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Unit -2

RF Transfer Amplifier Design and Matching Circuits

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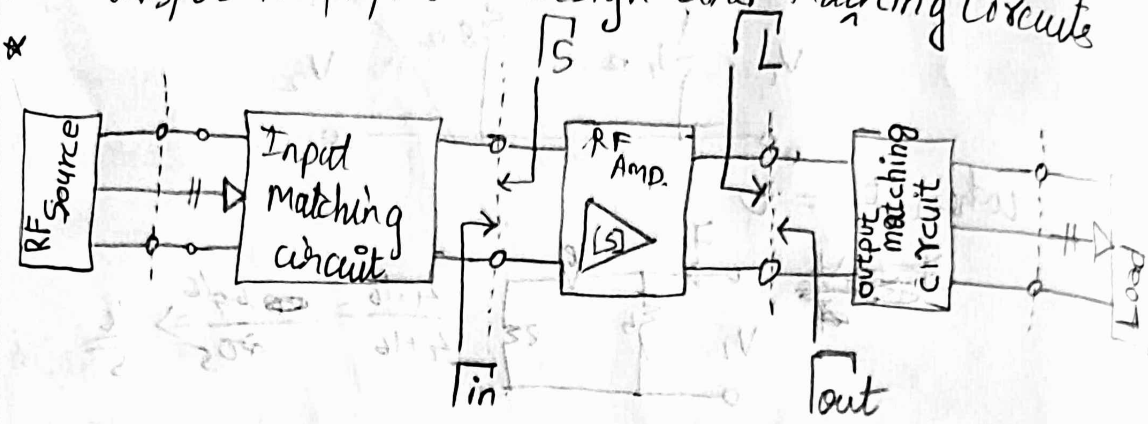
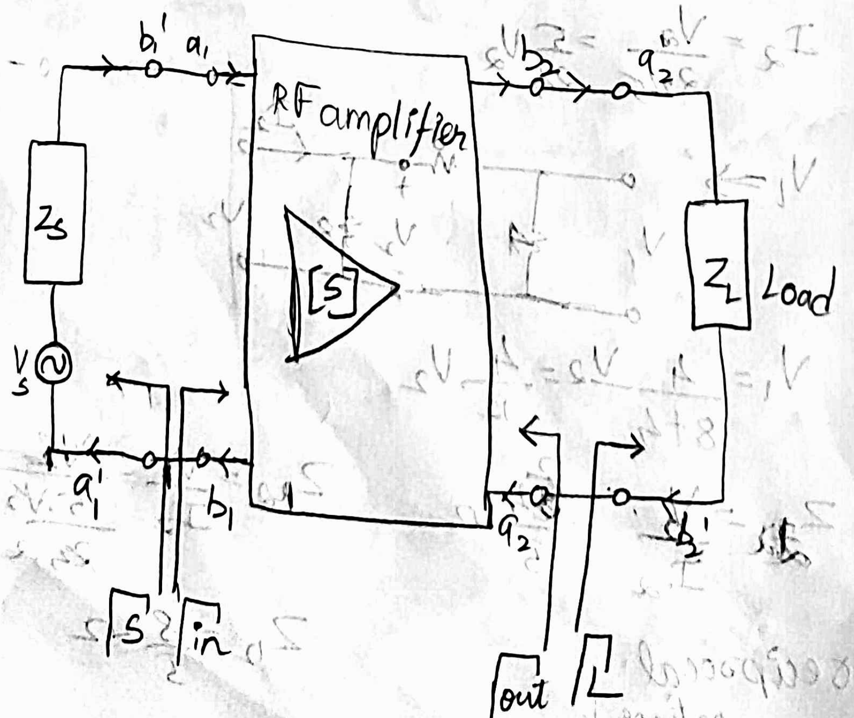
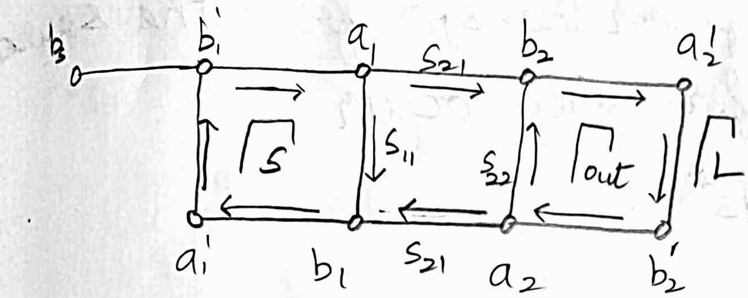


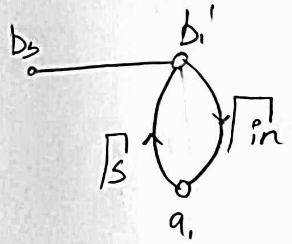
* Amplifiers can oscillate when terminated with certain ranges at source & load impedances.
* Matching networks can help stabilise the amplifier by keeping the source & load impedances in the appropriate range.
* In amplifier design process stability analysis is first step.
* The gain & noise figure, output power, BW & bias conditions are the basic requirement needed to develop an amplifier circuit.
* Amplifier power relations:



Signal flow graph.



* Incident Power, $P_{inc} = \frac{1}{2}|b_1'|^2$ ↳ rms voltage



using mason's rule [from control system]

$$\frac{b_1'}{b_s} = \frac{1}{1-\Gamma_s\Gamma_{in}}$$

So $P_{inc} = \frac{1}{2}\frac{|b_s|^2}{|1-\Gamma_s\Gamma_{in}|^2}$

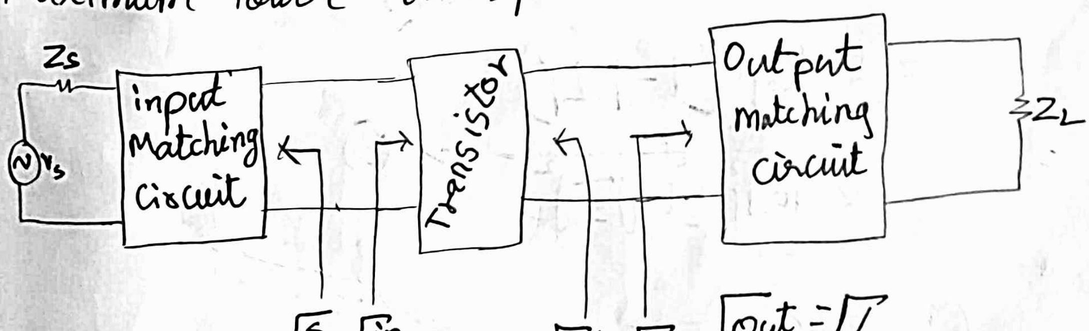
* Input Power, $P_{in} = P_{inc}\left[1-|\Gamma_{in}|^2\right]$

$$P_{in} = \frac{1}{2}\frac{|b_s|^2\left[1-|\Gamma_{in}|^2\right]}{|1-\Gamma_s\cdot\Gamma_{in}|^2}$$

* Power available at amplifier (P_A)

$$P_A = \frac{1}{2}\frac{|b_s|^2\left(1-|\Gamma_s|^2\right)}{\left|1-|\Gamma_s|^2\right|^2} \quad \text{i.e. } \Gamma_s = \Gamma_{in}$$

06/03/23 Maximum Power transfer theorem:-



$\Gamma_{out} = \Gamma_L$

$Z_{in} = Z_s^*$

$\Gamma_{in} = \Gamma_s^*$

If the input impedance is matched with complex conjugate of source impedance, or in terms of reflection coefficient, $[\Gamma_{in} = \Gamma_s^*]$ then the max^m power transfer from the source to the amplifer will occur

$$P_A = P_{in}\Big|_{\Gamma_{in} = \Gamma_s^*}$$

$$= \frac{1}{2} \frac{|b_s|^2 (1 - |\Gamma_{in}|^2)}{|1 - \Gamma_{in}\Gamma_s|^2}$$

$$= \frac{1}{2} \frac{|b_s|^2 (1 - |\Gamma_{in}|^2)}{|1 - (\Gamma_{in})^2|^2}$$

$$P_A = \frac{1}{2} \frac{|b_s|^2}{|1 - (\Gamma_{in})^2|} \rightarrow (1)$$

if $\Gamma_{in} = 0$ and $\Gamma_s \neq 0$

then

$$P_A = \frac{1}{2} |b_s|^2 \rightarrow (2)$$

Transducer power gain:- $[G_T]$

$$G_T = \frac{\text{Power delivered to load}}{\text{Power available at Amplifier}}$$

$$= \frac{\frac{1}{2} |b_s|^2 (1 - |\Gamma_L|^2)}{\frac{1}{2} |b_s|^2 (1 - |\Gamma_s|^2)} \rightarrow (3)$$

$$G_T = \frac{(1 - |\Gamma_L|^2)}{(1 - |\Gamma_s|^2)}$$

using mason's rule in SFG,

$$\left|\frac{b_2}{b_5}\right| = \frac{\sum P_K \Delta_K}{\Delta}$$

$P_1 = S_{21}$

$\Delta_1 = 1$

$\Delta = 1 - [S_{11}\Gamma_S + \Gamma_L S_{22} + S_{21}\Gamma_L S_{12}\Gamma_S + \Gamma_S S_{11}\Gamma_L S_{22}]$

$$= \frac{P_1 \Delta_1}{\Delta}$$

$$= \frac{S_{21}}{1 - (S_{11}\Gamma_S + \Gamma_L S_{22} + S_{21}\Gamma_L S_{12}\Gamma_S - \Gamma_S S_{11}\Gamma_L S_{22})}$$

$$= \frac{S_{21}}{1 - [S_{11}\Gamma_S + \Gamma_L S_{22} + (S_{21}S_{12} - S_{11}S_{22})\Gamma_L\Gamma_S]}$$

$$\left|\frac{b_2}{b_5}\right| = \frac{S_{21}}{(1 - S_{11}\Gamma_S) - (\Gamma_L S_{22}(1 - \Gamma_S S_{11}) - S_{21}S_{12}\Gamma_S\Gamma_L)}$$

Unilateral power gain:- $[G_{TU}]$

$$G_{TU} = \frac{|S_{21}|^2 (1 - |\Gamma_L|^2)(1 - |\Gamma_S|^2)}{|1 - \Gamma_S S_{11}|^2 \, |1 - \Gamma_L S_{22}|^2} \qquad S_{12} = 0$$

Additional Power relations:-

$$G_A = \frac{\text{Power available @ the network}}{\text{Power available @ source side}}$$

$$= \frac{P_N}{P_S \text{ or } P_A}$$

$$G_A = \frac{|S_{21}|^2 (1 - |\Gamma_S|^2)}{(1 - |\Gamma_{out}|^2)|1 - S_{11}\Gamma_S|^2}$$

$\downarrow$

Available power gain

Stability consideration :-

* An amplifier circuit must be stable over the entire freq. range

* The RF circuits tend to oscillate depending on the operating freq. and the terminations

* for the circuit's oscillation is possible if either input or output port impedance has the negative real part which implies that $\Gamma_{in} < 1$ or $\Gamma_{in} > 1$ & $\Gamma_{out} < 1$ or $\Gamma_{out} > 1$

* Γ_{in} & Γ_{out} depends on the source & load matching networks, the stability of amplifier which depends on Γ_S & Γ_L as presented by matching networks.

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* $|\Gamma_{in}| < 1 \Rightarrow |S_{11}| < 1 \Rightarrow$ stable circuit

$|\Gamma_{in}| < 1 \Rightarrow |S_{11}| > 1 \Rightarrow$ part of circuit is stable

* $|\Gamma_{in}| < 1 \Rightarrow |\Gamma_{out}| < 1 \Rightarrow |\Gamma_S| < 1 \Rightarrow$ Unconditionally stable

* in certain freq. ranges the above condition leads to conditionally stable circuit.

~~Uncondi~~

* The network is unconditionally stable if $|\Gamma_{in}|, |\Gamma_{out}|$ less than 1 for all passive source & Load impedances

* The network is conditionally stable if $|\Gamma_{in}|, |\Gamma_{out}|$ < 1 for certain range of ~~the~~ passive source & Load impedances

$$|\Gamma_{in}| = \left| S_{11} + \frac{S_{12} S_{21} \Gamma_L}{1 - S_{22}\Gamma_L} \right| < 1$$

$$|\Gamma_{out}| = \left| S_{22} + \frac{S_{12} S_{21} \Gamma_S}{1 - S_{11}\Gamma_S} \right| < 1$$

$$\Delta = S_{11} S_{22} - S_{12} S_{21}$$

if $|\Gamma_{in}| = 1$,

then $|\Gamma_L - C_L| = R_L$

$C_L \rightarrow$ centre of ~~circuit~~ circle

$R_L \rightarrow$ Radius of circle

$$C_L = \frac{(S_{22} - \Delta S_{11}^*)^*}{|S_{22}|^2 - |\Delta|^2}$$

$$R_L = \frac{S_{12} S_{21}}{|S_{22}|^2 - |\Delta|^2}$$

if $|\Gamma_{out}| = 1$,

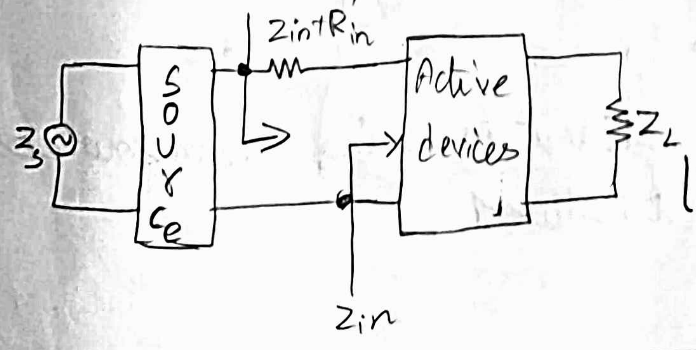
then $$C_S = \frac{(S_{11} - \Delta S_{22}^*)^*}{|S_{11}|^2 - |\Delta|^2}$$

$$R_S = \frac{S_{12} S_{21}}{|S_{11}|^2 - |\Delta|^2}$$

16/3/23 Stabilization methods :-

* Use active devices to stabilize the circuit.

↓ Transistors



instable $|\Gamma_{in}| > 1$

$|\Gamma_{out}| > 1$

$$|\Gamma_{in}| = \left| \frac{Z_{in} - Z_{out}}{Z_{in} + Z_{out}} \right| > 1$$

$$\Gamma_{out} = \left|\frac{Z_{out} - Z_0}{Z_{out} + Z_0}\right| > 1$$

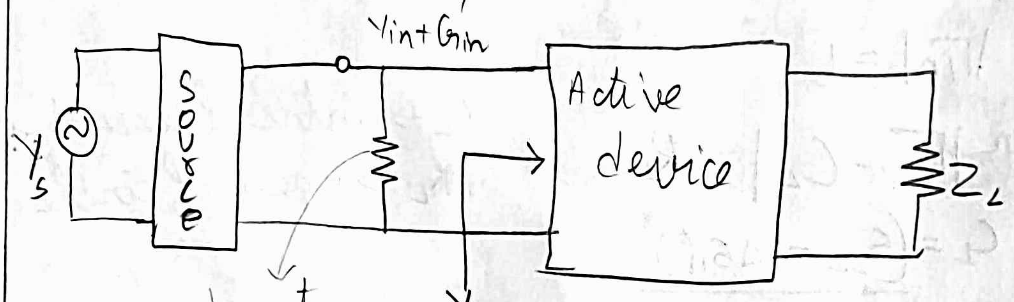
→ Load side output impedance $= Z_L$

* Common collector → high input impedance

$Z_{in} + R'_{in} + Z_s > 0$

↓

The stabilisation of input port for series resistance



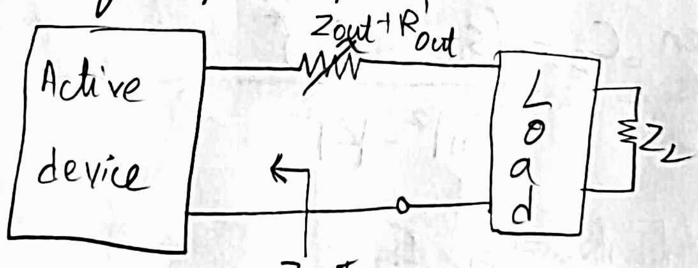
$Y_{in} + G'_{in} + Y_s > 0$

↓

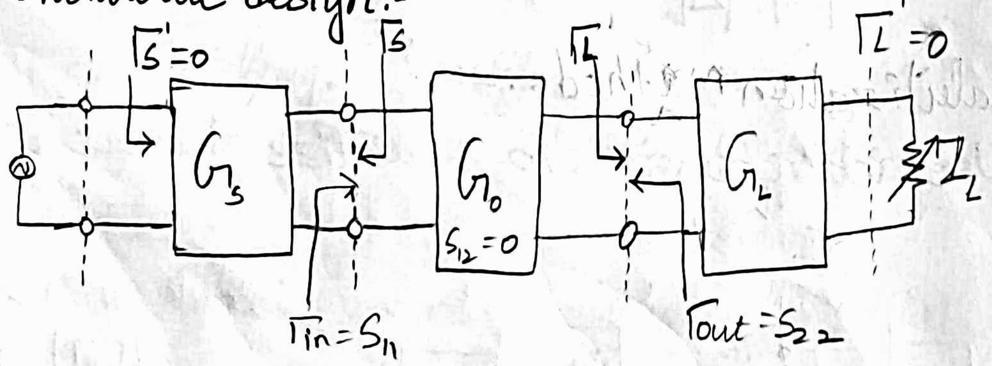
stabilization of input port through shunt conductance

* **Configuration of output port:-**

$Z_{out} + R'_{out} + Z_L > 0$



* **Unilateral design:-**



G_S = Gain of input port matching from source side

$G_0 \Rightarrow$ output port network

$G_L \Rightarrow$ Load

$G_{\text{Unilateral}} = G_S \times G_0 \times G_L = G_{TU}$

$$G_{TU} = \overbrace{\frac{1-|\Gamma_S|^2}{|1-S_{11}\Gamma_S|^2}}^{\text{input}} \times \overbrace{|S_{21}|^2}^{\text{forward}} \times \overbrace{\frac{|1-\Gamma_L|^2}{|1-\Gamma_L S_{22}|^2}}^{\text{output}}$$

input side $\Gamma_S = S_{11}$

Noise figure:-

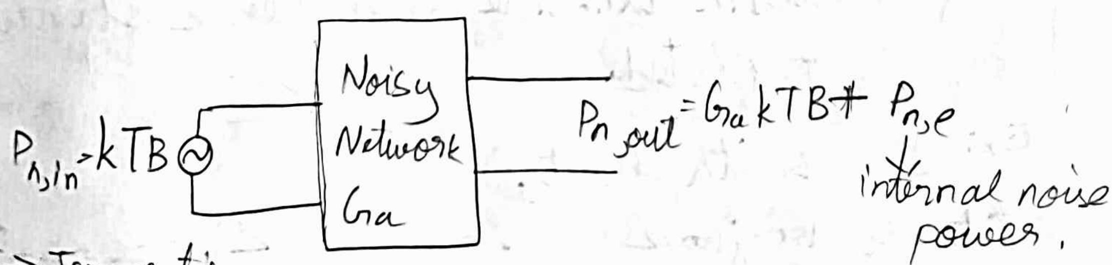
$$\star \frac{SNR_{\text{input port}}}{SNR_{\text{output port}}} = \frac{P_{\text{signal side, input}} \times P_{N,out}}{P_{\text{Noise side}} \times P_{S,out}}$$

* It is defined as ratio of the input signal to noise ratio to the output side SNR

$$NF = \frac{P_{S,in}}{P_{N,in}} \Big/ \frac{P_{S,out}}{P_{N,out}} = \frac{P_{N,out}}{P_{N,in} \times G_a}$$

$\star$ $Gain = \frac{P_{S,out}}{P_{S,in}} = G_a =$ Amplifier power gain.

* We need NF to weed out errors during txn.
* if we consider temperature



$T \rightarrow$ Temperature

$$NF = \frac{G_a kB(T+T_e)}{kTB \cdot G_a}$$

$$NF = \frac{T+T_e}{T} = 1 + \frac{T_e}{T}$$

$T_e \rightarrow$ internal noise Temperature

T in kelvin

$$\boxed{T_e = T(NF-1)}$$

12/3 Voltaage Standing Wave Ratio :- [VSWR] :-

* $VSWR = \frac{V_{max}}{V_{min}} = \frac{1-|\Gamma|}{1+|\Gamma|}$ $\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$

Z_0 = Output impedance

* VSWR is used to find efficiency in radio frequencies.

* VSWR is used to find max^m power transfered in RL, RC, RLC circuits through impedance matching.

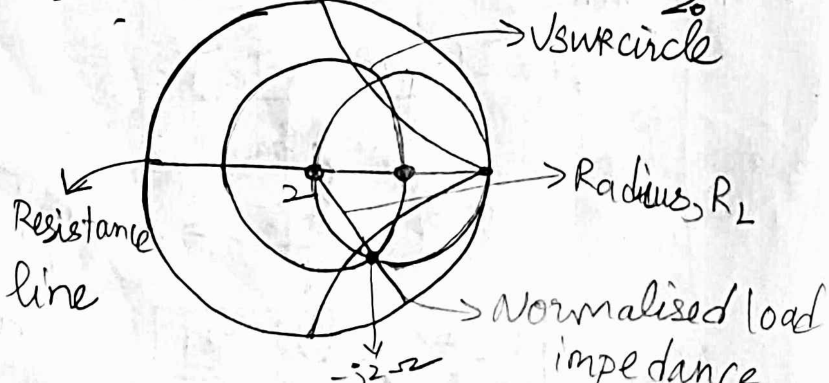
* VSWR is a measure of low freq. radio wave
is a measure of low efficiency radio freq. power is transmitted from a power source through a txn. line into a load.

* VSWR ∈ {1, ∞)

* In the smith chart the clock wise movement represents the increase in impedance and it represents towards the generator.

* Due to impedance mismatch, standing wave is generated in txn. line and hence standing wave is reflected.

Ex:- In smith chart,
let $Z_L = 100 - j100\,\Omega$ $Z_0 = 50\,\Omega$ $Z_L' = \frac{Z_L}{Z_0} = 2 - j2\,\Omega$



BroadBand Amplifiers :-

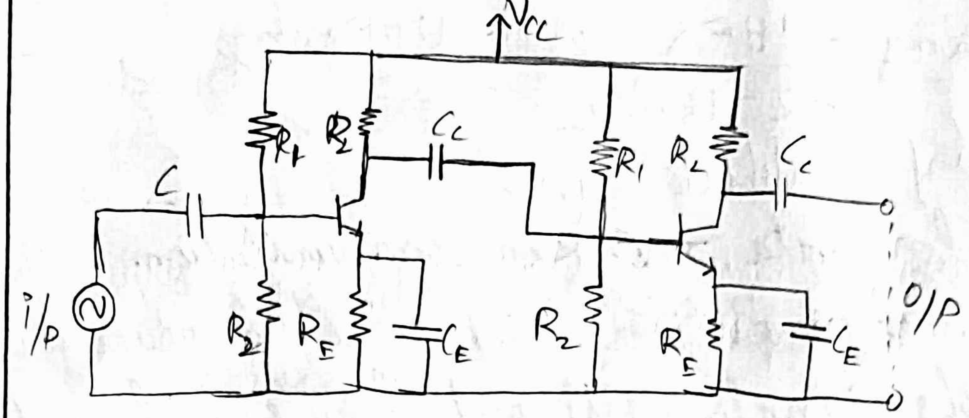
* frequency → VHF range to UHF range
  → 2 - 18 GHz

TV, wifi, satellite signals

* Used for data txn & Rxn communication.
* They are amplifiers which will reproduce a wide range of signals without any significant loss throughout the passband
* A typical Broadband amplifier is used as TV signal i.e. VHF to UHF. which means radio waves to transmit data in a wireless connection.
* ~~For designing~~ broadband amplifiers,
  ↳ Improve BW
  ↳ Acheive gain
  ↳ complexity is reduced.
  ↳ Compensated matching networks
  ↳ Balance amplifiers of different types.
  ↳ Provides large output voltage
  ↳ Less SNR.

Multistage amplifiers :-

* Overall gain = Multiply gain of individual stages
* Used in audio fidelity application, impedance matching, voltage amplification
* RC coupled amplifier is considered for biasing & stabilisation of circuit network performance.
* Becomes compact by upgrading technology.



Vcc
R1
R2
Cc
R1
RL
Cc
C
i/p
R2
RE
CE
R2
RE
CE
o/p

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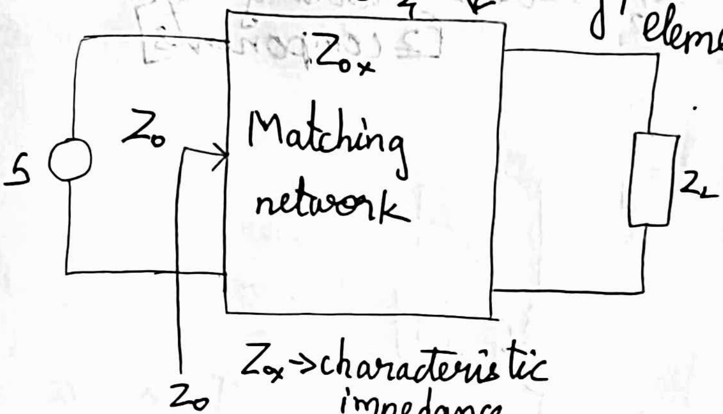
Unit-3

Impedance Matching Networks :-

* Maximum power should be transfered between source and load.

→ Quarter wave transformer

$l = \frac{\lambda}{4}$ ← only passive elements



Z_{0x} → characteristic impedance

$$Z_0 = \sqrt{\frac{R + jWC}{G + jWL}}$$

constant not conductance

$$Z_0 = \frac{Z_{0x}^2}{Z_L}$$

so $Z_{0x} = \sqrt{Z_0 Z_L}$

* To match the impedance of the load to that of the source, to achieve max^m power transfer
* This is accomplished by incorporating additional passive elements is connected in btw. source & load side. This network is generally refered as matching network.
  ↳ if $Z_L = Z_0$ ⇒ matching circuit impedance balanced circuit

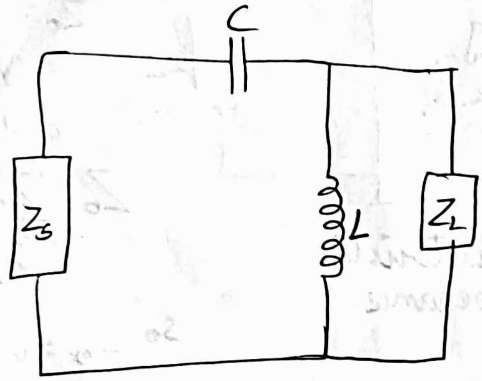
* The matching network, satisfy two main goal
  ↳ to meet system specs.
  ↳ to find the most inexpensive & reliable way to accomplish the first task

  ↳ To analyse & design the simplest possible matching networks, the so called 2 component network - RLC network, due to their element arrangement. These network use 2 reactive components to transform the load Z_L to the desired Zo:

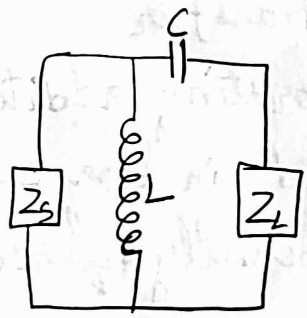
With load & source impedances, the component R, is alternatively connected in series shunt configuration.

Configurations of discrete matching networks. [2 components]

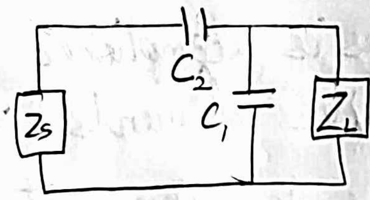
(i) Type 1:-



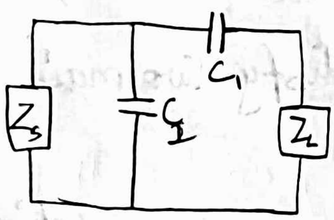
(ii) Type 2:-



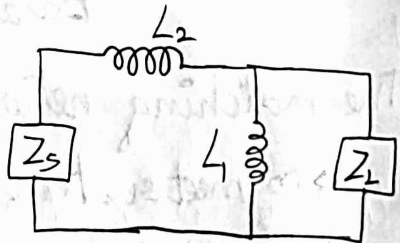
(iii) Type 3:-



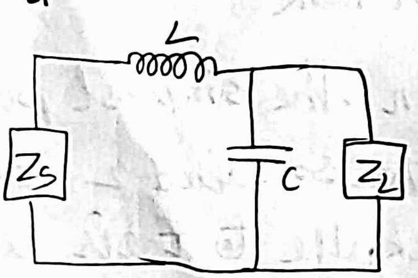
(iv) Type-4:-



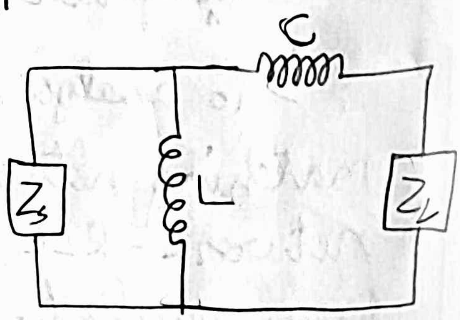
(v) Type 5:-



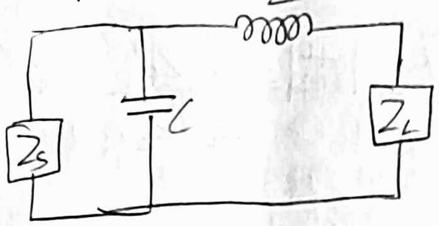
(vi) Type 6:-



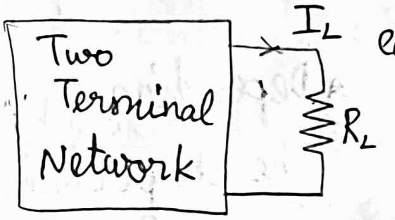
(vii) Type 7:-



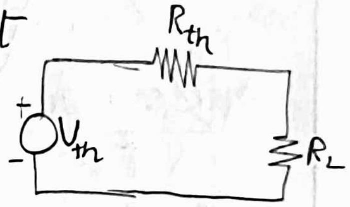
(viii) Type 8:-



Maximum power Transfer Theorem:-



equivalent circuit



Load current, $I_L = \dfrac{V_{th}}{R_{th}+R_L}$

Load Power, $P_L = I_L^2 \cdot R_L$

$$= \left[\frac{V_{th}}{R_{th}+R_L}\right]^2 \cdot R_L$$

for maximum power

$$\frac{dP_L}{dR_L} = 0$$

$$\frac{dP_L}{dR_L} = V_{th}^2 \left[\frac{[R_{th}+R_L]^2 - 2R_L[R_{th}+R_L]}{[R_{th}+R_L]^4}\right]$$

$$[R_{th}+R_L]^2 - 2R_L[R_{th}+R_L] = 0$$

$$[R_{th}+R_L]\left[(R_{th}+R_L) - 2R_L\right] = 0$$

$$[R_{th}+R_L]\,[R_{th} - R_L] = 0$$

$R_{th} = R_L$ for maximum power transfer, so

$$P_L = \frac{V_{th}^2}{(2R_L)^2} R_L$$

$$P_L = \frac{V_{th}^2}{4R_L}$$

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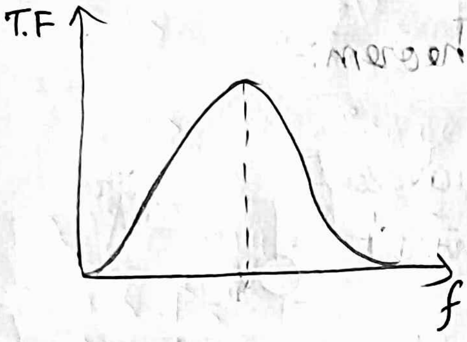
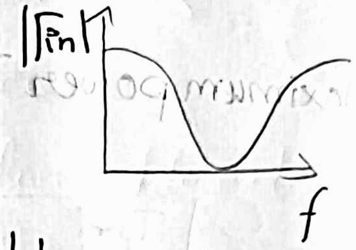
Frequency Response :-

* input reflection coefficient , $|\Gamma_{in}| = \frac{Z_s - Z_L}{Z_s + Z_L}$
* Transfer func. = $\frac{V_{out}}{V_s}$





* Depending on frequency, the shape changes.

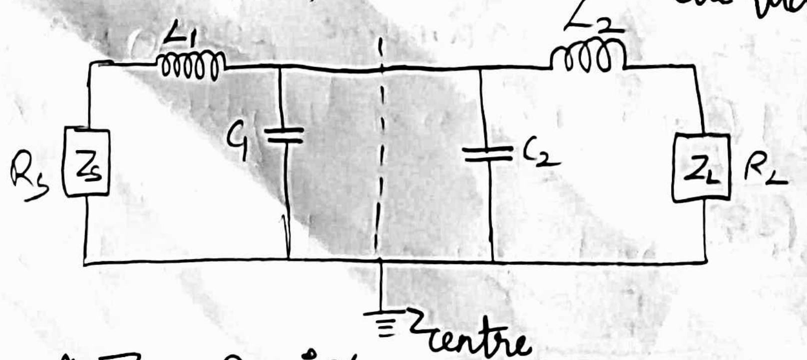
Quality factor (Q) :-

* $Q_r = \frac{f_0}{B.W.}$

* The Q, for matching networks can be estimated without decoupling on equivalent circuit or even computing the frequency response of a network. This is accomplished by the nodal quality factor.

T & π matching network :-

(i) <u>T Matching networks</u> :-



* $Z_s = R_s + jX_s$

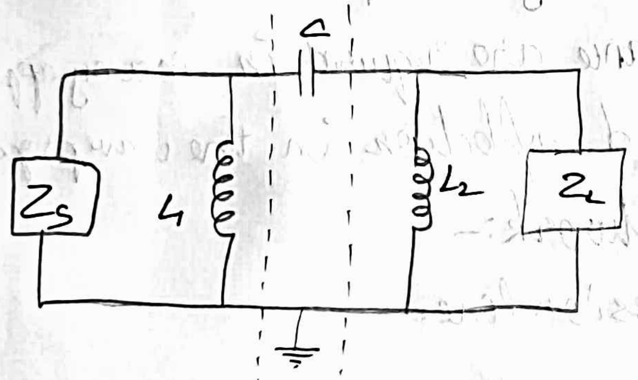
* At each node, the matching network, the impedance can be ~~equal~~ expressed in terms of a equivalent series impedance.

* Using impedance transformation max^m nodal Q.F, the relationship btw. loaded & nodal Q.F. is obtained as the above network.

* $Z_{centre} > Z_s < Z_L$ gives us control over frequency response.

* $Q_n = \frac{X_s}{R_s}$

(ii) π Matching network:-



$Z_{center} \Rightarrow$ control balance in circuit

24/2 Microstrip line matching networks:-

* Reduce matching losses.
* Minimise signal reflection in loadside
* To maximise power delivered to antenna
* It is a type of electrical ~~tx~~ txn. line which can be fabricated with any technology where as a conductor, semi-conductor or insulator is separated from ground plane by a dielectric layer is known as substrate

* Microstrip lines are used to convey micro-wave freq. signals
    ↳ To ensure max^m power transfer
    ↳ To avoid signal reflected waves
    ↳ To remove matching losses
    ↳ To maximise power delivered to antenna

reason to use microstrip

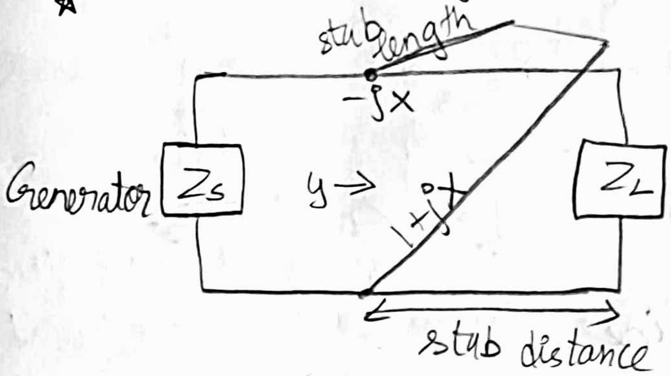
* Also microstrip lines provides max^m freq. response and Q.F.
* Matching networks involve discrete components however with ↑ freq & corresponding ↓ λ.
* This design is using the parasitic elements
* The match impedance are required in many applications to avoid unwanted reflection in the wave propagation

27/3 Stub Matching network:-
* Piece of transmission line.
* Two types:-
    ↳ Single stub < OC, SC
    ↳ Double stub

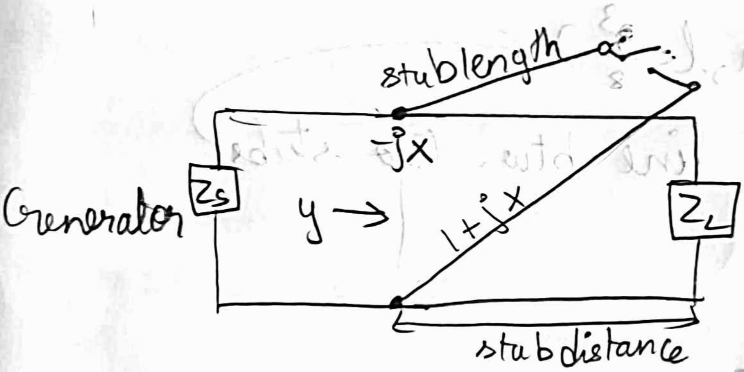
(i) Single stub matching network:-
* In this logic to completely ~~eliminate~~ elements the lumped components or passive components
* Stub is a piece of txn. line which can be SC or OC
* Generally it is a txn. line. It has a pure reactance.
* It is used for impedance matching

① Short Circuit Single stub:-

*



② Open Circuit singl stub:-



*Draw back ⇒ stub length is fixed ⇒ helps in frequency variation

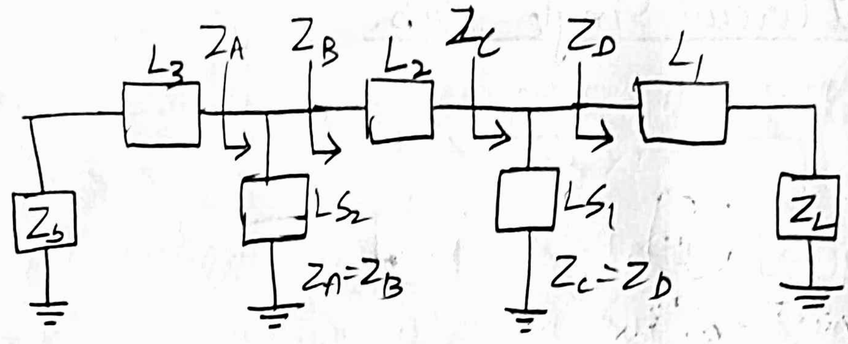
(ii) Double stub Matching Network:-

* The main draw back of single stub is fixed length of txn. line btw stub input & stub output (stub length).

* Variable txn. line length is required btw input & output side.

* General topology of such a network that matches an arbitary load impedence to an source impedance.

* It may create difficulties for variable tunners to overcome this, we use 3dB or 5dB or 10dB gain double stub matching network.



$L_3, L_2, L_1 \rightarrow$ txn. line

* In double stub matching network, 2 SC & 2 OC stub are connected in ||lel with a fixed length txn. line placed in btw. input & output side

stub length, $l = \frac{3}{8}\lambda$

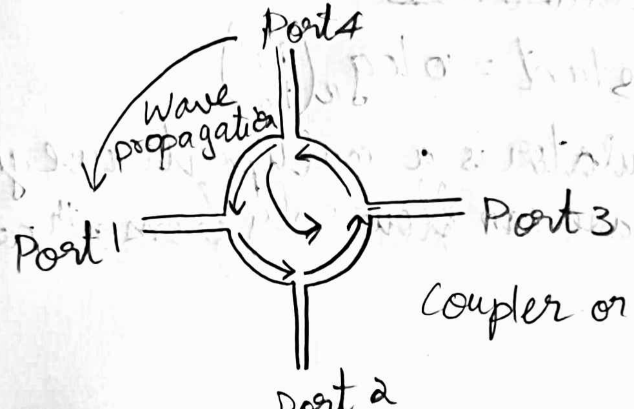
* Length of line btw. two stubs

~~Terminations~~

-7/3

Unit - IV

Terminations :-



Coupler or micro wave circulator

* Control magnetic fields.
* A microwave circulator is a multiport wave guide junc. in which the wave can flowly only from n^{th} port to $(n+1)^{th}$ port in one junction
* The phase shift btw port 1 to port 2 is 90°, ~~dir~~
  port 2 to port 3 is 180°
  port 3 to port 4 is 270°

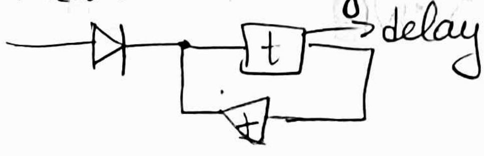
if from port 1 to port 3

wave directn. → wave 1 - wave 3 = $(2m+1)\pi$ rad/sec
wave 2 - wave 4 = $2n\pi$ rad/sec

m, n is mode of propagation from transmission line which he is not willing to teach.

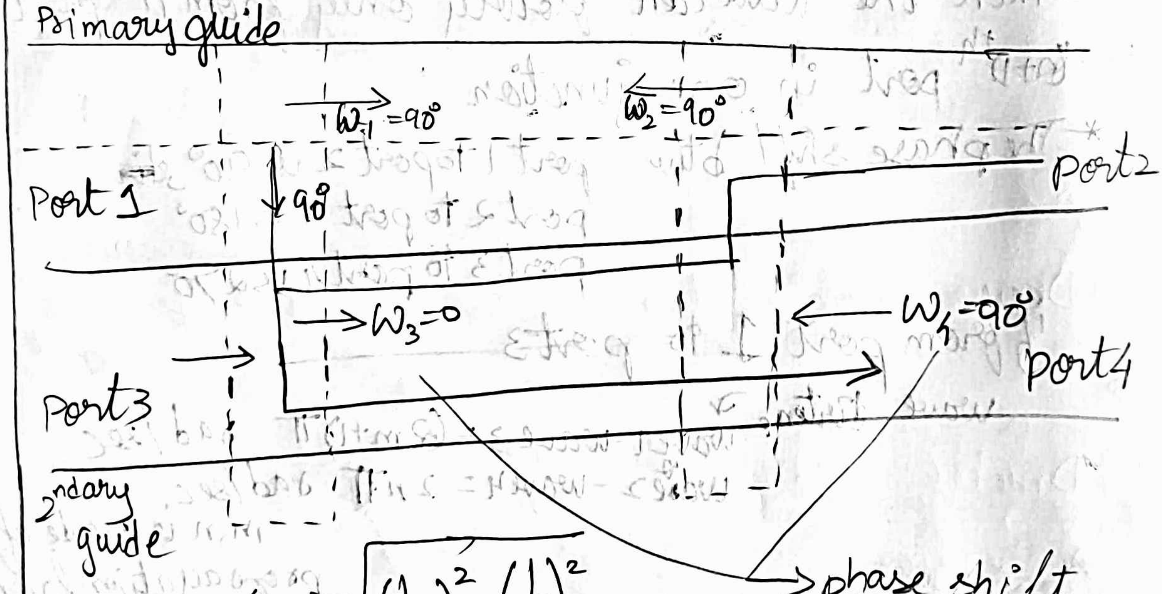
Phase Shifter :-

* It is a 2-port device whose basic func. is provide a change in phase (fixed or variable) of RF signal with insignificant attenuation.
* Application :-
  - Phased Array Antenna
  - Electronically controlled phase shifter
  - Test & measurement system.



Attenuators:-

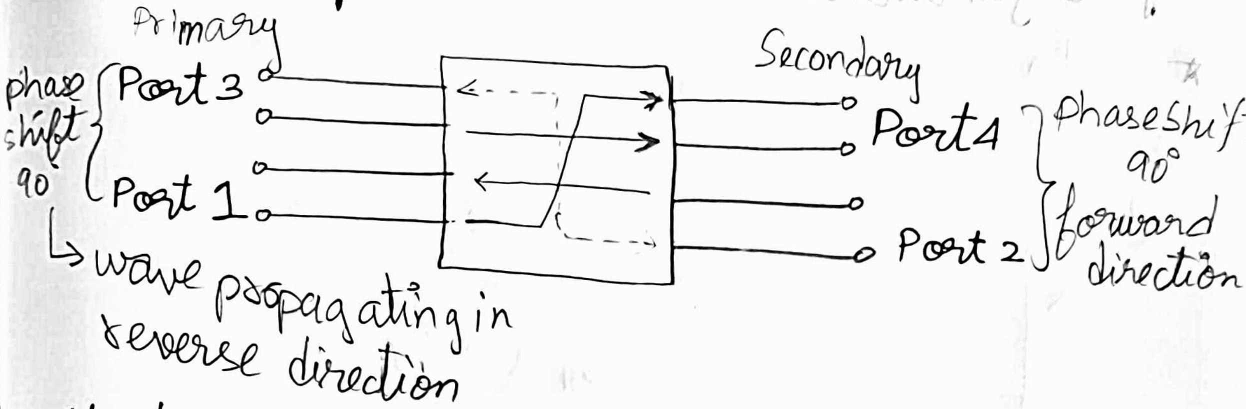
* It is a device, reduces power of signal
* ~~A microwave circulator~~
* Attenuation constant $= 10 \log_{10}\left(\frac{P_i}{P_o}\right)$
* A microwave circulator is a multiport wave guide junction in which wave can flow only from n^{th} port to $(n+1)^{th}$ port.



$$\alpha = 2\pi\sqrt{\left(\frac{1}{\lambda_c}\right)^2 - \left(\frac{1}{\lambda}\right)^2}$$

* Types:-
  - ↳ Fixed Attenuator.
  - ↳ Variable Attenuator
  - ↳ Step Attenuator
    - Fixed power
  - ↳ Continuously variable attenuator
    - Co axial line
    - Min^m loss
    - Max^n VSWR

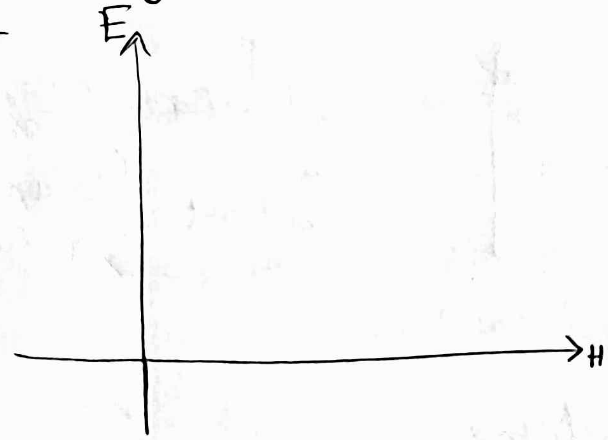
/03 Directional Coupler :-



* Used in wave guides junctions.
* Coupling factor $= 10 \log_{10} \left(\frac{P_{in}}{P_o} \right)$
* Directivity $= 10 \log_{10} \left[\frac{P_{forward}}{P_{Reverse}} \right]$

* A waveguide directional coupler is a 4 port waveguide junc. device that samples part of the EMW power to the main waveguide.
* It is a passive 4 port device. It consists of primary guide with ports 1 & 3 and secondary guide with port 2 & 4.
* Phase shift btw. port 1 & port 3 is 90° similarly for port 2 & port 4 phase shift between the is 90°
* It is made up of two connected waveguides
* The waveguides are coupled through holes btw. them. The directional coupler is said to be consisting of main arm and an auxillary arm.

Hybrid junctions:-

★ 

★ On E&H plane, a junc. is formed by attaching two simple waveguides, one is parallel & other is series to a rectangular waveguide.

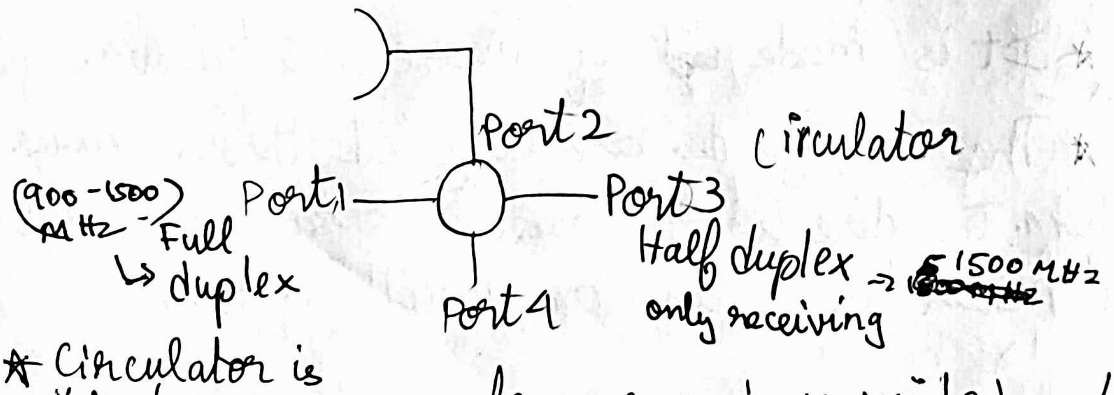
★ Waveguides are txn. lines which are arranged

★ In hybrid junction, it is 4 port devices, each port is terminated in its characteristic impedance

★ The power entering primary side, is forward dirn. & 2ndary side is reverse dirn.

31/3 Circulator & Isolator:-

★ Wideband antenna frequency - 900-1600 MHz

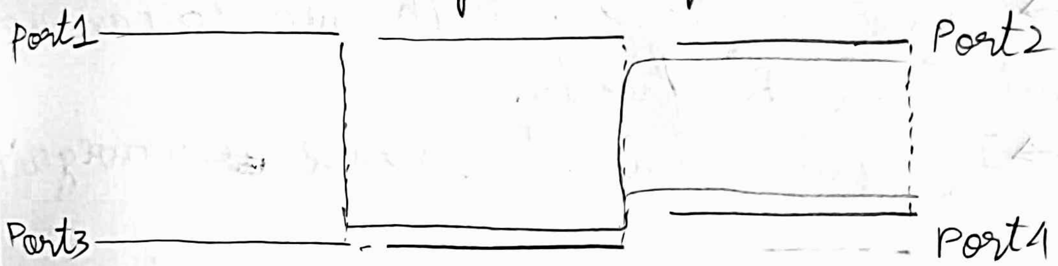


★ Circulator is
Used to change frequency in wide band with different freq. in txn. or rxn.

★ Circulator → no missmatching
→ Less power loss

* By using circulator, with one antenna we can use it ~~to~~ for ~~two~~ two antennas txn. equivalence
* Only magnetic field is transmitted.

Isolator → directional coupler concept



* A circulator is a microwave passive multiport device in which the incident wave at port 1 is coupled to the port 2 only, incident wave at port 2 is coupled to port 3 only.
* The ideal circulator is a matched device ~~both~~ i.e. when all the ports are terminated in a matched load except one port, the input impedance of other ports is equal to characteristic impedance of the other line.
* Applications:- ATC,
* Advantages:-
  ↳ It can accomodate 2 different applications of frequencies using single antenna.
  ↳ Loss is ideally zero. Practical → 0.2 dB W

* Isolator is a passive device which txn. the wave in both forward & reverse dirn.
* It means that the port 1 to port 2 → 90°+90° = 180° phase shift.
* Port 1 to Port 3 to Port 4 → 0°+90°+90° = 180°

* Behave like p-n junction.

* Used for load balancing
* Advantages:-
  ↳ Signal can travel in both dirn. so can use both $\vec{E}$ & $\vec{B}$ fields.
  ↳ If impedance mismatch, we use waveguide