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EC 2403 - RF AND MICROWAVE ENGINEERING

UNIT - I

Two Port RF Networks - Circuit Representation

Introduction :-

Microwave network :-

A microwave n/w is formed when several μw devices and components such as attuators, resonators, filters, amplifiers. etc. are coupled together by transmission lines or waveguides for the desired transmission of microwave signal.

RF/μw devices, ckts and components can be classified as one, two, three or N-port networks. A majority of ckt use 2 port networks.

A 2 port n/w has only 2 acces ports, one for I/P & one for O/P

Frequence range 1 GHZ to 100 GHZ

Wavelength - 30cm to 0.3mm in free space.

Microwave network theory :-

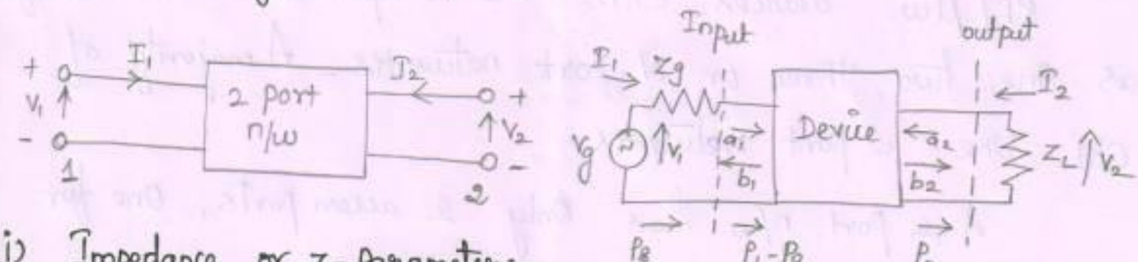
1. Low frequency Parameter
2. High frequency parameter

Low frequency Parameter:-

* When physical length of n/w is much lower than the wavelength of the μw device (or) Component, Then the Parameter are called low frequency Parameter.

* It describe 2 Port n/ws. & their parameter such as
 - Impedance or Z parameter
 - Admittance or Y parameter
 - Hybrid or h parameter
 - Transmission or ABCD Parameter

Figure: 2 port network



(i) Impedance or Z-Parameter:-

I/p & o/p Voltages are expressed interms of I/p & o/p currents. It is otherwise known as open circuited parameter i.e

$$V_1 = Z_{11} I_1 + Z_{12} I_2$$

$$V_2 = Z_{21} I_1 + Z_{22} I_2$$

where

$$Z_{11} = \frac{V_1}{I_1} \Big|_{at \; I_2 = 0}$$ → I/p impedance with o/p open circuited

$$Z_{22} = \frac{V_2}{I_2} \Big|_{at \; I_1 = 0}$$ → o/p impedance with I/p open circuited

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$Z_{12} = \frac{V_1}{I_2} \Big|_{I_1=0}$ mutual or reverse transfer impedance with I/p open circuited

$Z_{21} = \frac{V_2}{I_1} \Big|_{I_2=0}$ mutual or forward transfer impedance with o/p open circuited

In matrix form

$$[V] = [Z][I]$$

$$[V] = \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} \quad [I] = \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

(ii) Admittance or Y parameter:

I/p & o/p currents are expressed interms of i/p & o/p Voltages. It parameter also known as Short circuited parameters.

i.e $I_1 = Y_{11} V_1 + Y_{12} V_2 \quad I_2 = Y_{21} I_1 + Y_{22} V_2$

where

$Y_{11} = \frac{I_1}{V_1} \Big|_{V_2=0}$ i/p admittance with o/p is short circuited

$Y_{22} = \frac{I_2}{V_2} \Big|_{V_1=0}$ O/p admittance with I/p is short circuited

$Y_{12} = \frac{I_1}{V_2} \Big|_{V_1=0}$ mutual or reverse transfer admittance when i/p is short circuited

$Y_{21} = \frac{I_2}{V_1} \Big|_{V_2=0}$ mutual or forward transfer admittance when o/p is short circuited

In matrix form

$$[I] = [Y][V]$$

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$

(iii) Hybrid or h parameters:

I/p Voltage & o/p current is expressed interms of i/p current & o/p Voltage.

$$V_1 = h_{11} I_1 + h_{12} V_2$$

$$I_2 = h_{21} I_1 + h_{22} V_2$$

where

$h_{11} = \frac{V_1}{I_1} \Big|_{V_2=0}$ → i/p impedance with o/p is Short circuited

$h_{22} = \frac{I_2}{V_2} \Big|_{I_1=0}$ → o/p admittance with I/p is open circuited

In matrix form

$$\begin{bmatrix} V_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ V_2 \end{bmatrix}$$

$h_{12} = \frac{V_1}{V_2} \Big|_{I_1=0}$ reverse Voltage transfer ratio when i/p is open circuited

$h_{21} = \frac{I_2}{I_1} \Big|_{V_2=0}$ forward current Transfer ratio when o/p is Short circuited

iv) ABCD Parameter

I/p Voltages & currents are expressed interms of o/p voltage & current

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i.e $V_1 = AV_2 - BI_2$

$I_1 = CV_2 - DI_2$

where

$A = \frac{V_1}{V_2} \Big|_{I_2=0}$ → ratio of i/p voltage to o/p voltage when o/p is open circuited i.e reverse voltage ratio when o/p is open circuited

$B = \frac{V_1}{I_2} \Big|_{V_2=0}$ → ratio of i/p voltage to o/p current when o/p is short circuited i.e. Transfer impedance when o/p is short circuited

$C = \frac{I_1}{V_2} \Big|_{I_2=0}$ → ratio of i/p current to o/p voltage when o/p voltage is open circuited i.e transfer admittance when o/p is open circuited

$D = \frac{I_1}{I_2} \Big|_{V_2=0}$ → ratio of i/p current to o/p current when o/p is short circuited i.e reverse current transfer ratio when o/p is short circuited

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ -I_2 \end{bmatrix}$$

ABCD parameter widely used in transmission line theory.

These parameter called as transmission parameters.

- These parameter express the sending end values (i.e V_1 & I_1) interms of receiving end values (i.e V_2 & I_2) and are convenient to represent each junction when a number of circuits are connected together in cascade

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} \cdots \begin{bmatrix} A_n & B_n \\ C_n & D_n \end{bmatrix}$$

These parameter can be measured under short or open circuit condition for used in the analysis of the circuit.

High Frequency parameters:

Z, Y, H & ABCD parameter are based on the following consideration at each of the n/w ports

(i) Net voltage (V) & Net current (i)

(ii) Short & open circuit terminations

H, Y, Z & ABCD parameter can not be measure at microwave freq due to following reasons.

(i) Equipment is not readyily available to measure totale V & total I at the ports of the n/w

(ii) Short ckt & open ckt are difficult to achieve over a wide range of freq

(iii) presence of active devices such as power transistors & tunnel diodes. makes the circuit unstable for short (or) open circuit.

– S parameter used in high frequency devices

Scattering matrix:

Scattering matrix is a Square matrix which gives all the combinations of power relationships b/w the various i/p & o/p ports of a μw junction

Scattering parameter

The elements of scattering matrix are called scattering coefficients or scattering parameters.

Formulation of the S-parameter (4)

X·8m

1.4.1 S- matrix representation of Two port network

The incident & reflected amplitudes of μw at any Port are used to characterise a μw ckt.

I/p Pwr at the n^{th} Port. $P_{in} = 1/2\,|a_n|^2 \rightarrow (1)$

Reflected Pwr at the n^{th} port $P_{rn} = 1/2\,|b_n|^2 \rightarrow (2)$

$a_n \rightarrow$ normalized incident wave amplitude at n^{th} port

$b_n \rightarrow$ " reflected " " "

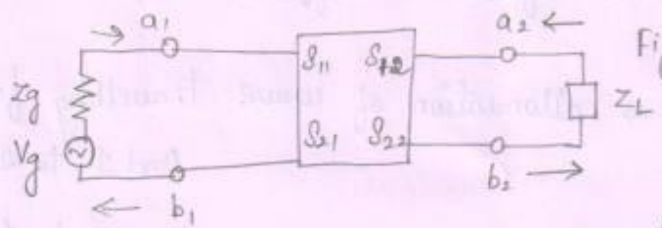

Fig: two-Port n/w

The total Voltage waves is the sum of incident & reflected Voltage waves V_i & V_r respectively

Voltage at port 1, $V_1 = V_{i1} + V_{r1}$

" " 2. $V_2 = V_{i2} + V_{r2}$

V_{i1} - incident V wave at port 1

V_{i2} - " " port 2

V_{r1} - reflected " " port 1

V_{r2} - " " port 2

$a_1 = \left(\frac{V_{i1}}{\sqrt{Z_0}}\right) = \frac{V_1 - V_{r1}}{\sqrt{Z_0}}$

(w.r.t V_1)

$a_2 = \frac{V_{i2}}{\sqrt{Z_0}} = \frac{V_2 - V_{r2}}{\sqrt{Z_0}}$

$b_1 = \frac{V_{r1}}{\sqrt{Z_0}} = \frac{V_1 - V_{i1}}{\sqrt{Z_0}}$

$b_2 = \frac{V_{r2}}{\sqrt{Z_0}} = \frac{V_2 - V_{i2}}{\sqrt{Z_0}}$

Total Power flow

$$P_o = P_i - P_r$$

$$P_o = \frac{1}{2}\left[|a|^2 - |b|^2\right]$$

In 2 port n/w the relation b/w Incident & reflected waves are expressed in terms of Scattering parameters S_{ij}'s

$$b_1 = S_{11}a_1 + S_{12}a_2 \qquad b_2 = S_{21}a_1 + S_{22}a_2$$

$S_{11} = \frac{b_1}{a_1}\Big|_{at\ a_2=0}$ → reflection coefficient at port 1

$S_{12} = \frac{b_1}{a_2}\Big|_{at\ a_1=0}$ → attenuation of wave travelling from port 1 to 2

$S_{21} = \frac{b_2}{a_1}\Big|_{at\ a_2=0}$ → " " " port 2 to 1

S_{22} $\frac{b_2}{a_2}\Big|_{at\ a_1=0}$ → Reflection coefficient at port 2

In matrix form

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \rightarrow \text{for 2 port}$$

Multi-port n/w

$$\underbrace{\begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix}}_{\text{reflected waves (or) O/ps}} = \underbrace{\begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1n} \\ S_{21} & S_{22} & \cdots & S_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ S_{n1} & S_{n2} & \cdots & S_{nn} \end{bmatrix}}_{\text{S\_matrix}} \underbrace{\begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_n \end{bmatrix}}_{\text{Incident waves (or) I/ps}}$$

1.4.2 Losses of S parameter (5)

(i) Insertion loss (dB)

It is a measure of the loss of energy in transmission through a line or device compared to direct delivery of energy without the line or device

$$I.L = 10 \log \left(\frac{P_i}{P_o}\right)$$

$$= 10 \log \frac{|a_1|^2}{|b_2|^2}$$

$$= 20 \log \frac{|a_1|}{|b_2|}$$

$$= 20 \log \left(1/|S_{12}| \right)$$

I.L is contributed by

- Mismatch loss at the I/p
- " " O/p
- Attenuation loss through the device

(ii) Attenuation loss (dB) (or) Transmission loss

It is a measure of the power loss due to signal absorption in the device

$$= 10 \log \frac{P_i - P_r}{P_o}$$

$$= 10 \log \left(\frac{1 - |S_{11}|^2}{|S_{12}|^2}\right)$$

$$= 10 \log \frac{|a_1|^2 - |b_1|^2}{|b_2|^2} = 10 \log \frac{1 - \frac{|b_1|^2}{|a_1|^2}}{|b_2|^2/|a_1|^2} = 10 \log \frac{1 - |S_{11}|^2}{|S_{12}|^2}$$

iii) Reflection loss (dB)

It is a measure of power loss during transmission due to the reflection of the signal as a result of impedance mismatch

$$= 10 \log \frac{P_i}{P_i - P_r}$$

$$= 10 \log \frac{|a_1|^2}{|a_1|^2 - |b_1|^2}$$

$$= 10 \log \frac{1}{1 - \frac{|b_1|^2}{|a_1|^2}}$$

$$= 10 \log \frac{1}{1 - |S_{11}|^2}$$

iv) Return loss (dB)

It is a measure of the power reflected by a line or n/w through a line

$$= 10 \log \frac{P_i}{P_r}$$

$$= 10 \log \frac{|a_1|^2}{|b_1|^2}$$

$$= 20 \log \frac{1}{|S_{11}|}$$

(6)

Properties of [S] matrix

(i) Zero diagonal elements for perfect matched Network

For an ideal N-port N/w with matched termination $S_{ii} = 0$. Since there is no reflection from any port. Therefore, under perfect matched conditions, the diagonal elements of [S] are zero.

ii) Symmetry of [S] for a reciprocal n/w

A reciprocal device has the same transmission characteristic in either direction of a ports and is characterized by a symmetric scattering matrix.

$$S_{ij} = S_{ji} \; (i \neq j)$$

which result $[S]_t = [S]$

Proof:-

For a reciprocal n/w with the assumed normalization, the impedance matrix equation is

$$[V] = [Z][I] = [Z](|a| - |b|) = [a] + [b]$$

$$([Z] + [U])[b] = ([Z] - [U])[a]$$

$$[b] = ([Z] + [U])^{-1}([Z] - [U])[a] \rightarrow ①$$

where [U] - Unit matrix

The S-matrix eqn for the n/w is

$$[b] = [S][a] \rightarrow ②$$

Comparing ① & ② we get

$$[S] = ([Z] + [U])^{-1}([Z] - [U])$$

The transpose of [S] is

$$[S]_t = [[Z]+[U]]_t^{-1} ([Z]-[U])_t$$

Since the Z-matrix is symmetrical

$$([Z]+[U])_t^{-1} = ([Z]+[U])^{-1}$$

$$([Z]-[U])_t = ([Z]-[U])$$

$$\therefore [S]_t = ([Z]+[U])^{-1} ([Z]-[U]) = [S]$$

It is proved that $[S]_t = [S]$ for symmetrical junction.

iii) Unitary Property for a lossless junction

For any lossless n/w the sum of the products of each term of any row or of any column of the S-matrix multiplied by its complex conjugate is Unity

For a lossless n-port devices, the total power leaving N-ports must be equal to the total power i/p to these ports, so that

$$\sum_{n=1}^{N} |b_n|^2 = \sum_{n=1}^{N} |a_n|^2$$

i.e

$$\sum_{n=1}^{N} \left| \sum_{i=1}^{n} S_{ni} a_i \right|^2 = \sum_{n=1}^{N} |a_n|^2$$

if Only i^{th} port is excited & all other ports are matched terminated all $a_n = 0$ except a_i so that

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$$\sum_{i=1}^{N} |S_{ni} a_i|^2 = \sum_{n=1}^{N} S_{ni} S_{ni}^*$$

$$\sum_{n=1}^{N} |S_{ni}|^2 = 1 = \sum_{n=1}^{N} S_{ni} S_{ni}^*$$

Therefore, for a lossless junction

$$\sum_{n=1}^{N} S_{ni} S_{ni}^* = 1 \longrightarrow (1)$$

if all $a_n = 0$ except a_i & a_k

$$\sum_{n=1}^{N} S_{nk} S_{ni}^* = 0 \quad i \neq k \longrightarrow (2)$$

In matrix notation, these relations can be expressed as

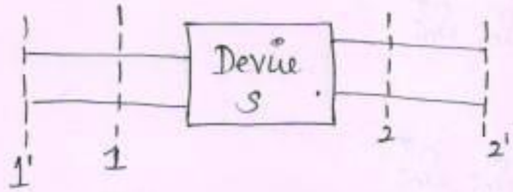
$$[S]^* [S]_t = [U] \quad \text{or} \quad [S]^* = [S]_t^{-1} \longrightarrow (3)$$

A matrix [S] for lossless n/w which satisfies the above 3 condition is called a unitary matrix.

iv) Phase Shift Property

Complex S-parameters of a m/w are defined with respect to the positions of the port or reference planes.

For a 2 port n/w with Unprimed reference planes 1 and 2



If the reference planes 1 & 2 are shifted Outward to 1' & 2' by electrical phase shifts $\phi_1 = \beta_1 l_1$ & $\phi_2 = \beta_2 l_2$. The new Variable

$$a_1 e^{j\phi_1},\ b_1 e^{-j\phi_1},\ a_2 e^{j\phi_2},\ b_2 e^{-j\phi_2}$$

$$S_{11}' = \frac{b_1'}{a_1'} = e^{-j2\phi_1} S_{11}$$

$$S_{22}' = \frac{b_2'}{a_2'} = e^{-j2\phi_2} S_{22}$$

$$S_{12}' = \frac{b_1'}{a_2} = e^{-j(\phi_1+\phi_2)} S_{12} = S_{21}'$$

The new matrix S' is given by

$$[S'] = \begin{bmatrix} e^{-j\phi_1} & 0 \\ 0 & e^{-j\phi_2} \end{bmatrix} [S] \begin{bmatrix} e^{-j\phi_1} & 0 \\ 0 & e^{-j\phi_2} \end{bmatrix}$$

This property is valid for any number of Ports & is called the phase shift property applicable to a shift or reference planes.

Reciprocal n/w :- (8)

A reciprocal n/w is defined to be a n/w that satisfies the reciprocity theorem

Reciprocity Theorem:-

Its state that when some amount of electromotive force is applied at one point (e.g in branch K, V_K) in a passive linear n/w, that will produce the current at any other point (e.g branch m, i_m). The same amount of current (in branch K, i_K) is produced when the same electromotive force is applied in the new location (branch m, V_m) that is

$$V_K / i_m = V_m / i_K$$

or

$$Z_{Km} = Z_{mK}$$

In terms of S parameter, [S] matrix is symmetrical

$$S_{ij} = S_{ji} \quad (i \neq j) \quad \text{where } i = 1, 2, \ldots N, \; j = 1, 2, \ldots N$$

Symmetrical Reciprocal N/w

– A special case, reciprocal N/w is a symmetrical n/w. These n/ws have identical size & arrangement for corresponding electrical elements in reference to a plane or line of symmetry.

- The I/p impedance at the i/p port is equal to the impedance in the o/p n/w

- The equality of the I/p & o/p impedances leads to the equality of i/p & o/p reflection coefficients.

- In general for any symmetrical passive N-port n/w

$$S_{ii} = S_{jj}$$

$$S_{ij} = S_{ji} \; (i \neq j)$$

- For any symmetrical n/ws, we can always write as

$$S_{11} = S_{22}$$

$$S_{12} = S_{21}$$

Lossless N/ws

In any lossless passive n/w, its containing no resistive elements, always the power entering the ckt will be equal to the power leaving the n/w which leads to the conserved in power.

Unitary Property of |s| matrix

- It states that for a passive lossless N port N/w, the sum of the products of each term of any on row (or any one column) multiplied by its own complex conjugate is unity

$$\sum_{i=1}^{N} S_{ij} S_{ij}^{*} = 1 \quad j = 1, 2 \ldots N \longrightarrow (1)$$

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Eqn (1) becomes,

$$S_{11}S_{11}^* + S_{21}S_{21}^* = 1 \longrightarrow (2)$$

$$S_{12}S_{12}^* + S_{22}S_{22}^* = 1 \longrightarrow (3)$$

if the lossless n/w is also reciprocal, then the above 2 eqn can be reduced as follows

$$S_{12} = S_{21} \longrightarrow (4)$$

$$|S_{11}| = |S_{22}| \longrightarrow (5)$$

$$|S_{11}|^2 + |S_{21}|^2 = 1 \longrightarrow (6)$$

Zero property of [S] matrix:

– It states that "for a passive lossless N-port n/w, the sum of the product of each term of any row or any column multiplied by the complex conjugate of the corresponding terms of any other row or column is zero.

$$\sum_{K=1}^{N} S_{Ki} S_{Kj}^* = 0 \longrightarrow (7)$$

i & j – row & column numbers.

for a 2 port n/w

$$S_{11}S_{12}^* + S_{21}S_{22}^* = 0 \longrightarrow (8)$$

$$S_{12}S_{11}^* + S_{22}S_{21}^* = 0 \longrightarrow (9)$$

if the lossless n/w is also reciprocal, the above eqn can be reduced as follows

$$S_{12} = S_{21}$$

$$S_{11}S_{21}^* + S_{21}S_{22}^* = 0 \longrightarrow (10)$$

$$|S_{11}| = |S_{22}| \rightarrow (11)$$

A unitary matrix is one" the matrix which satisfies both the unitary & zero property".

Analysis of Reciprocal lossless n/ws:

Zero & Unit properties of the S-matrix, the S parameter of a reciprocal lossless n/w are constrained by eqn (4), (5), (6) & (10) as

$$S_{21} = S_{12} \rightarrow (12)$$

$$|S_{11}| = |S_{22}| \rightarrow (13)$$

$$|S_{11}|^2 + |S_{21}|^2 = 1 \rightarrow (14)$$

$$S_{11} S_{21}^* + S_{21} S_{22}^* = 0 \rightarrow (15)$$

let,

$$S_{11} = |S_{11}| e^{j\theta_{11}}$$

$$S_{22} = |S_{22}| e^{j\theta_{22}} \text{ \&}$$

$$S_{21} = |S_{21}| e^{j\theta_{21}}$$

eqn (14) we get

$$|S_{21}| = (1 - |S_{11}|^2)^{1/2} \rightarrow (16)$$

Using above expression. eqn (15) may be written as

$$|S_{11}| e^{j\theta_{11}} |S_{21}| e^{-j\theta_{21}} + |S_{21}| e^{j\theta_{23}} |S_{11}| e^{-j\theta_{22}} = 0 \rightarrow (17)$$

Sub eqn (16) into eqn (17)

$$|S_{11}| e^{j\theta_{11}} (1 - |S_{11}|^2)^{1/2} e^{-j\theta_{21}} + (1 - |S_{11}|^2)^{1/2} e^{j\theta_{21}} |S_{11}| e^{-j\theta_{22}} = 0 \quad (18)$$

(10)

$$|S_{11}|(1-|S_{11}|^2)^{1/2}\left[e^{j(\theta_{11}-\theta_{21})}+e^{j(\theta_{21}-\theta_{22})}\right]=0 \rightarrow (19)$$

which implies that

$$\left(e^{j(\theta_{11}-\theta_{21})}+e^{j(\theta_{21}-\theta_{22})}\right)=0 \Rightarrow e^{j(\theta_{11}-\theta_{21})}=e^{-j\pi}e^{j(\theta_{21}-\theta_{22})}$$

$$\Rightarrow \theta_{11}+\theta_{22}=2\theta_{21}-\pi\pm 2n\pi$$

(or)

$$\theta_{21}=\frac{\theta_{11}+\theta_{22}}{2}+\pi\left(\frac{1}{2}+n\right) \text{ for } n=0,1,2\cdots \quad (20)$$

- The eqn (19) & (20) from the magnitude & phase of S_{21} or S_{12} in terms of magnitude & phase of S_{11} & S_{22}

- From a measurement knowledge of S_{11} & S_{22}, we can completely describe and specify a reciprocal lossless 2 port n/w.

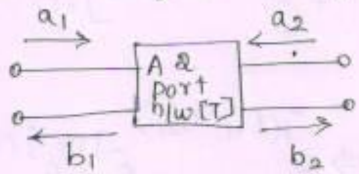
Transmission Matrix:-

- when cascading a number of 2 port n/ws in series a more useful n/w representation is needed to facilitate the calculation of the overall n/w parameters.

- At low frequencies, the transmission matrix is defined in terms of the net i/p voltage & current as the independent variables & the o/p & current as the dependent variables

- At high RF & μw frequencies, the transmission matrix [T] is expressed in terms of the incident & reflected waves as the independent variables & the o/p incident & reflected waves as the dependent variables

Transmission matrix for a 2 port n/w



– To extend the concept of the S-parameter representation to cascaded n/ws, it is more efficient to rewrite the power wave expression arranged in terms of i/p & o/p ports.

– The transmission matrix for a 2 port n/w is given by

$$\begin{bmatrix} a_1 \\ b_1 \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} b_2 \\ a_2 \end{bmatrix} \rightarrow (1)$$

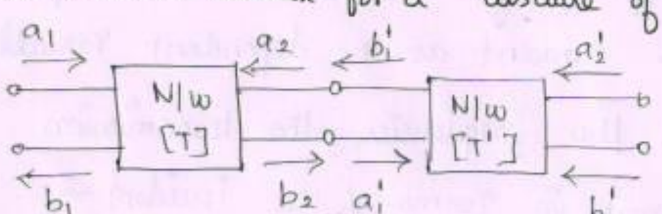
The relationship b/w S & T parameters can be derived using the above basic definition as follows

$$\begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} = \begin{bmatrix} 1/S_{21} & -S_{22}/S_{21} \\ S_{11}/S_{21} & S_{12} - \dfrac{S_{11} S_{22}}{S_{21}} \end{bmatrix} \rightarrow (2)$$

The relationship b/w [S] in terms of [T] matrix

$$\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} = \begin{bmatrix} T_{21}/T_{11} & T_{22} - \dfrac{T_{21} T_{12}}{T_{11}} \\ 1/T_{11} & -T_{12}/T_{11} \end{bmatrix} \rightarrow (3)$$

Transmission matrix for a cascade of 2 port n/w



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For a cascade connection of 2 port n/w

$$\begin{bmatrix} a_1 \\ b_1 \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \cdot \begin{bmatrix} b_2 \\ a_2 \end{bmatrix} \rightarrow (4)$$

$$\begin{bmatrix} a_1' \\ b_1' \end{bmatrix} = \begin{bmatrix} T_{11}' & T_{12}' \\ T_{21}' & T_{22}' \end{bmatrix} \begin{bmatrix} b_2' \\ a_2' \end{bmatrix} \rightarrow (5)$$

Based on the parameter convention shown in fig that

$$\begin{bmatrix} a_2 \\ b_2 \end{bmatrix} = \begin{bmatrix} b_1' \\ a_1' \end{bmatrix} \longrightarrow (6)$$

For the combined system

$$\begin{bmatrix} a_1 \\ b_1 \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} T_{11}' & T_{12}' \\ T_{21}' & T_{22}' \end{bmatrix} \begin{bmatrix} b_2' \\ a_2' \end{bmatrix} \rightarrow (7)$$

The total T-matrix is the multiplication of the 2 T matrices

$$[T]_{tot} = [T][T'] \rightarrow (8)$$

INTRODUCTION To RF COMPONENT

- Wire
- Resistor
- Capacitor
- Inductor

WIRE

A wire is a passive device normally used for interconnecting several hw components.

- It is the simplest element having zero resistance, which makes it appear as a short ckt at DC & low AC frequencies.

wire in a ckt can take on many form

(i) wire wound resistor
(ii) wire wound inductor
(iii) leaded capacitor
(iv) Element to Element interconnect application

How will you standardize the size of wires?

To standardize the size of wires, the American wire Gauge (AWG) system is commonly used in the United States. For instance, the diameter of the wire can be determined by its AWG value.

Problems

It associated with a wire can be traced to major areas

(i) Skin effect
(ii) Straight - wire inductance

Resistors

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The most common ckt element in low frequency electronics is a resistor whose purpose is simply to produce a voltage drop by converting some of the electric energy into thermal energy when an electric current passes through it.

Purposes of Resistors:-

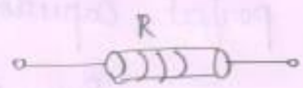
(i) In transistor bias n/ws, to establish an operating point

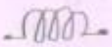
(ii) In attenuators, to control the flow of Power

(iii) In signal combiners, to produce a higher o/p power

(iv) In transmission lines, to create matched conditions

Type of Resistors:-

(i) Carbon Composition resistors, 

(ii) wire wound resistors 

(iii) Metal film resistors 

(iv) Thin film chip resistors 

Capacitors:-

It is a device that consist of 2 conducting surfaces separated by an insulating material or dielectric. The dielectric is usually ceramic, air, paper, mica or plastic. The capacitance is the property that permits the storage of charge when a potential difference exists b/w the conductors. It is measured in farads.

Type of capacitors

* perfect capacitors
* practical capacitors

Quality factor

It is the measure of the ability of an element to store energy, equal to 2π times the average energy stored divided by the energy dissipated per cycle

$$Q = \frac{X_C}{R_{EQ}} = \frac{1}{\omega C R_{EQ}} = \frac{1}{PF}$$

In practical capacitor $R_{EQ} \downarrow$ $Q \uparrow$ $R_{EQ} = 0$

in perfect capacitor $Q = \infty$

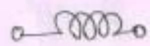
$R_{EQ} = 0$

$PF = 0$

$Q = \infty$ perfect capacitor

Inductors:-

A wire is wound in such a manner as to ↑ the magnetic flux linkage b/w the turns of the coil. The ↑ flux linkage ↑ the wire's self inductance



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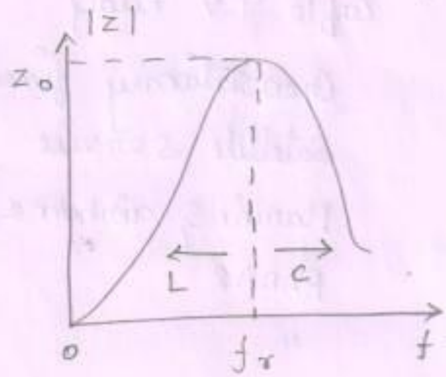
(i) $f < f_r$: inductor reactance ↑ f ↑

(ii) $f > f_r$: " behave capacitor & f ↑ reactance ↓

(iii) $f = f_r$ resonance take place in an inductor



Quality factor

$$Q = \frac{X_L}{R_s} = \frac{\omega L}{R_s}$$

perfect inductor

$$R_s = 0 \Rightarrow Q = \infty$$

Applications of RF

* Communication
* RADAR
* Commercial & Industrial application

F.B	Frequency	Application
VHF	88-108 MHz	FM broad casting
UHF	824-894 MHz	CDMA mobile Phone Service
		GSM " "

UHF	2400 MHZ	WLAN
SHF	5000-5850 MHZ	Unlicensed National Information Infrastructure
SHF	6,425-6,523 MHZ	Cable T.V Relay
SHF	3,700-4200 MHZ	Geo stationary fixed Satellite service
X band	8-12.5 GHZ	Marine & airborne radar
Ku band	12.5-18 GHZ	RADAR
K "	18-26.5 GHZ	"
Ka "	26.5-40 GHZ	"

RF applications:-

Military:-

- Mobile & remote RF communication is becoming more important in matteres of national defense.
- From Vechicle telemetry to robotic control & enemy monitoring. millitary officials are benefiting from the flexibility & safety provided by high performance RF solutions.

Remote monitoring (14)

- It takes many forms from sensors monitoring on plant floors & in harsh environments to automated meter reading of public utility meters.

- wireless remote monitoring is currently saving industries millions of dollars each year by providing up to the minute information that previously had to be gathered by personnal travelling to each remote sensor or meter location.

Weather stations:-

- The battery powerd radio modem solution provides wireless data offload from remote weather stations at distance upto 5 miles.

- The data can be automatically forwarded to other locations over the Internet by FTP or e-mail.

- The low power design allows one set of batteries to provide power for 1 year with daily data offload or five to ten months when offloading hourly. This greatly reduces the cost of implementing & maintaining the remote weather stations.

Ware housing:-

- Materials handlers & warehous managers are benefiting from electronic tagging of inventory.

- pick & Place system & mobile material handling devices can more quickly store & retrive inventory while logging important statistical information.

- Digi wireless products provide connection in warehouse where data cables and other wiring is difficult to impractical