}{\lambda_0^2} = \frac{1}{\lambda_g^2} + \frac{1}{\lambda_c^2}$$

λ_g = guided wavelength

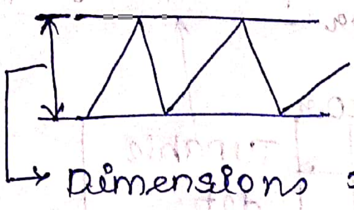
λ_c = Freq of operation.



$\lambda_c = 2a$

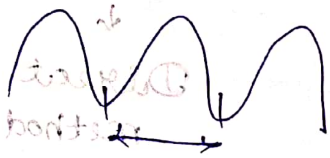
waveguide.

Freq & dimensions are fixed



Dimensions should be proper

For λ_g ⇒



$$d_{min} = \frac{\lambda_g}{2}$$

$$\lambda_g = 2 d_{min}$$

Explain Test bench then explain the procedure briefly.

Relation of S parameter & Z para / Y

18.08.25

Measurements - VSWR

↓ primary focus

$$S = \frac{1+|\Gamma|}{1-|\Gamma|}$$ → Network Analyser / VSWR meter

$$S = \frac{V_{max}}{V_{min}}$$

Network Analyser → Ref^n coefficient
↓
VSWR

VSWR

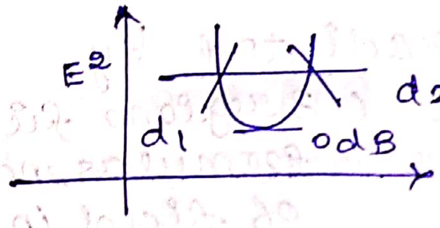
Directional coupler → RF Detector (Schottky diodes) → Sgl cond'ng unit → Sgl proc unit (DSP, μP) → Disp ↓ power supply

differential

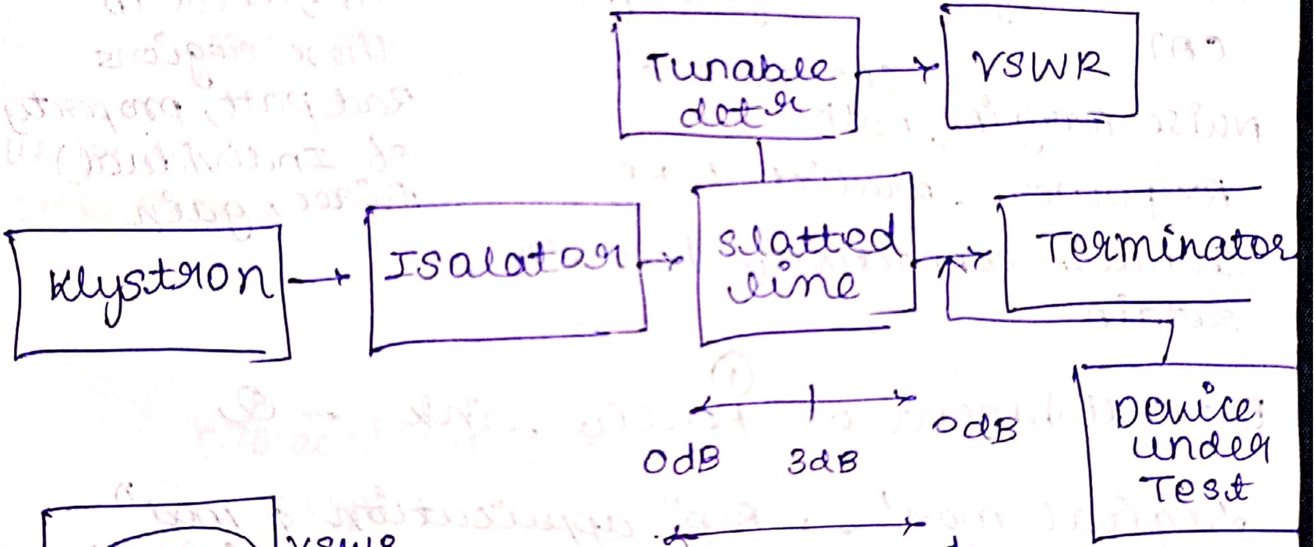
VSWR — Low ⇒ VSWR 4 & <4 directly read
— High ⇒ >4 (Analytical calculation)

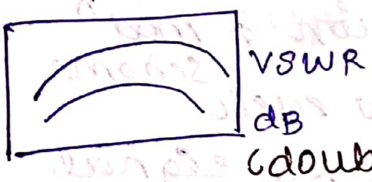
we go with double minima method
↓
slotted line section

$$\theta = \frac{\lambda g}{\pi(d_1 - d_2)}$$



Half power in Elect $= \left(\frac{E}{\sqrt{2}}\right)^2$





(double minima method)

$$T = \frac{P_{for}}{P_{ref}}$$

21.08.25

Impedance measurement:

Relationship b/w VSWR and Reflection coefficient

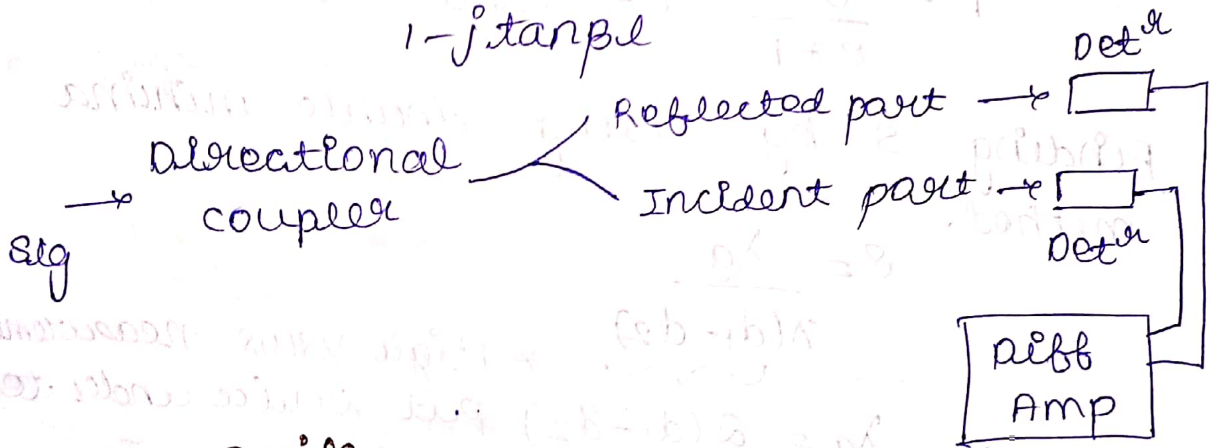
* Barlage (Balance Bridge) → Low μwave frequencies
* Slotted line → Medium and high.
* Impedance meters → Direct, High freq.
* Network Analyser → Medium, High freq
  → S-parameter accounted

$Z_0 = 50\Omega$

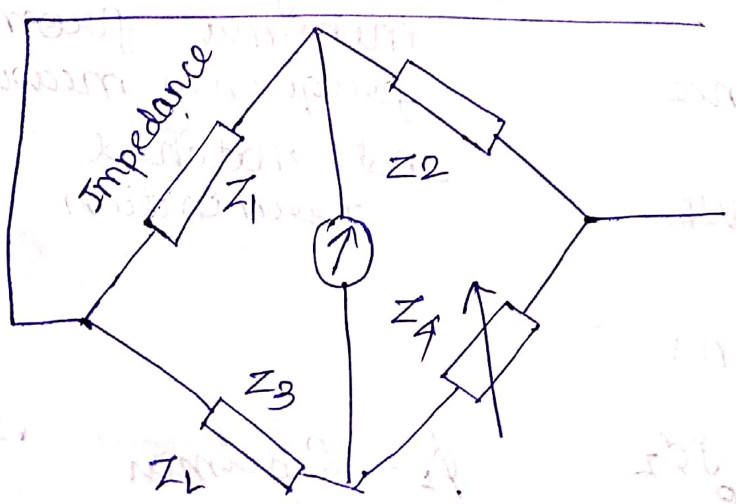
$$Z = Z_0 \frac{1+|\Gamma|}{1-|\Gamma|}$$

unknown Impedance $= Z_0 \dfrac{1+j\tan\beta l}{1-j\tan\beta l}$

Known Impedance + S parameter valuation.



Balance Bridge



→ All Impe. matches Galvanometer zero deflection

→ mismatch also shown in Galvanometer

$$\frac{Z_1}{Z_3} = \frac{Z_2}{Z_4}$$

$Z_3 = \frac{Z_4}{Z_2} \times Z_1$ if Z_3 is unknown.

and initially fixing variable impedance Z_4 and fixed Z_1 & Z_2 impedance tuning we can get null deflection

phase: $\theta_1 + \theta_3 = \theta_2 + \theta_4$

Slotted line section

$$Z_L = Z_0 \frac{1+|\Gamma|}{1-|\Gamma|}$$

$$\Gamma = \frac{S-1}{S+1} \quad S = VSWR$$

Finding S by using double minima method.

$$S = \frac{\lambda_g}{\pi(d_1 - d_2)}$$

→ High VSWR measurement put device under test

$$\lambda_g = 2(d_1 - d_2)$$

→ using 2 successive minima from frequency measurement and matched Termination

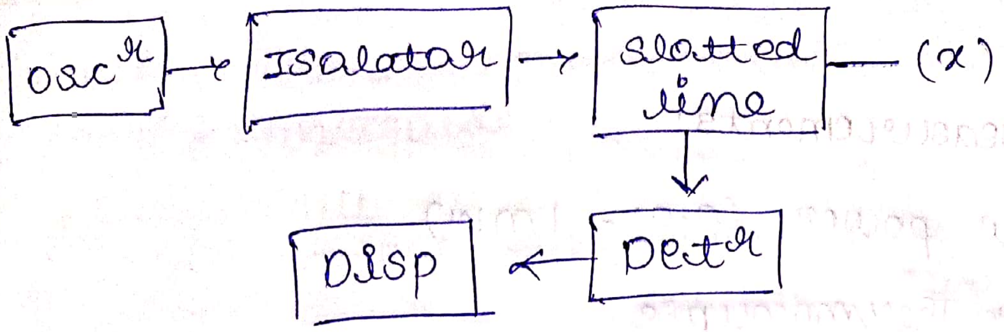
DUT ⇒ matches Impedance
↓
Low VSWR

phase variation:

$$\Gamma_L = \Gamma e^{j\phi_L}$$

$$\phi_L = 2\beta d_{min}$$

$$\beta = 2\pi/\lambda_g$$



(x)

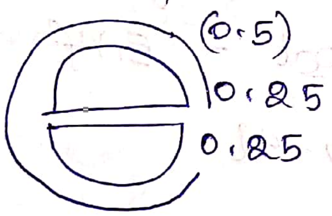
1. Load → S
2. Matched Termination → X_{min} (d_1')
3. perfect conductor → Vmin → d_2'
(move slotted line)

$$d_{min} = d_2' - d_1'$$

Smith chart

→ VSWR circle

→ Dmin - plot towards load



Short ckt end <<< Impedance >>> open end

For admittance

$$Y = \frac{1}{Z}$$

$$Y = \frac{1}{Z + 0.5j}$$

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25.08.25

power Measurements:

very low power (0.01 – 1mW)

↳ Thermocouple

low power (0.1 – 10mW)

↳ Balometer

Medium power (10mW – 10W)

↳ Balometer with directional coupler

High power (10W – 1KW)

↳ calorimetric watt

very low power:

Sb - Bi Thermocouple - wires joined together - plates get heated - EMF gets generated between Sb-Bi

low power

Balometer → Resistive temperature variances

↓

Either in waveguide meters (or) co-axial cables.

→ positive (P↑ R↑) Barreters

→ Negative (P↑ R↓) Thermistors Resistors

Input power → waveguide

Cut to detect → Galvanometer

(null deflection = no power)

variations in Resistivity → Deflections

Medium power

Bolometer + DC

↓

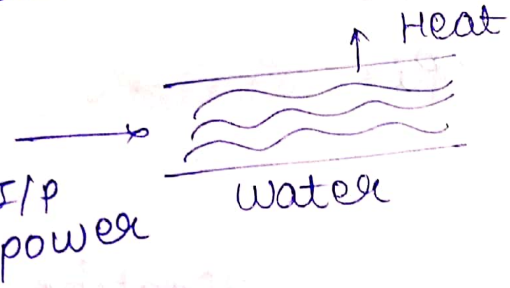
couples the signals

→ Boosting up the signal.

→ Increase coupling factor

High power

calorimetric wattmeter



(Temperature variations)

checks the Inlet and outlet temp. variation

$$P = 4.187 \cdot c \cdot Vd \cdot \Delta T \cdot W$$

c - specific heat of water

v - rate of water

d - density of water

Attenuation measurement:

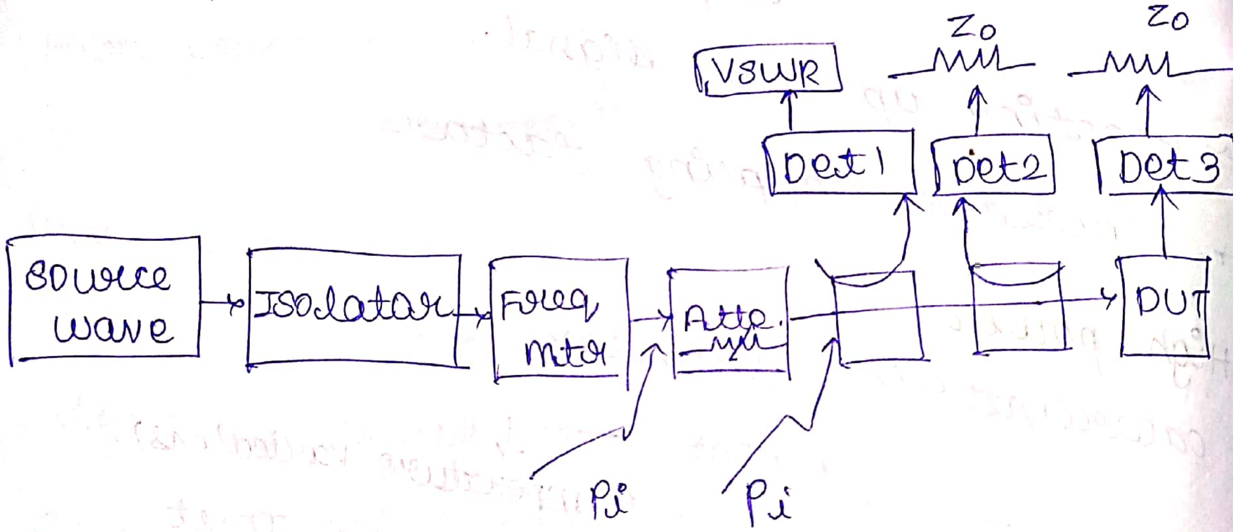
DUT by subtracting reflection loss from insertion loss.

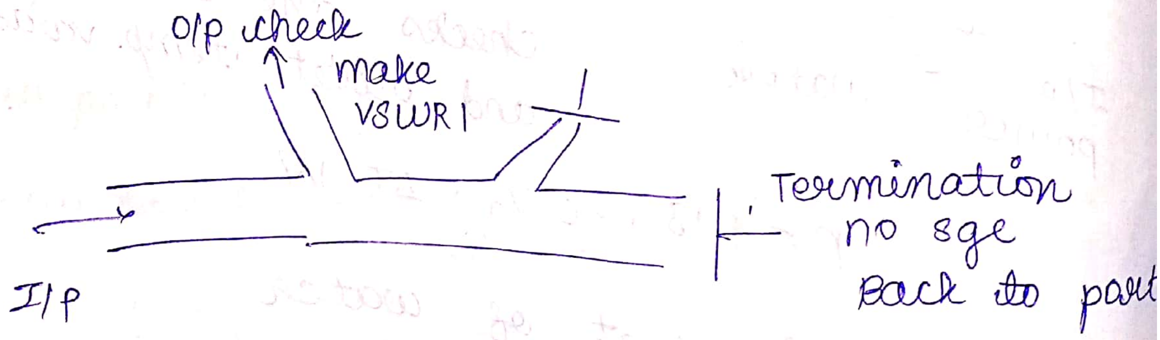
Forward dir → DUT

reflected power — Any Reflections

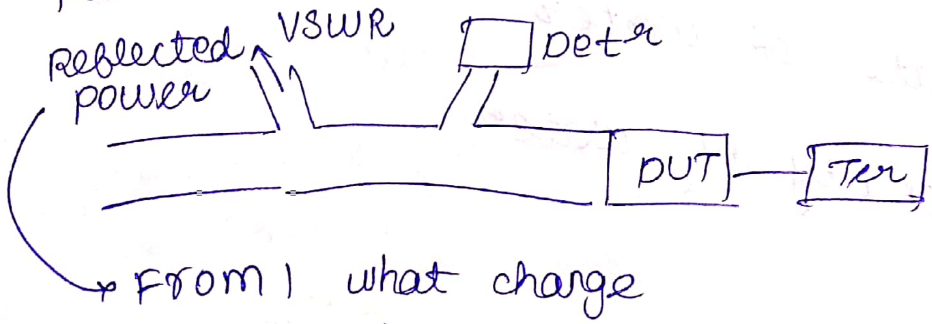
coupled power

output port → matched Termination



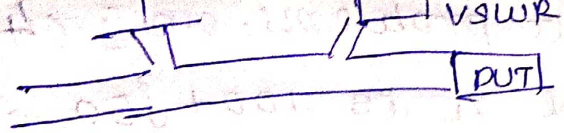


Freeze no reflector



→ From 1 what change

(Refn loss) Return loss as other parts are not at Ter. now



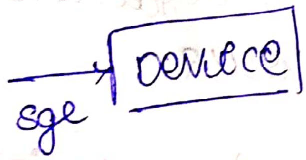
→ VSWR at coupling port.

→ variations give Insertion loss.

Attenuation loss = Reflection loss − Insertion loss.

Noise Measurement

Spectrum Analyser



→ with device, signal variations & without device variation difference provides Noise figure)

→ S/N over particular spectrum.

* Thermistors not used in real time approach

* calorimetric value is not for real time not for RF commⁿ.

* Low + medium power we engage → Bolometer is normally of use.

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26.08.25 Smith chart problems. CIA-II (4 marks)

1. Load Impedance of Z_L is $100+j50\ \Omega$ is connected to 50Ω transmitter line. plot normalized load on smith chart. determine Γ_L both magnitude and phase. calculate VSWR.

2. For the Transmitter line with $Z_0 = 75\Omega$ the Γ_L at the load is measured as $0.4\angle 60°$. Locate Γ_L Ref^n coefficient. determine Z_L, calculate VSWR.

3. The Transmission line of characteristic impedance 50Ω is terminated with a load $Z_L = 25 - j25\ \Omega$, plot the load on the smith chart and draw constant VSWR circle. determine VSWR Find input impedance at a distance $\lambda/8$ from the load

Given:

1. $Z_0 = 50\Omega$

$Z_L = 100 + j50\ \Omega$

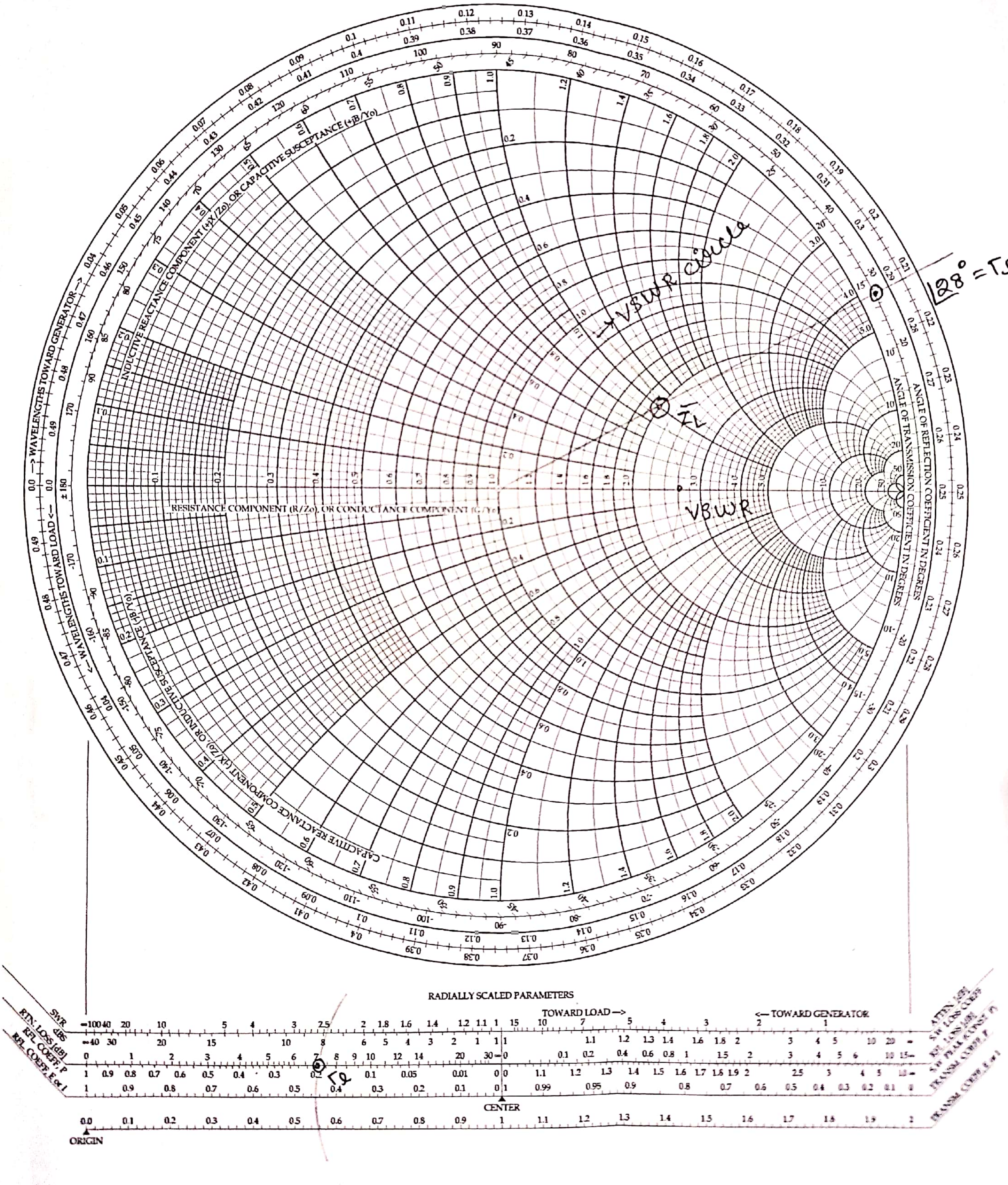
$$\bar{Z}_L = \frac{100+j50}{50} = 2+1j$$

Ref^n coeff (power) $= 0.2\angle 28°$

VSWR = 2.6

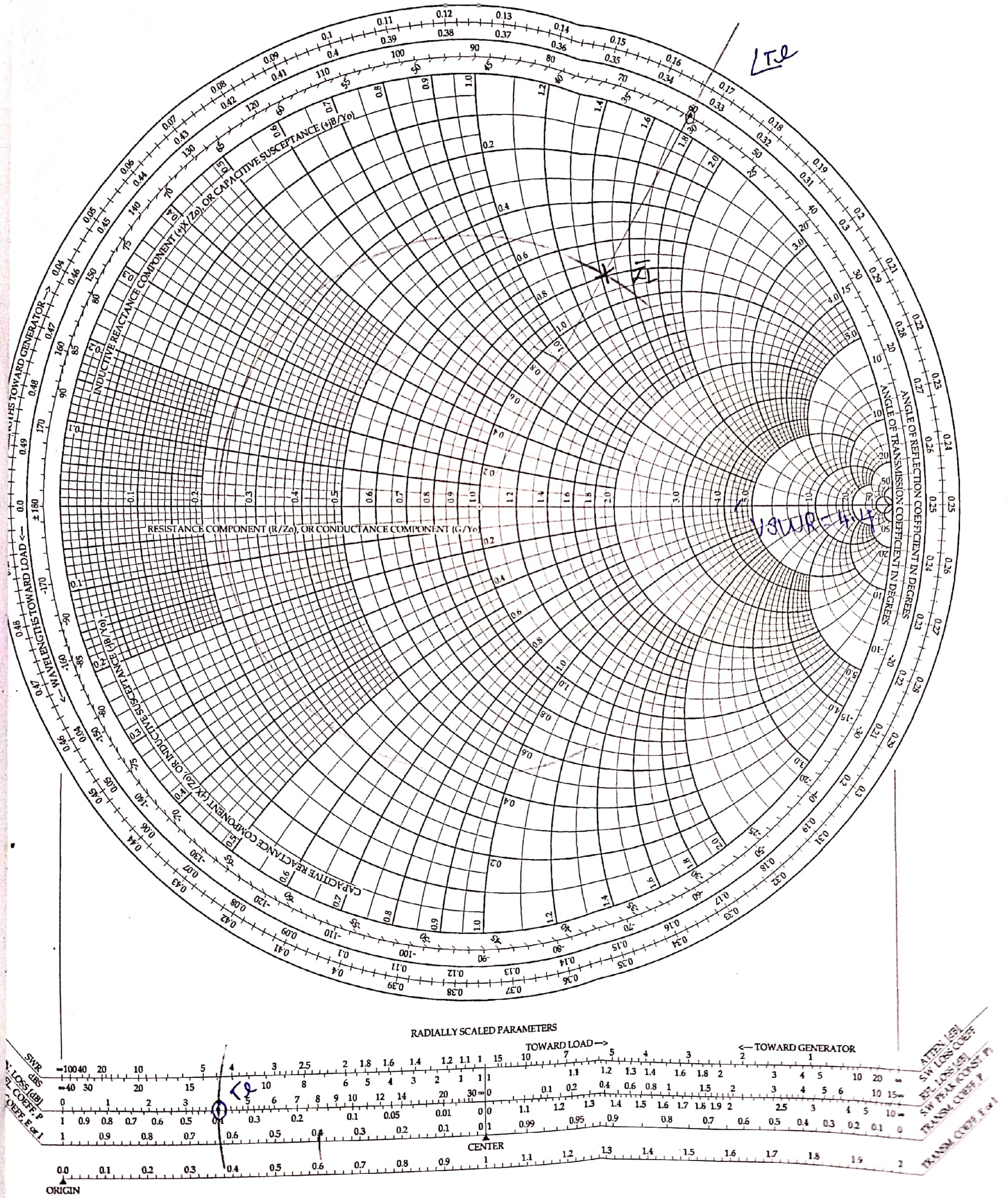
Q1).

Smith Chart



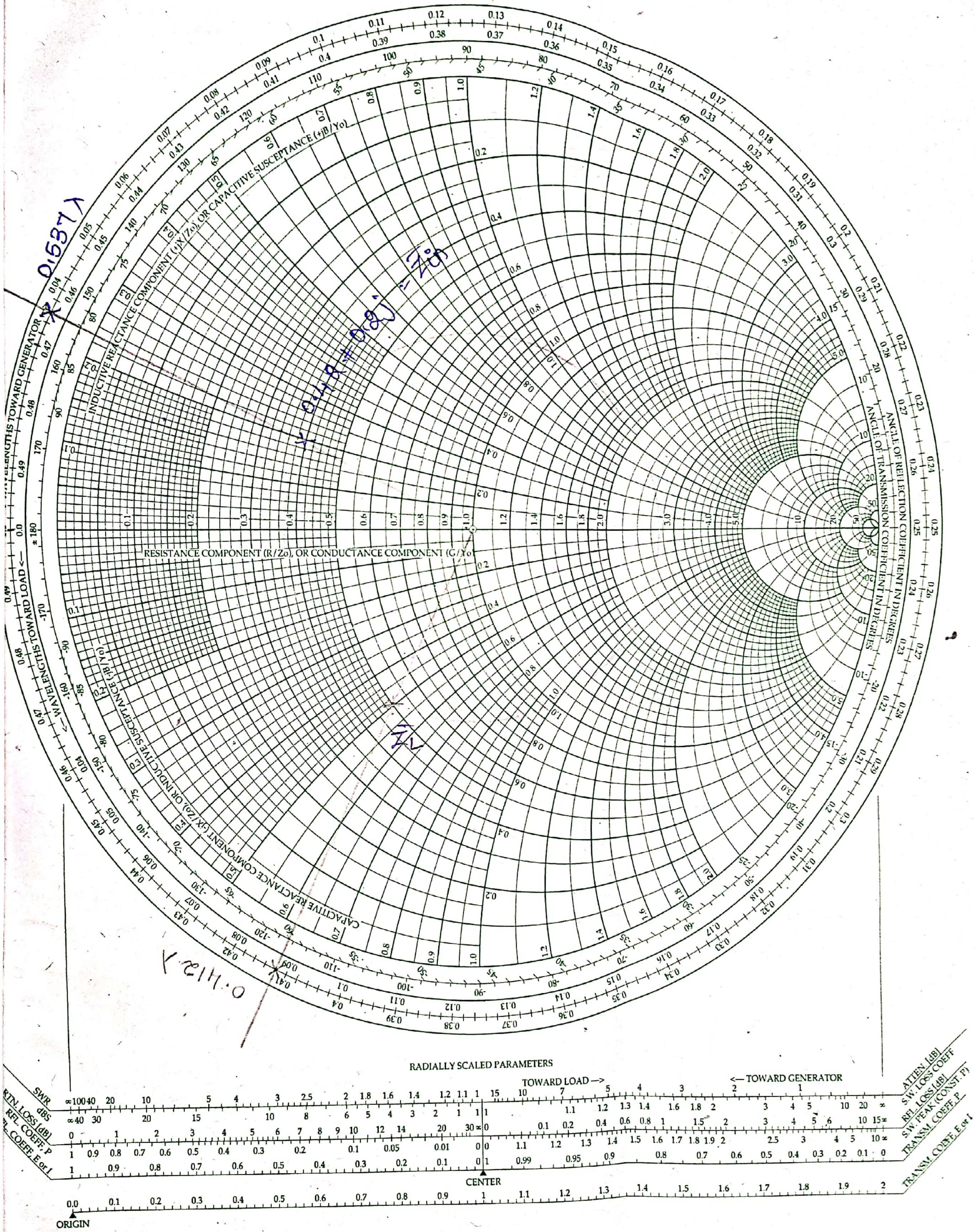
2) Q2)

Smith Chart



3) Q3)

DATE



Smith Chart

2) Ref^n coefficient = $0.4 \angle 60^\circ$

$$\bar{Z}_L = \frac{Z_L}{Z_0}$$

$$0.8 + 1.4j = \frac{Z_L}{Z_0}$$

$Z_0 = 75$

$Z_L = 60 + 105j^\circ$

A - II

= 20 = 5×4

0 = 30 (Either or) = 10×3

50

3. $Z_l = 25 - 25j^\circ$

$$\bar{Z}_l = \frac{25 - 25j^\circ}{50} = 0.5 - 0.5j.$$

$\bar{Z}_{in} = 0.42 + 0.2j$

$Z_{in} = (0.42 + 0.2j)\, 50 = 21 + 10j$

Towards Gen^r: Z_l given and find source

Towards Load: Z_s given and find Load.