Unit 1 : Microwave principles & devices

MWI-1

40

CO1: After studying this unit the student will be able to gain knowledge about microwave principles, freq ranges, applications, Hazards, devices & demonstrate ability to solve problems

"Microwaves are EMW radiations that lie in the freq range of 0.3 GHz to 100 GHz (ITU) or 1 GHz to 100 GHz (IEEE).

∴ λ_{min} = 30cm to 0.3cm

This was developed by US navy during world war II for detecting enemy targets, but now it is used in all applications.

CHARACTERSTICS & ADVANTAGES:-

1. Large b/w capability: we use digital modln like ASK, FSK, BPSK etc. where fc is from microwave region. 5 to 10% of fc is the usable b/w. Large b/w is possible, very max large no of information can be transmitted.
   eg: 1 microwave chnl can support — 400 Audio or 4 Video chls.
2. Flexibility w.r.t. beam width:
   - B.W is $\propto \lambda$, In Radars wide beam width is used in Search RAs & small B.W is used in tracking RAs.
   - Narrow B.W is useful in terrestrial comm for establishing Point to point lines.
   - Large b/w ant are used in Sat transponders, where large Estates can be covered by ant beam.
   - $\lambda g \propto \lambda$, miniature ant are used in mobile phones (patch, ...) compactness possible.
3. Can easily propagate thro different layers of atmosphere
   - good penetration with low atten. Important in LEO, MEO, Geosyncho & polar orbit Satellites
   - low path loss, fading, important in TV, RADAR & mobile comm.
4. Resistant to Automotive / Ignition noise of vehicles, used in mobile applns.
5. Easily passes thro dielectrics, results in Inductive / dielectric heating — principle used in Microwave oven & industrial appln.

MWI-3

6. High power μwave sources like klystron, magnetron, TWT etc which can generate kW or MW of (pulsed) CW power used for long distance comm (TV | RADAR | SAT | DVB etc). MWI-2

7. Low power μwave generators used in medical applications.

DISADVANTAGES:-

* μwave exhibits rectilinear propagation (or LOS propagation) (∥ to light waves) hence limited to Radio Horizon (≤40 to 60 km). After which we have to use μwave repeaters because of bulging nature of earth.
* High power are injurious to Health.
* They don't propagate thru good conductors & water. Reflect / Scattering takes place.
* High power sources requires lot of cooling.
* μwave Ckts are complex.

Microwave Freq Subbands and their applications

SHF (Super High Freq)

Band Name	Freq range (in GHz)	Applications
L	1-2	Military telemetry, GPS, GSM mobile, Amateur radio, cord telephones, Cellular PCS.
S	2-4	Weather Radar, Surface Ship radar, Comm Satellites, Microwave oven (2.45 GHz), Radio astronomy, Sat transponders, WLAN, AMRS (Aeronautical Mobile Services), WiMAX, Bluetooth, Zigbee
C	4-8	Long distance telecomm (DTV, Sat TV, DTH, DVB etc).
X	8-12	Lab Testing, Sat Comm, RADAR, Terrestrial broadband, Amateur radio, Space comm
Ku	12-18	Sat Remote Sensing, Secured/Defence comm, RADAR, Astronomical observations, Automotive Radar, Sat comm
K	18-27	
Ka	27-40	
mm waves	40-300 GHz	Radar Research, Fixed Sat Services (Geo Synch Sat comm), Terrestrial Comm, Deep Space tracking, Military Radar, Target testing & tracking, Scientific research

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5. Easily passes thro dielectrics, resulting in Induction / dielectric heating — principle used in micro ovens & industrial applns.

...tor has an insertion loss of 1dB,
...n is 30dB, VSWR=1.5. Find S...
...ce (B.W)
...with PB gain - 3dB upto 4GHz
...20dB from 10GHz. R
...w = 10...

MWI-4

...nes:-

Applications:
TV broadcasting, Internet, Telephone lines,
AVB, video conferencing etc.

MWI-2

6. High power μwave sources like klystron, Magnetron, TWT etc which can generate lower MWs of pulsed/cw power used for long distance comm (TV/RADAR/SAT/DVB etc).
7. Low power μwaves are used in medical applications.

DISADVANTAGES:-

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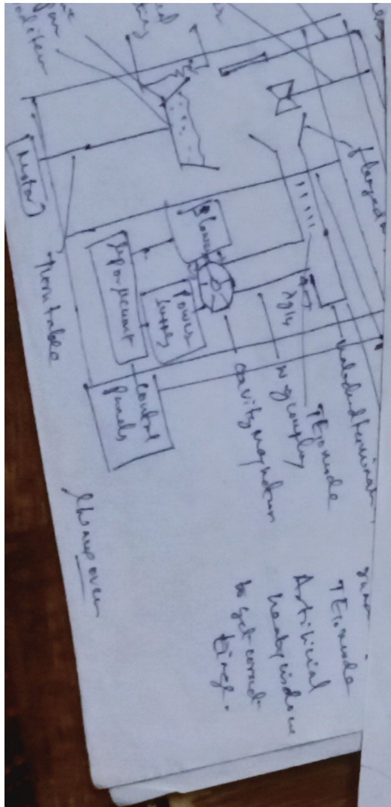

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mm wave	40 - 300 GHz	Radar Research, Fixed Sat Services (Geo Synch Sat comm), Terrestrial Comm, Deep Space tracking, Military Radar, Target testing & tracking, Scientific research

MW1-3

PB gain - 3dB upto 4GHz

-20dB from 10GHz. $R_0 = 50\Omega$

$Z_{low} = 10\Omega$ $\epsilon_r = 4$, $\lambda = 10^{44}$

Application of Microwaves:-

I Communication Applications:

- Sat comm – TV broadcasting, Internet, Telephone lines, AVB, video conferencing etc.
- Tropospheric comm.
- Wireless mobile phones, cellular comm.
- police wireless (walkie-talkie)
- civil aviation (ATC), Rail comm.
- GPS, GPRS, WLAN, navigational aids

II RADAR applications:

- weather prediction / monitoring
- Remote sensing –
  - Agriculture
  - ONGC
  - sea exploration
- Radio Astronomy
- Airport surveillance (ATC)
- MTI
- Tsunami / Earthquake early warning systems
- Doppler radars
- Missile guidance
- IFF
- searching / Tracking
- Radar beacons / Altimeters

III Industrial Applications:-

- Testing of materials (flaws concentration etc).
- Thickness detectors
- furnace ovens
- mining for detecting poisonous gases
- Drying of coffee / paints / paper etc.
- Breaking concrete / steel girders / stones etc.

IV Medical Applications:-

- Medical diagnostic scanners (CT, ECG, EEG etc)
- Low power in treatment of tumors (cancer)
- Hyperthermia / diathermy applications

4. Find S-matrix of a 3dB coupler
   Find S-matrix of a T-section of a Txn line characterised Zo & terminated with Zo

5. A 3dB circulator has an insertion loss of 1dB, isolation loss is 30dB, VSWR = 1.5. Find S-matrix

6. Design a HP filter with Butterworth (B.W) Pass band gain -3dB upto 4GHz, Stop band attn. -20dB from 10GHz. R

Dielectric Heating principle

M1N1-5

27

In 1946 Dr P. Spencer of USA noticed that, a candy kept in his pocket melted when he was working with cavity magnetron, an egg splattered in front of klystron etc.

Dielectric materials like food items, human body parts exhibits losses due to nonzero σ & ε. Microwave can penetrate these items (upto 25 or 25mm called skin depth) & dissipate heat due to ohmic losses. Microwave impart energy to crystal or molecular structure resulting in rotation, vibration of bonds & movement of electrons. Due to conduction of microwave ε is complex

$$\epsilon_r = \epsilon_r' - j\epsilon_r'' \qquad \text{where } \epsilon_r'' = \frac{\sigma}{\omega\epsilon_0}$$

Normal   loss component

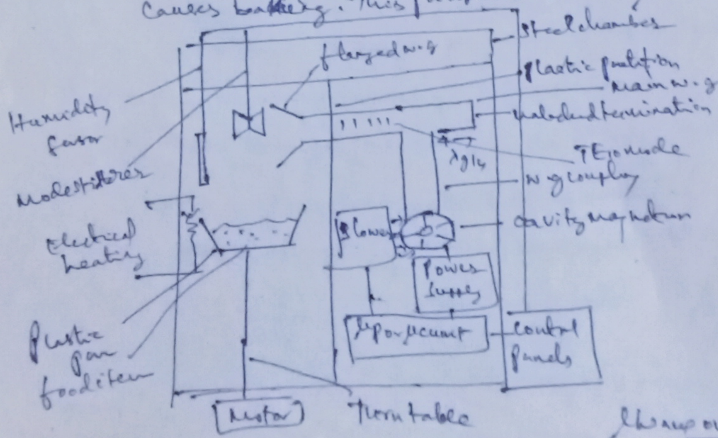
w.k.T losses in dielectric is measured in terms of loss factor or tanδ

$$\tan\delta = \epsilon_r''/\epsilon_r' = \frac{\sigma}{\omega\epsilon_0\epsilon_r'}$$

Amount power dissipated is measured in terms of power density

$$P_d = \sigma|E_i|^2 \ W/m^3$$, where $|E_i|$ is the dielectric field of wave in volts/m.

Since E_i is nonuniform this creates hot spots in food items which causes baking. This principle is used in microwave oven



Operation
Magnetron works at 2.45 GHz
Mode stirrer randomizes the TE10 mode
Artificial heating is done to get correct timing.

Microwave oven

MWI-7

:- High power microwave are hazardous to the
. Hazards are classified into 3 catagories
...ding Emmission on Personal
——— " ——— ordnance
——— " ——— Fuel

...wave radiation on human beings causes different ailments
...ia (type of blood cancer) * Infertility or sterility
... biological cellular processes.
...se different parts like blood, bone, tissues, capillaries, which

MWI-6

Specifications :-

* Electrical I/P power - 1 to 1.5 kW
* O/P microwave power from source - 600 to 700 W
* Oven size in terms of volume - 20 to 25 lts
  - 800-1200 W
  - 1200-1800 W
* other facilities like cooking, heating, fast cooking, defrosting, baking, crisping, roasting, child lock, feather touch operation, clock setting etc.
* Industrial ovens operate at 915 MHz.

* Don't energize Radar TX on board an aircraft or a motor vehicle during fuelling.
* Don't break or make electrical or ground wire during fuelling
* —"— install transmitting antennas in the vicinity of oil wells
* Properly protect the containers from high power µwaves.

within 1 km of human habitat no towers
Safe exposure level in India 0.92 W/m^2
SAR per mobile phone 2 W/kg of the user body mass, lowered to 1.6 W/kg in 1 gm of tissue – Average height is $\approx 0.5\lambda$

SCATTERING PARAMETERS or S-parameters

waves we use no. of two port & multiport devices like lifiers, oscillators, mixers, circulators etc. To study their

MW1-7

29

Hazards of µwaves :- High power µwaves are hazardous to the echosystem. Hazards are classified into 3 categories

HERP – Hazards of Emwaves on personal
HERO – —"— ordnance
HERF – —"— Fuel

(1) HERP : High power radiation on human beings causes different types of ailments
* leukemia (type of blood cancer) * Infertility or sterility
* affects biological cellular processes.

This is because different parts like blood, bone, tissue, cartilages, kidney, muscles, brain etc. act as dielectrics through which µwaves can penetrate. [marginal: much, Intestine]

constant viewing of µwave causes eyeball or lens or cornea damage. People working in Atomic research stations, Thermal power stations, µwave power stations suffer from these disorders. They wear a protective gown in the work place.

If human body size is $\geq \lambda/10$ it absorbs µwaves, where λ is wavelength of µwaves. Depth of penetration into human body & effects depend on parameters like
* strength * height * portion of the body * orientation of body

HERP is measured in terms of 3 parameters
(a) P_d = Average power density = $EH = E^2/377\Omega$ or $H^2 377$

(b) SAR = specific absorption rate in watts/kg
(Rate of absorption of µwave / unit mass of substrate in watts/kg)

$$= \frac{\sigma E^2}{m_d}$$

σ = conductivity of body
E = Field strength
m_d = mass density of material

... feeding, ... board an aircraft or a vector

* Don't wear or make electrical or ground wire during feeding
* — " — install transmitting antennas in the vicinity of ordnance

* Properly protect the containers from high power microwave

Note:-
- within 1 km of human habitat no towers
- Safe exposure level in India 0.92 w/m²
- SAR for mobile phone 2 w/kg of the user body mass, lowered to 1.6 w/kg in 1 gm of tissue – Average height is ≥ 0.5λ

SCATTERING PARAMETERS or S-parameters

In microwave we use no. of two port & multiport devices like couplers, amplifiers, oscillators, mixers, circulators etc. To study their performance they must be characterized. At low freq 2 port n/w or devices are characterized by ABCD, Z, Y & h (hybrid) parameters. These can't be used at microwave because

* microwave propagates in free space, deep inside a transmission line (Txn) or w.g. where it is difficult to connect various ...

30 mobile phones in the range of 918–2450 MHz causes hot spots inside the skull, if kept in pocket causes kidney ailments
glioma (brain cancer)

MW-8

(c) Rate of temp rise due to microwave Heating

$$dT/dt = Q/s_p \quad (°C/secs)$$

where Q = SAR + Metabolic rate of heat production / unit mass

s_p = specific heat of substance

Two global organizations monitor radiations on personnel

I IRPA – International Radiation Protection Association

II ANSI – American National Standard Institute Inc

PEL (Permissible Exposure Levels) depends on parameters like
or MPE (Maximum — " —)
* country * geographical location of place * climatic condition * power level * orientation
* vegetation * population in the area
of body to radiation, * Skin depth etc.

→ High intensity radiation from RADAR, H power Txn lines, TX etc.

(2) HERO:- ordnance or defence equipments like weapon systems, safety & emergency devices, EED's (Electro Explosive devices), Rocket / missile launchers / guiding systems; during etc. react to peak power. Human body reacts to average power. EMWs can cause currents strong enough to create electrical sparks & may cause unwanted triggering of the devices.

Hence weapon systems are protected by

* storing them in Arsenal with thick concrete walls through which microwave can't penetrate
(form)
* providing proper earthing
* covering in the form of shields / jackets

normal power

$|a|^2$ or $\frac{1}{2}\frac{|V_i|^2}{Z_0}$

$|b|^2$ or $\frac{1}{2}\frac{|V_r|^2}{Z_0}$

$\frac{1}{2}[|a|^2-|b|^2]$

$\frac{1}{2}[|V_i|^2-|V_r|^2]$

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

$I_2 = \frac{a_2 - b_2}{\sqrt{Z_0}}$

parameter representation ... be a 2 port N/W i.e. 2×2 matrix

S_{12} ... S_{22} ... a_1, a_2

... S_{1n} ... a_1, a_2 ... n×n matrix

[MW1-9]

31

(c) <u>HERF</u>:- μwave/RF induced arcs of strength > 50 Volt-Amps can cause ignition of fuel materials like petrol, High speed petrol, kerosine, diesel, gasoline, Hydrazine, LPG etc. Hence proper care must be taken

* Switch of mobile phones in fueling station / petrol bunks
* Don't energize Radar TX on board an aircraft or a motor vehicle during fuelling
* Don't break or make electrical or ground wire during fuelling
* —"— install transmitting antennas in the vicinity of oil wells
* properly protect the containers from high power μwave.

<u>Note</u>:-
- within 1 km of human habitat no towers
- Safe exposure level in India $0.92\,W/m^2$
- SAR for mobile phone $2\,W/kg$ of the user body mass, lowered to $1.6\,W/kg$ in 1 gm of tissue – Average height is 20.5 λ

SCATTERING PARAMETERS or S-Parameters

In μwave we use no. of two port & multiport devices like coupler, amplifier, oscillator, mixer, circulator etc. To study their performance they must be characterized. At low freq 2 port n/w or devices are characterized by ABCD, Z, Y & h (hybrid) parameters. These can't be used at μwave because

* μwave propagates in free space, deep inside a highline / TXn or w.g where it is difficult to connect various meters.
* For above parameter determination we require O.C & S.C which difficult in a w.g or TXn line.
* Most of the measurements are f- dependent
* In active device ckt like μwave trs, klystron, TWT & magnetron, if we provide S.C or O.C these will be loading

representation ... 2 port N/W i.e 2×2 matrix

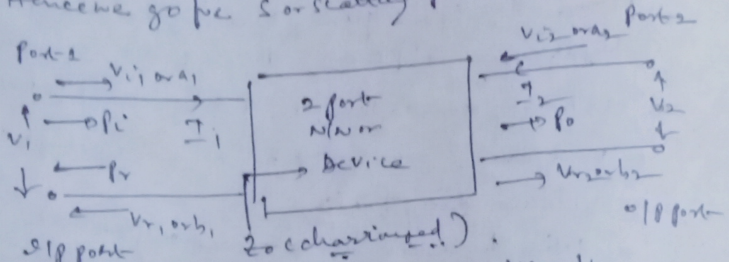
here ... n×n matrix

... Incident column vector (1×n)

32

* Dimension of component/device are comparable to λ they disappear & hence V/I are not well defined $\boxed{MW1-10}$

Hence we go for S or scattering parameters.



Z_0 (characterised).

* V_1, V_2 are terminal voltages at the ports, $V_1 = V_{i1} + V_{r1}$, $V_2 = V_{i2} + V_{r2}$

* If type of parameter is not specific, we call it as signal $a_1, a_2 \rightarrow$ Incident signals, $b_1, b_2 \rightarrow$ reflected signals

* S parameter is defined as $= b/a$ or $V_r/V_i = \frac{\text{reflected signal}}{\text{incident signal}}$

  As a or b : V_r or V_i are complex, S is also complex

* Functional relationships are

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

or

$$V_{r1} = S_{11} V_{i1} + S_{12} V_{i2}$$
$$V_{r2} = S_{21} V_{i1} + S_{22} V_{i2}$$

* $S_{11} = b_1/a_1 \Big]_{a_2=0}$ or $\frac{V_{r1}}{V_{i1}}\Big]_{V_{i2}=0}$ i.e Refl coeff at port 1 with port 2 matched or properly terminated i.e $a_2 = 0$ or $V_{i2} = 0$

lly $S_{22} = b_2/a_2 \Big]_{a_1=0}$

$S_{12} = b_1/a_2 \Big]_{a_1=0}$ or $\frac{V_{r1}}{V_{i2}}\Big]_{V_{i1}=0}$ i.e Attenuation factor of wave travelling from port 2 to port 1 with port 1 properly terminated

1 ——— 2

V_i Device 2'

V_r

(2-2') Initial ref planes

(B-B') new —"—

$V_r = S V_i$

al ref plane drifts by a distance of 'l', then voltages

experience phase change of $\pm \beta l$

$e^{-j\beta l}$

i.e. $V_r e^{j\beta l} = S V_i e^{-j\beta l}$

or $V_r = S' V_i$ where $S' = S e^{-j2\beta l}$ —(1)

S' → S-matrix for new ref plane. Mag. of S remains same but phase

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$\boxed{\text{MWI-11}}$

33

IIIly $S_{21} = b_2/a_1 \Big]_{a_2=0}$ or $V_{r2}/V_{i1} \Big]_{V_{i2}=0}$.

<u>Note</u>:- from above definitions it is clear that as compared to LF parameters, S-parameters doesnot need S.C or O.C but only matched terminations. → Normal power

* P_i = Normalized I/P power $= \frac{1}{2}|a|^2$ or $\frac{1}{2}\frac{|V_i|^2}{Z_0}$

P_r = —"— reflected —"— $= \frac{1}{2}|b|^2$ or $\frac{1}{2}\frac{|V_r|}{Z_0}$

$\therefore P_0$ = O/P power $= P_i - P_r = \frac{1}{2}\left[|a|^2 - |b|^2\right]$

or $\frac{1}{2}\left[|V_i|^2 - |V_r|^2\right]$

* $a_1 = \frac{V_{i1}}{\sqrt{Z_0}} = \frac{V_1 - V_{r1}}{\sqrt{Z_0}}$, $b_1 = \frac{V_{r1}}{\sqrt{Z_0}} = \frac{V_1 - V_{i1}}{\sqrt{Z_0}} = \frac{V_1}{\sqrt{Z_0}} - a_1$

$\therefore V_1 = (a_1 + b_1)\sqrt{Z_0}$.

IIIly $I_1 = \frac{a_1 - b_1}{\sqrt{Z_0}}$ & $I_2 = \frac{a_2 - b_2}{\sqrt{Z_0}}$.

* Matrix form of S-parameter representation

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$ for a 2-port-N/W i.e 2×2 matrix

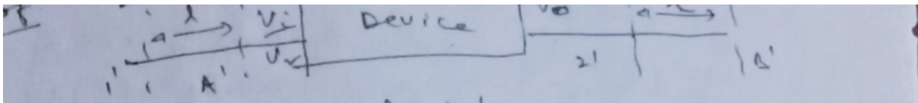
* For a n-port-N/W, we have

$$\begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1n} \\ S_{21} & S_{22} & \cdots & S_{2n} \\ \vdots & & & \\ S_{n1} & S_{n2} & \cdots & S_{nn} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_n \end{bmatrix}$$ n×n matrix

* Vector form

$$\underset{\substack{\downarrow \\ \text{Reflected} \\ \text{Column vector} \\ (1\times n)}}{b} = \underset{\substack{\downarrow \\ \text{Scattering matrix} \\ (n\times n)}}{S}\; a \rightarrow \text{Incident-Column Vector } (1\times n)$$

or $V_r = S V_i$



(1-1'), (2-2') Initial ref planes
(A-A'), (B-B') new —〃—

For Initial ref plane $V_r = S V_i$
If plane drifts by a distance 'l', then voltages experiences a phase change of $\pm \beta l$

i.e $V_r e^{j\beta l} = S V_i e^{-j\beta l}$

or $V_r = S' V_i$ where $S' = S e^{-j2\beta l}$ —(1)

$\downarrow$ ... new ref plane.

34 In μwave ckts/devices/N/ws we express several losses in terms of S-parameters, for 2-port n/ws with [MWT-12]

$P_i \to$ i/p power to port 1, P_r — reflected power from port 1
$P_o \to$ o/p —〃— at —〃— 2

(A) **Insertion loss (dB):** loss due to mismatch between source & load or N/W1 & N/W2 or Device 1 & Device 2

$$= 10 \log \frac{P_i}{P_o} = 10 \log \frac{|a_1|^2}{|b_2|^2} = 20 \log \frac{1}{|b_2|/|a_1|} = 20 \log \frac{1}{|S_{21}|}$$

$$= -20 \log |S_{21}|$$

* For a symmetric or bilateral n/w $S_{12} = S_{21}$ & $S_{11} = S_{22}$

$\therefore$ I.L $= -20 \log |S_{12}|$

* For unilateral or asymmetric n/w $S_{12} \neq S_{21}$ we define

Isolation loss $= -20 \log |S_{12}|$

(b) **Attenuation or Txn loss (dB):-** loss due to n/w/devices/ckts

$$= 10 \log \frac{P_i - P_r}{P_o} = 10 \log \frac{1 - |S_{11}|^2}{|S_{21}|^2}$$

i.e for an ideal n/w $P_o = P_i - P_r$ $\therefore$ A.L or T.L $= 0$

For non ideal n/w $P_o \neq P_i - P_r$ $\therefore$ A.L $\neq 0$.

$$= 10 \log \frac{|a_1|^2 - |b_1|^2}{|b_2|^2} = 10 \log \frac{1 - \left[\frac{|b_1|}{|a_1|}\right]^2}{\left[\frac{|b_2|}{|a_1|}\right]^2}$$

(c) **Reflection loss of a port (dB):** Due to improper termination of the port

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

(d) **Return loss (dB):-** loss in the n/w due to discontinuity

$$= 10 \log \frac{P_i}{P_r} = 20 \log \frac{1}{|S_{11}|}$$

4. **Zero property:** Sum of products of any one row or column of S-matrix multiplied by the complex conjugate of the corresponding elements of any other row or column is zero. MW1-14

$$\sum_{i=1}^{n} S_{ik} S_{ij}^{*} = 0$$ where $k = 0, 1, 2, \ldots n$, $j = 0, 1, 2, \ldots n$

k & j are the row or columns of the matrix

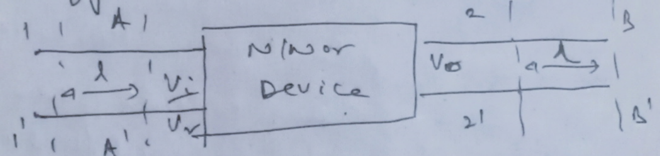
eg:- For a 2x2 matrix, if we consider 1st & 2nd row

$$S_{11} S_{21}^{*} + S_{12} S_{22}^{*} = 0$$

5. **phase shifting property:-**

Reference plane in μwave devices & ckts shifts due to o.c/s.c, frequency change etc. Under these conditions magnitude of S-parameter remains same but only phase changes.

Proof:-



(1-1'), (2-2') Initial ref planes

(A-A'), (B-B') New — II —

For Initial ref plane $V_r = S V_i$

If plane drifts by a distance of 'l', then voltages experiences a phase change of $\pm \beta l$

i.e $V_r e^{j\beta l} = S V_i e^{-j\beta l}$

or $V_r = S' V_i$ where $S' = S e^{-j2\beta l}$ —(1)

S-matrix for new ref plane

From (1) it is clear that mag of S remains same but phase changes

Properties of S-matrix :

MW 1-13

1. Zero diagonal Elements : For a perfectly matched N/W this property holds good.

For a 'n' port N/W with matched termination of all ports (i.e no reflections in these ports) i.e

$S_{ii} = 0$ for $i = 1, 2, \ldots n$

$$[S] = \begin{bmatrix} 0 & S_{12} & S_{13} & \cdots & S_{1n} \\ S_{21} & 0 & S_{23} & \cdots & S_{2n} \\ \vdots & & & & \\ S_{n1} & S_{n2} & \cdots & & 0 \end{bmatrix}$$

2. Symmetry Property : For a reciprocal device or bilateral device — same characteristics in either direction

$S_{ij} = S_{ji}$ where $i \neq j$

or $\underset{\sim}{S} = \underset{\sim}{S}^T$ eg: For a 2 port N/W

$S_{11} = S_{12}$, $S_{12} = S_{21}$

i.e signal propagation same in either direction

3. Unitary property :- Sum of products of each term of any row or column of S-matrix multiplied by its complex conjugate is unity.

eg: If we consider 1st row of a $n \times n$ matrix, then

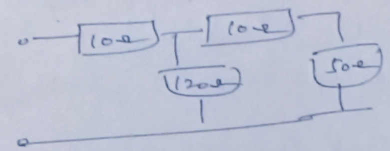
$$S_{11} S_{11}^* + S_{12} S_{12}^* + \ldots + S_{1n} S_{1n}^* = 1$$

For a lossless N/W or device, O/P power at a port is sum of powers from all other remaining ports.

This demonstrates power balance

EC710 Problems UNIT-1 Microwave & Antennas. 21 1

1) Find S-matrix of a T-N/W



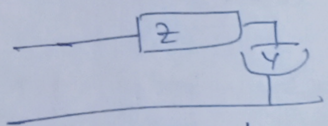
2. S parameters of a 2 port N/W are

$S_{11} = 0.4\angle 0°$, $S_{22} = 0.2\angle 0°$; $S_{12} = S_{21} = 0.3\angle 90°$

* Find all losses of the N/W
* Test the various properties satisfied by S matrix

3. Find S-matrix of a 3dB coupler

4. Find S matrix of a T-Section of a Txn line characterised Z_0 & terminated with Z_0



5. A 3dB circulator has an insertion loss of 1dB, isolation loss is 30dB, VSWR=1.5. Find S matrix.

Microwave filter (B.W)

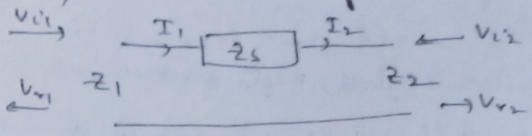
6. Design a HP filter with PB gain -3dB upto 4GHz Stop band attn. -20dB from 10GHz. $R_0 = 50\Omega$

$Z_{high} = 150\Omega$, $Z_{low} = 10\Omega$ $\epsilon_r = 4$, $x = 1.044$

$\left[\frac{2Z_0}{D.r} \quad \frac{}{D.r} \right]$

(1) Find S-matrix of T n/w

(3) Find S-matrix of series element



Soln:- In a series element ckt $I_1 = I_2$, V

w.k.T $V_{r1} = S_{11} V_{i1} + S_{12} V_{i2}$

22 7. Design a 5th order LP Stripline chebyschev filter with $\boxed{2}$
P.B ripple $-0.5dB$ with $\epsilon_r = 10$, $Z_{high} = 150\Omega$,
$Z_{low} = 10\Omega$ $R_o = 50\Omega$
P.B gain $-3dB$ upto 5GHz, I.L 20dB from 7.5GHz

8. For data of problem 6 design LP filter

9. — " — 7 — " — HP filter

10. S matrix of a Two port N/w is

$$S = \begin{bmatrix} \frac{5}{13} & j\,12/13 \\ j\,12/13 & \frac{5}{13} \end{bmatrix}$$

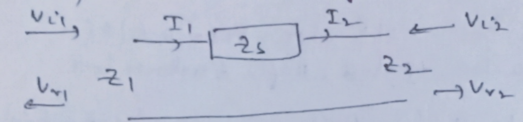
* Test different properties & infer accordingly

* Find all the losses.

—x—

(1) Find S-matrix T n/w [MN1-P1]

(3) Find S-matrix of series element S. [MN1-P1]



Sol:- In a series element ckt $I_1 = I_2$, $V_{i1} = V_{r2} + V_{r1}$ if $V_{i2} = 0$ & $V_{i2} = V_{r1} + V_{r2}$ if $V_{i1} = 0$.

w.k.T $V_{r1} = S_{11}V_{i1} + S_{12}V_{i2}$

$V_{r2} = S_{21}V_{i1} + S_{22}V_{i2}$

∴ As in previous case $S_{12} = 1 - S_{11}$, $S_{21} = 1 - S_{22}$

$$S_{11} = \frac{Z_{R1} - Z_{S1}}{Z_{R1} + Z_{S1}}$$

$Z_{R1} = Z_s + Z_2$, $Z_{S1} = Z_1$

$$\therefore S_{11} = \frac{Z_2 + Z_s - Z_1}{Z_1 + Z_2 + Z_s}$$

$$S_{12} = 1 - S_{11} = \frac{2Z_1}{Z_1 + Z_2 + Z_s}$$

$$S_{22} = \frac{Z_{R2} - Z_{S2}}{Z_{R2} + Z_{S2}}$$

$Z_{R2} = Z_s + Z_1$, $Z_{S2} = Z_2$

$$\therefore S_{22} = \frac{Z_1 + Z_s - Z_2}{Z_1 + Z_2 + Z_s}$$

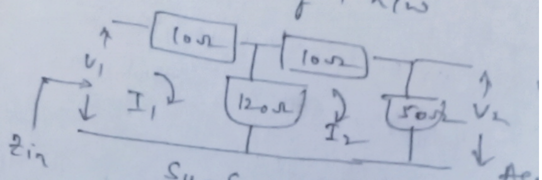
$$\therefore S_{21} = 1 - S_{22} = \frac{2Z_2}{Z_1 + Z_2 + Z_s}$$

$$\therefore S = \begin{bmatrix} \frac{Z_2 + Z_s - Z_1}{Z_1 + Z_2 + Z_s} & \frac{2Z_1}{D.r} \\ \frac{2Z_2}{D.r} & \frac{Z_1 + Z_s - Z_2}{D.r} \end{bmatrix}$$

if $Z_1 = Z_2 = Z_0$

$$S = \begin{bmatrix} \frac{Z_s}{Z_s + 2Z_0} & \frac{2Z_0}{Z_s + 2Z_0} \\ \frac{2Z_0}{D.r} & \frac{Z_s}{D.r} \end{bmatrix}$$

(1) Find S-matrix of T n/w



$S_{11} = S_{22} = Z_R - Z_n$

14 4) S-parameters of a 2 port n/w are

MW 1-P4

$S_{11} = 0.2\angle 0°$, $S_{22} = 0.1\angle 0°$, $S_{12} = S_{21} = 0.6\angle 90°$

Find Insertion loss, Txn loss, Refln & return loss.

(i) $I.L = -20\log|S_{12}|$ or $-20\log|S_{21}|$ $\because$ N/w is symmetric because $S = S^T$

$= -20\log 0.6 = 4.4\,dB$

(ii) Attnor Txn loss $= 10\log \dfrac{1-|S_{11}|^2}{|S_{21}|^2}$

$= 10\log \dfrac{1-.2^2}{.6^2} = 4.3\,dB$

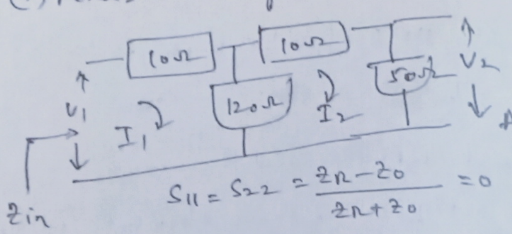
(iii) Refln loss $= 10\log \dfrac{1}{1-|S_{11}|^2} = 10\log \dfrac{1}{1-.2^2}$

$= .18\,dB$

(iv) Return loss $= 20\log \dfrac{1}{|S_{11}|} = 20\log \dfrac{1}{0.2}$

$= \underline{14\,dB}$

(1) Find S-matrix of T n/w



$Z_{in} = 10 + (120) \parallel^{el} (10+50)$
$= 50\,\Omega$

A S N/w which symmetric

$$S_{11} = S_{22} = \frac{Z_R - Z_0}{Z_R + Z_0} = 0$$

Also $S_{12} = S_{21}$, $I_1 = \dfrac{V_1}{Z_{in}} = \dfrac{V_1}{50}$ —(1)

$$\therefore I_2 = \frac{I_1 (120)\,\Omega}{(120+50+10)\,\Omega} \quad —(2)$$

eq (1) in (2) gives. $I_2 = \dfrac{V_1 (120)}{180 \times 50}$ —(3)

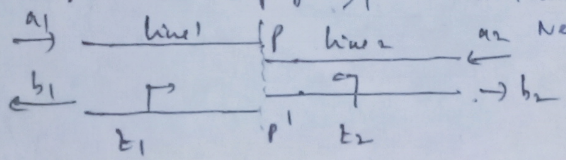
But $I_2 = \dfrac{V_2}{Z_0} = \dfrac{V_2}{50}$ —(4)

$\therefore$ From eq (3) & (4) $\dfrac{V_2}{V_1} = S_{21} = S_{12} = \dfrac{50 \times 120}{180 \times 50} = .667$

$$\therefore S = \begin{bmatrix} 0 & .667 \\ .667 & 0 \end{bmatrix}$$

(2) Two Txn lines of char. imped. Z_1 & Z_2 are joined at plane $P P'$. Express S-parameter of the combination in terms of impedances assuming lines are properly/matched terminated.

Sol:



Neglecting loading effects.

18

* If line 2 is matched terminated, then at p-p' line imped $= Z_2$

$$\frac{b_1}{a_1} = \therefore S_{11} = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

IIIly if line 1 is properly terminated

$$\frac{b_2}{a_2} = S_{22} = \frac{Z_1 - Z_2}{Z_1 + Z_2} = -S_{11}$$

* If line 2 is matched terminated then $a_2 = 0$

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

we have $b_1 = S_{11} a_1$ or $S_{11} = \frac{b_1}{a_1}$
& $S_{21} = b_2 / a_1 \Big]_{a_2 = 0}$

IIIly If line 1 ——— $a_1 = 0$

$b_1 = S_{12} a_2$ or $S_{12} = b_1 / a_2 \Big]_{a_1 = 0}$ & $b_2 = S_{22} a_2$

$S_{22} = b_2 / a_2$

* from fig if $a_2 = 0$, $a_1 = b_1 + b_2$

$$\therefore b_2 = a_1 - b_1$$

$$b_2 / a_1 = S_{21} = 1 - \frac{b_1}{a_1} = 1 - S_{11}$$

$$\therefore S_{21} = 1 - \frac{Z_2 - Z_1}{Z_2 + Z_1} = \frac{2Z_1}{Z_1 + Z_2}$$

IIIly

$$S_{12} = 1 - S_{22} = \frac{2Z_2}{Z_1 + Z_2}$$

$$\therefore S = \begin{bmatrix} \frac{Z_2 - Z_1}{Z_2 + Z_1} & \frac{2Z_2}{Z_1 + Z_2} \\ \frac{2Z_1}{Z_1 + Z_2} & \frac{Z_1 - Z_2}{Z_1 + Z_2} \end{bmatrix}$$