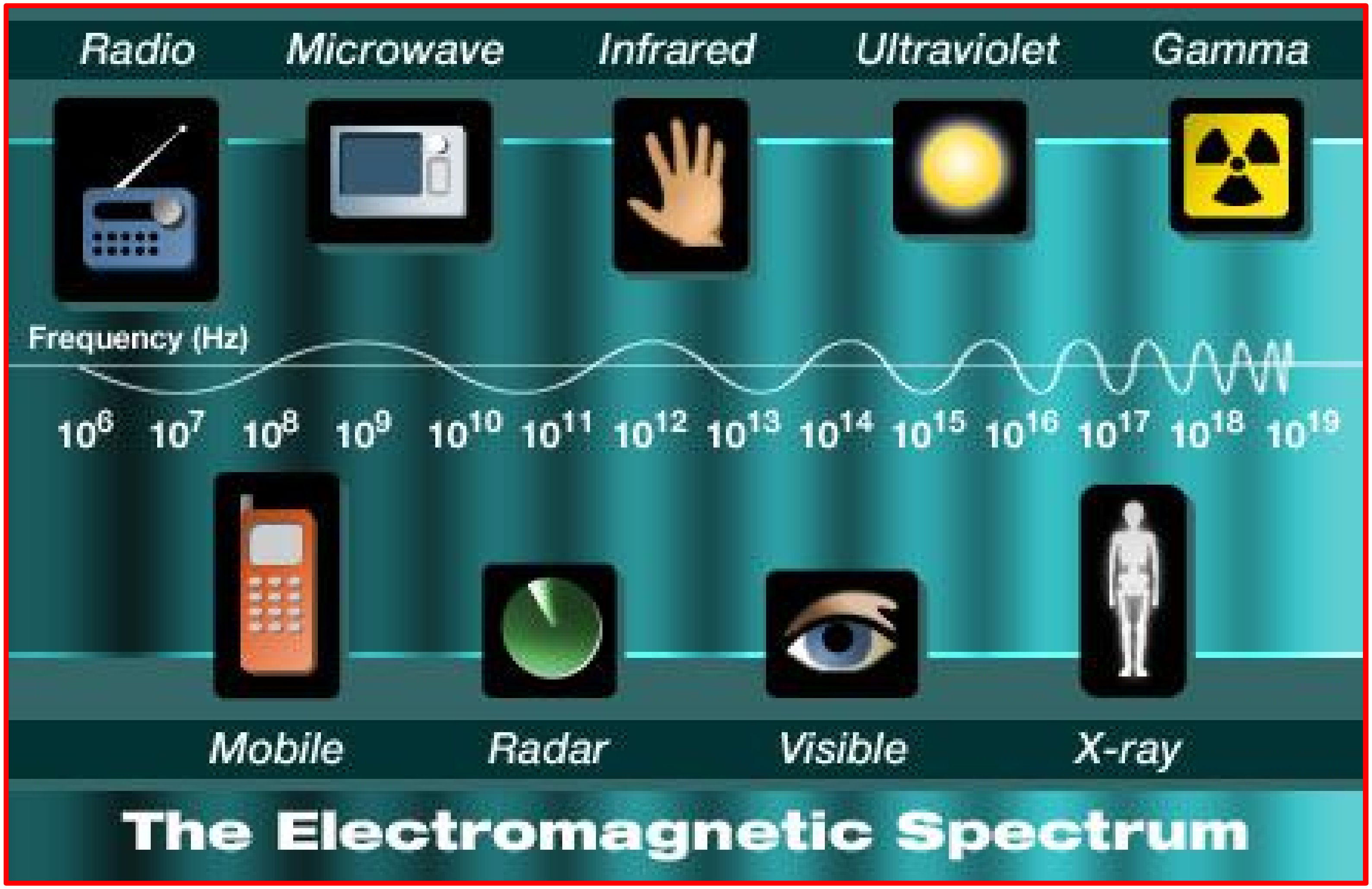
UNIT I MICROWAVE NETWORK THEORY

Introduction –Microwave frequency range, applications of microwaves– Scattering matrix representation of multi port network properties of S-parameters – S matrix of a two port network with mismatched load – Z and ABCD parameters-Comparison between [S] - [Z] and [Y] matrices

Electromagnetic spectrum



Microwaves

- Microwaves are electromagnetic waves whose frequencies range from about 300 MHz – 300 GHz (1 MHz = 10 6 Hz and 1 GHz = 10 9 Hz) or wavelengths in air ranging from 100 cm – 1 mm.

- The word *Microwave* means *very short wave*, which is the shortest wavelength region of the radio spectrum and a part of the electromagnetic spectrum.

Properties of Microwaves

1. Microwave is an electromagnetic radiation of short wavelength.
2. They can reflect by conducting surfaces just like optical waves since they travel in straight line.
3. Microwave currents flow through a thin outer layer of an ordinary cable.
4. Microwaves are easily attenuated within short distances.
5. They are not reflected by ionosphere

Microwave Applications

- Communication
  - Terrestrial
  - Satellite
- Radar
  - Civilian
    - Air traffic control
    - Aircraft navigation
    - Ship safety
    - Space vehicles
    - Remote sensing
    - Law enforcement
  - Military
    - Surveillance
    - Navigation
    - Guidance of weapons
    - Electronic warfare
    - C^3
- Industrial and Biomedical
  - Process control
  - Drying
  - Curing
  - Treatment of elastomers
  - Waste treatment
    - Nuclear
    - Cellulosic
  - Monitoring
  - Imaging
  - Hyperthermia
- Heating
  - Industrial
  - Household

Applications

- Microwaves have a wide range of applications in modern technology, which are listed below

1. **Telecommunication**: Intercontinental Telephone and TV, space communication (Earth – to – space and space – to – Earth), telemetry communication link for railways etc.
2. **Radars:** detect aircraft, track / guide supersonic missiles, observe and track weather patterns, air traffic control (ATC), burglar alarms, garage door openers, police speed detectors etc.

Commercial and industrial applications

- Microwave oven
- Drying machines – textile, food and paper industry for drying clothes, potato chips, printed matters etc.
- Food process industry – Precooling / cooking, pasteurization / sterility, hat frozen / refrigerated precooled meats, roasting of food grains / beans.
- Rubber industry / plastics / chemical / forest product industries
- Mining / public works, breaking rocks, tunnel boring, drying / breaking up concrete, breaking up coal seams, curing of cement.
- Drying inks / drying textiles, drying / sterilizing grains, drying / sterilizing pharmaceuticals, leather, tobacco, power transmission.
- Biomedical Applications (diagnostic / therapeutic) – diathermy for localized superficial heating, deep electromagnetic heating for treatment of cancer, hyperthermia (local, regional or whole body for cancer therapy).

THE SCATTERING MATRIX

- Usually we use Y, Z, H or ABCD parameters to describe a linear two port network.
- These parameters require us to open or short a network to find the parameters.
- At radio frequencies it is difficult to have a proper short or open circuit, there are parasitic inductance and capacitance in most instances.
- Open/short condition leads to standing wave, can cause oscillation and destruction of device.
- For non-TEM propagation mode, it is not possible to measure voltage and current. We can only measure power from E and H fields.

THE SCATTERING MATRIX

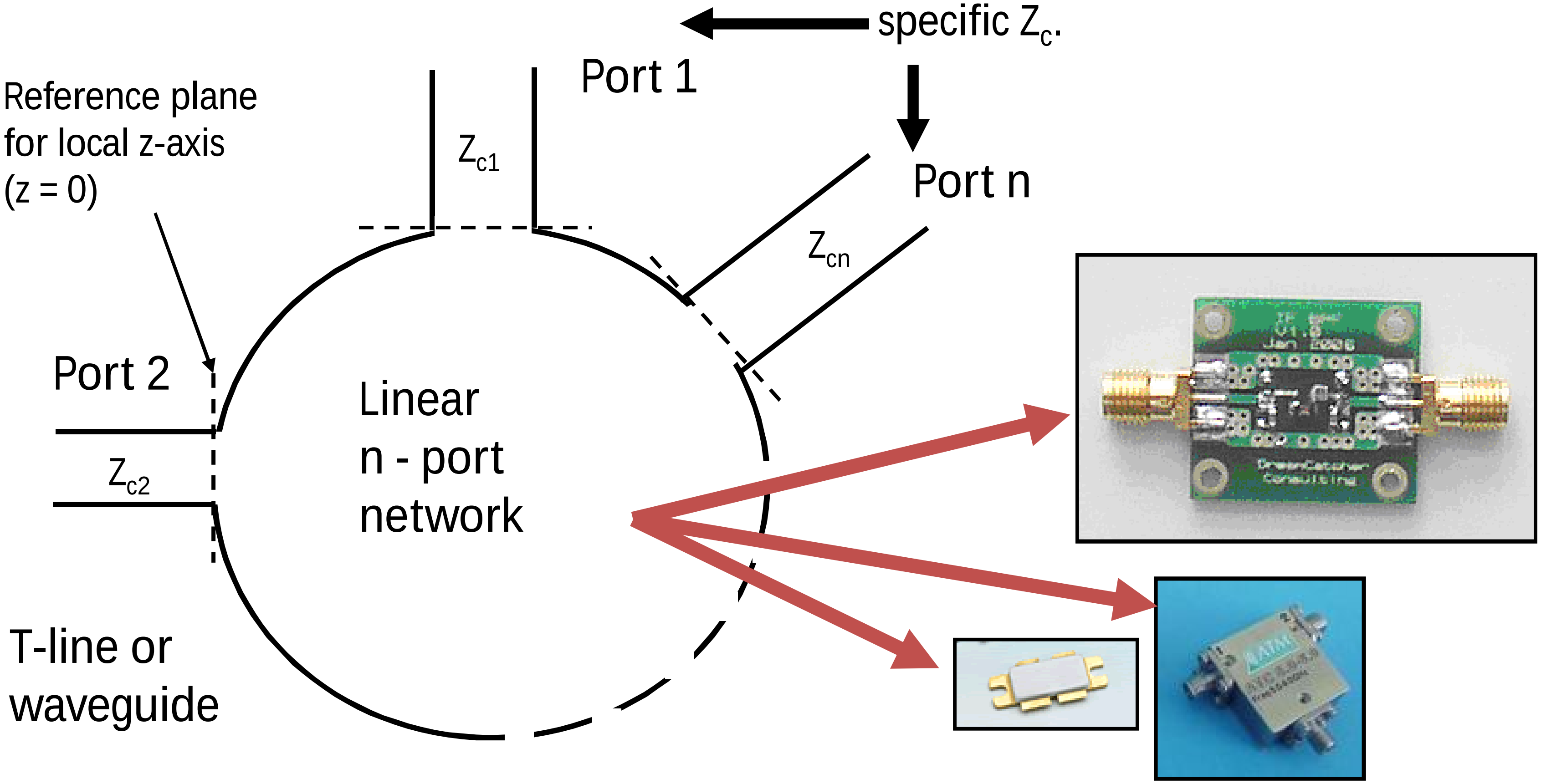
- Hence a new set of parameters (S) is needed which
  - Do not need open/short condition.
  - Do not cause standing wave.
  - Relates to incident and reflected power waves, instead of voltage and current.

- As oppose to V and I, S-parameters relate the reflected and incident voltage waves.
- S-parameters have the following advantages:

1. Relates to familiar measurement such as reflection coefficient, gain, loss etc.
2. Can cascade S-parameters of multiple devices to predict system performance (similar to ABCD parameters).
3. Can compute Z, Y or H parameters from S-parameters if needed.

THE SCATTERING MATRIX

- Consider an n – port network:



Each port is considered to be connected to a Tline with specific Z_c.

Port 1

Port n

Reference plane for local z-axis (z = 0)

Z_{c1}

Z_{cn}

Port 2

Z_{c2}

Linear
n - port
network

T-line or
waveguide

THE SCATTERING MATRIX

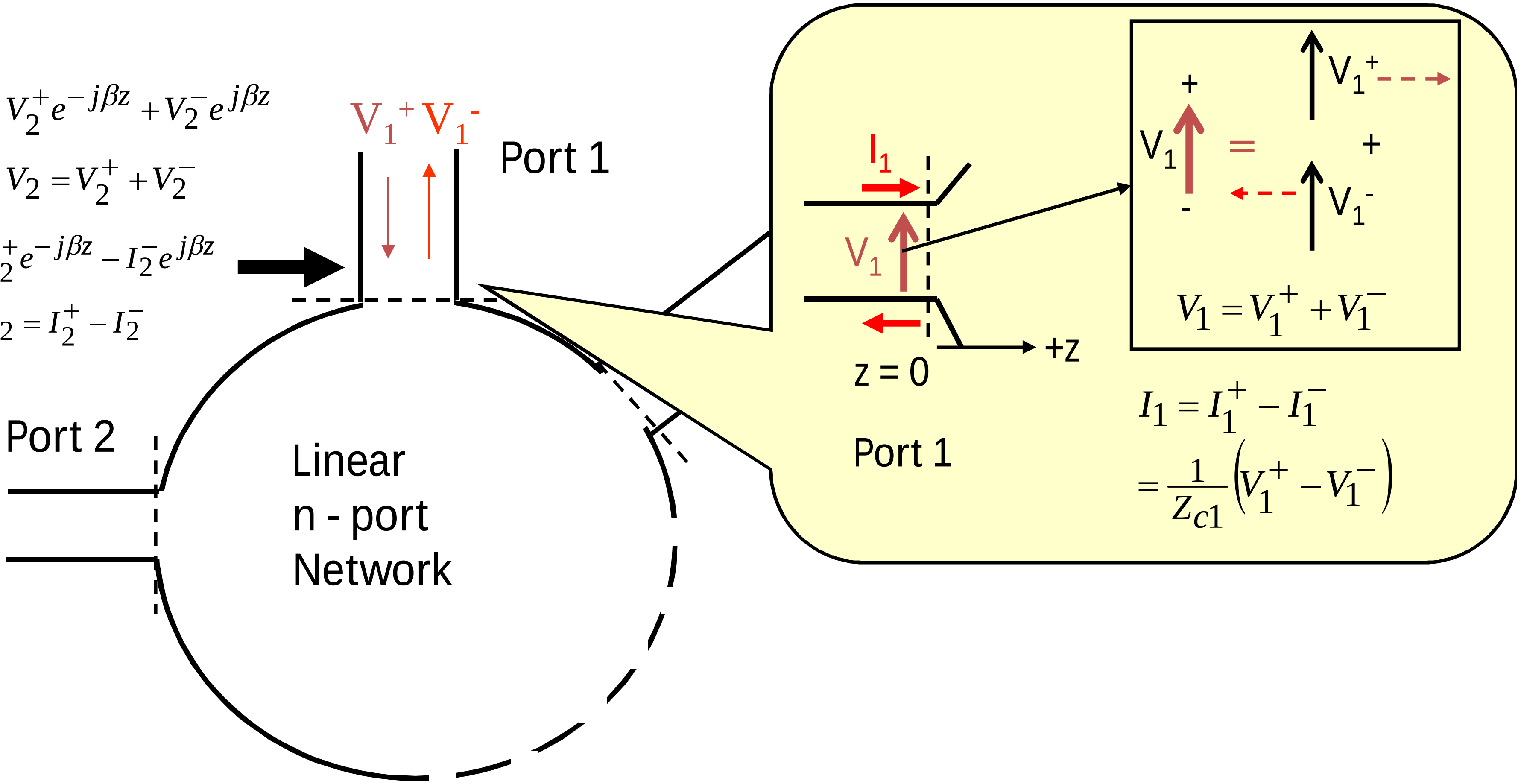
- There is a voltage and current on each port.
- This voltage (or current) can be decomposed into the incident (+) and reflected component (-).

$$V(z)=V_2^+e^{-j\beta z}+V_2^-e^{j\beta z}$$

$$V(0)=V_2=V_2^++V_2^-$$

$$I(z)=I_2^+e^{-j\beta z}-I_2^-e^{j\beta z}$$

$$I(0)=I_2=I_2^+-I_2^-$$



$$V_1=V_1^++V_1^-$$

$$I_1=I_1^+-I_1^-$$

$$=\frac{1}{Z_{c1}}\left(V_1^+-V_1^-\right)$$

THE SCATTERING MATRIX

- The port voltage and current can be normalized with respect to the impedance connected to it.
- It is customary to define normalized voltage waves at each port as:

Normalized incident waves

$$a_i = \frac{V_i^+}{\sqrt{Z_{ci}}}$$

$$a_i = I_i^+ \sqrt{Z_{ci}}$$

(4.3a)

i = 1, 2, 3 ... n

$$b_i = \frac{V_i^-}{\sqrt{Z_{ci}}}$$

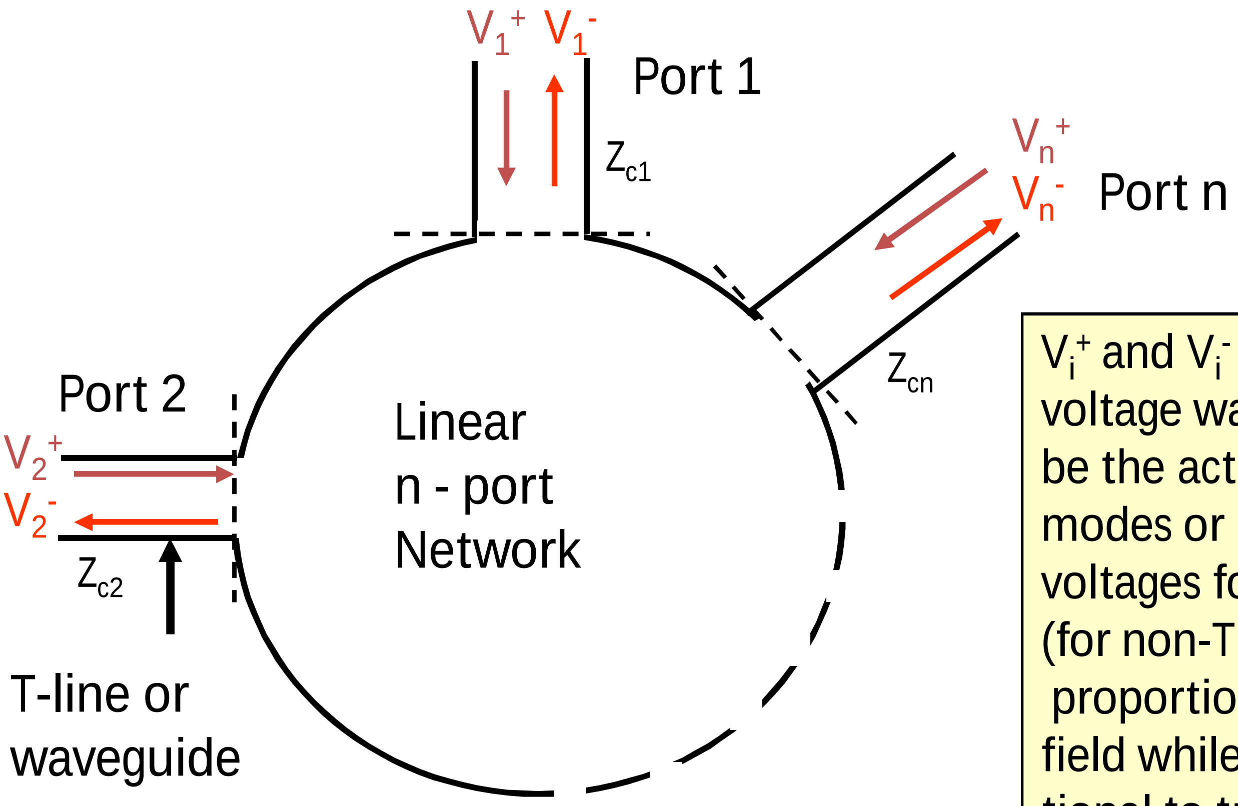
$$b_i = I_i^- \sqrt{Z_{ci}}$$

Normalized reflected waves

(4.3b)

THE SCATTERING MATRIX

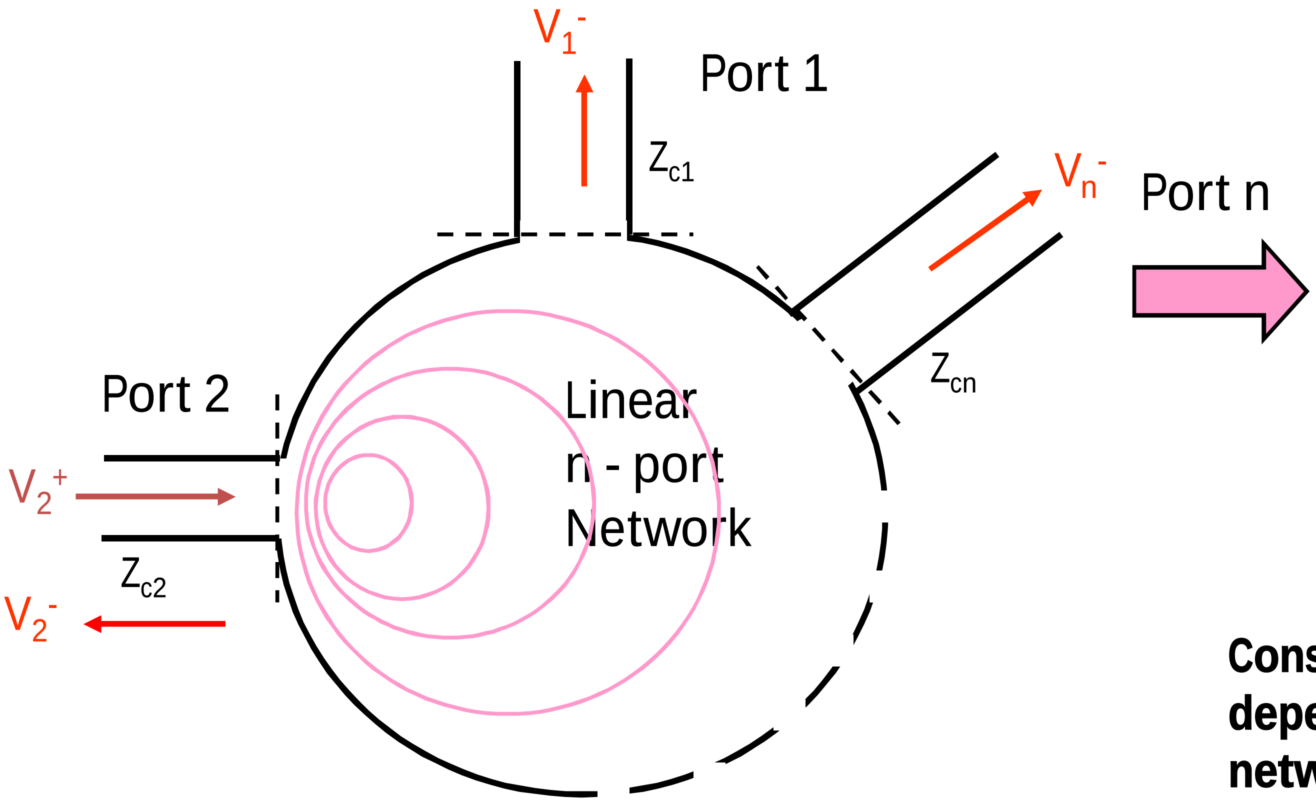
- Thus in general:



V_i^+ and V_i^- are propagating voltage waves, which can be the actual voltage for TEM modes or the equivalent voltages for non-TEM modes. (for non-TEM, V is defined proportional to transverse E field while I is defined proportional to transverse H field, see [1] for details).

THE SCATTERING MATRIX

- If the n – port network is linear (make sure you know what this means!), there is a linear relationship between the normalized waves.
- For instance if we energize port 2:



$$V_1^- = s_{12} V_2^+$$

$$V_2^- = s_{22} V_2^+$$

$$\vdots$$

$$V_n^- = s_{n2} V_2^+$$

Constant that depends on the network construction

THE SCATTERING MATRIX

- Considering that we can send energy into all ports, this can be generalized to:

$$\begin{aligned} V_1^- &= s_{11}V_1^+ + s_{12}V_2^+ + s_{13}V_3^+ + \cdots + s_{1n}V_n^+ \\ V_2^- &= s_{21}V_1^+ + s_{22}V_2^+ + s_{23}V_3^+ + \cdots + s_{2n}V_n^+ \\ &\;\;\vdots \\ V_n^- &= s_{n1}V_1^+ + s_{n2}V_2^+ + s_{n3}V_3^+ + \cdots + s_{nn}V_n^+ \end{aligned} \qquad \textbf{(4.4a)}$$

- Or written in Matrix equation:

$$\overline{V^-} = \overline{\overline{S}}\,\overline{V^+} \quad \text{or} \quad \begin{bmatrix} V_1^- \\ V_2^- \\ \vdots \\ V_n^- \end{bmatrix} = \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1n} \\ s_{21} & s_{22} & \cdots & s_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ s_{n1} & s_{n2} & \cdots & s_{nn} \end{bmatrix} \begin{bmatrix} V_1^+ \\ V_2^+ \\ \vdots \\ V_n^+ \end{bmatrix} \qquad \textbf{(4.4b)}$$

- Where sij is known as the g er, or just S-parameters for short. From (4.3), each port *i* can have different characteristic impedance Zci

THE SCATTERING MATRIX

- Consider the *N*-port network shown in figure 4.1.

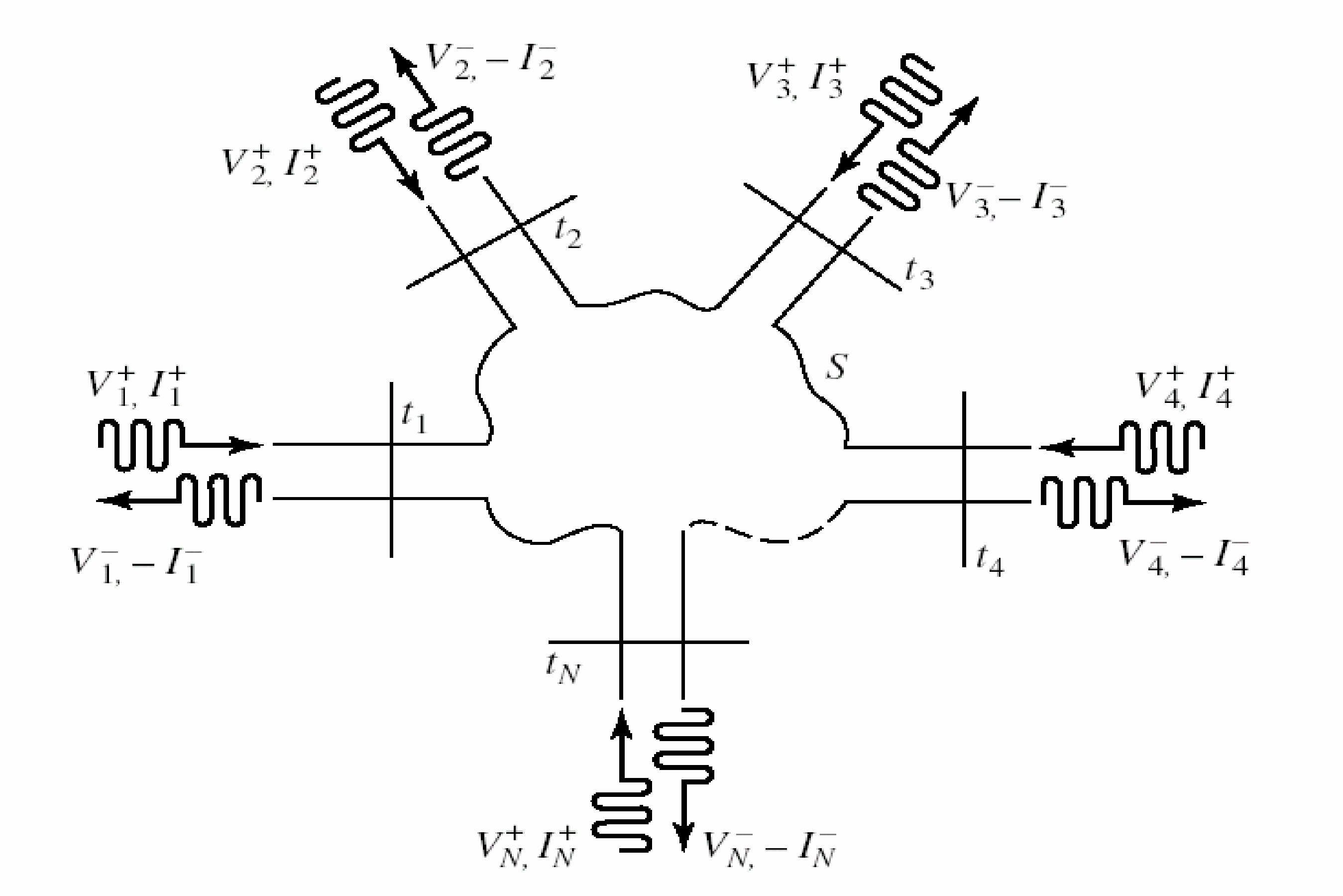


Figure 4.1: An arbitrary *N*-port microwave network

THE SCATTERING MATRIX

- V_n^+ is the amplitude of the voltage wave incident on port *n*.
- V_n^- is the amplitude of the voltage wave reflected from port *n*.
- The scattering matrix or [S] matrix, is defined in relation to these incident and reflected voltage wave as:

$$\begin{bmatrix} V_1^- \\ V_2^- \\ . \\ . \\ . \\ V_n^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & . & . & . & S_{1N} \\ S_{21} & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ S_{N1} & . & . & . & . & S_{NN} \end{bmatrix} \begin{bmatrix} V_1^+ \\ V_2^+ \\ . \\ . \\ . \\ V_n^+ \end{bmatrix} \qquad [4.1a]$$

THE SCATTERING MATRIX

or $$[V^-] = [S][V^+]$$ [4.1b]

A specific element of the [S] matrix can be determined as:

$$S_{ij} = \left. \frac{V_i^-}{V_j^+} \right|_{V_k^+ = 0,\ for \rightarrow k \neq j}$$ [4.2]

S_{ij} is found by driving port *j* with an incident wave V_j^+, and measuring the reflected wave amplitude, V_i^-, coming out of port *i*.

The incident waves on all ports except *j*-th port are set to zero (which means that all ports should be terminated in matched load to avoid reflections).

Thus, S_{ii} is the reflection coefficient seen looking into port *i* when all other ports are terminated in matched loads, and S_{ij} is the transmission coefficient from port *j* to port *i* when all other ports are terminated in matched loads.

THE SCATTERING MATRIX

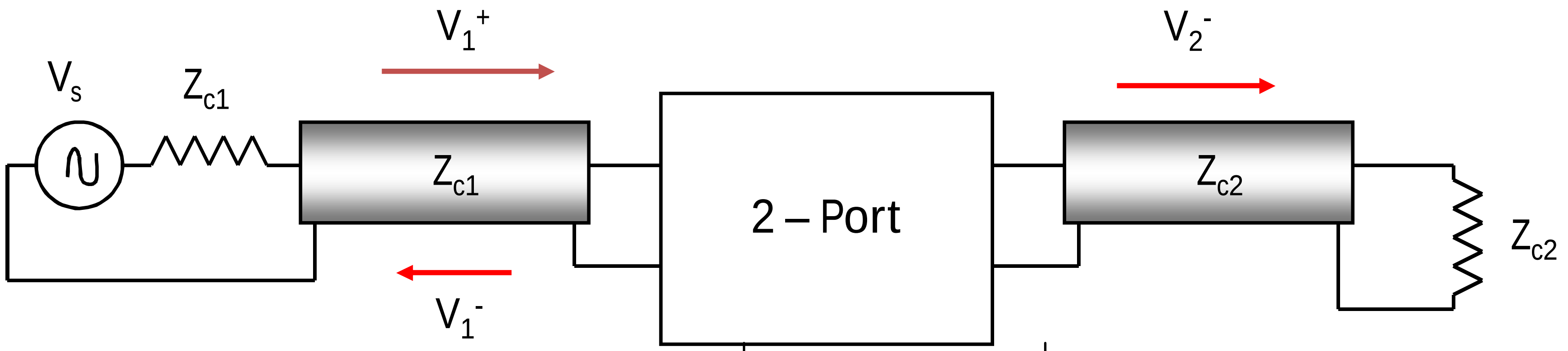
- For 2-port networks, (4.4) reduces to:

$$\begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{bmatrix} \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix} = \overline{\overline{S}} \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix} \qquad \textbf{\textit{(4.5a)}}$$

$$s_{11} = \left.\frac{V_1^-}{V_1^+}\right|_{V_2^+=0} \qquad s_{21} = \left.\frac{V_2^-}{V_1^+}\right|_{V_2^+=0} \qquad s_{22} = \left.\frac{V_2^-}{V_2^+}\right|_{V_1^+=0} \qquad s_{12} = \left.\frac{V_1^-}{V_2^+}\right|_{V_1^+=0} \qquad \textbf{\textit{(4.5b)}}$$

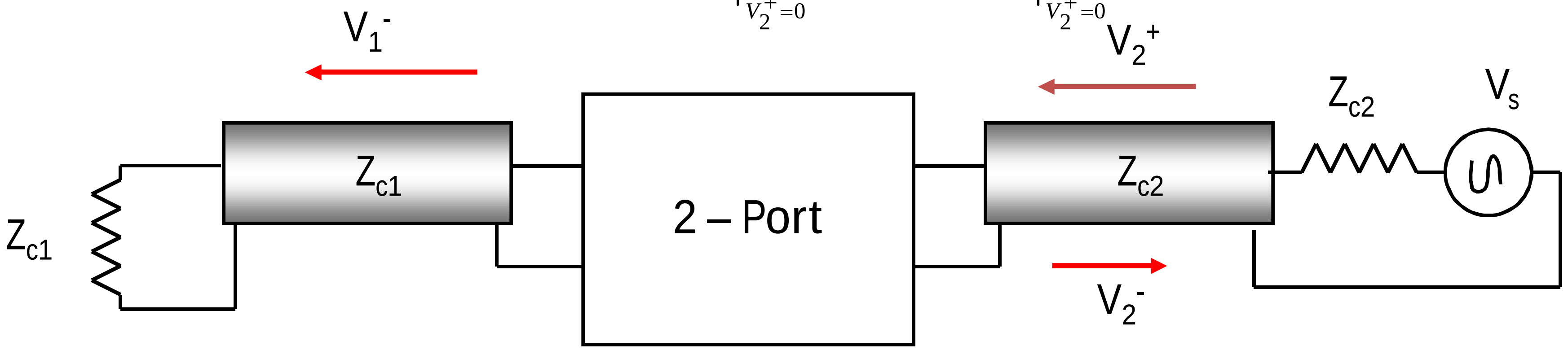
- Note that $V_i^+ = 0$ implies that we terminate *i* th port with its characteristic impedance.
- Thus zero reflection eliminates standing wave.

THE SCATTERING MATRIX



Measurement of s_{11} and s_{21}:

$$s_{11} = \left.\frac{V_1^-}{V_1^+}\right|_{V_2^+=0} \qquad s_{21} = \left.\frac{V_2^-}{V_1^+}\right|_{V_2^+=0}$$



Measurement of s_{22} and s_{12}:

$$s_{22} = \left.\frac{V_2^-}{V_2^+}\right|_{V_1^+=0} \qquad s_{12} = \left.\frac{V_1^-}{V_2^+}\right|_{V_1^+=0}$$

THE SCATTERING MATRIX

- Input-output behavior of network is defined in terms of normalized power waves
- S-parameters are measured based on properly terminated transmission lines (and not open/short circuit conditions)

$$S_{11} = \frac{b_1}{a_1}\Big|_{a_2=0}$$

$$S_{21} = \frac{b_2}{a_1}\Big|_{a_2=0}$$

Require proper termination on port 2

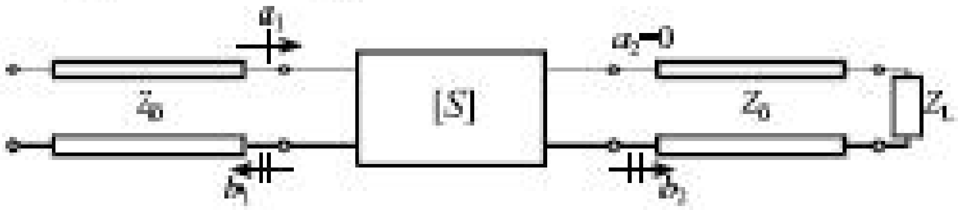
$$S_{22} = \frac{b_2}{a_2}\Big|_{a_1=0}$$

$$S_{12} = \frac{b_1}{a_2}\Big|_{a_1=0}$$

Require proper termination on port 1

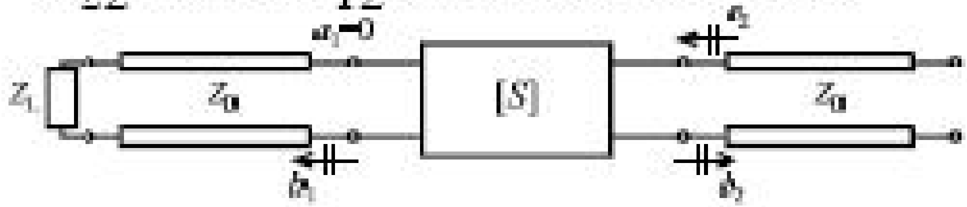
THE SCATTERING MATRIX

Properly terminated port 2 in order to make S_{11} and S_{21} measurements



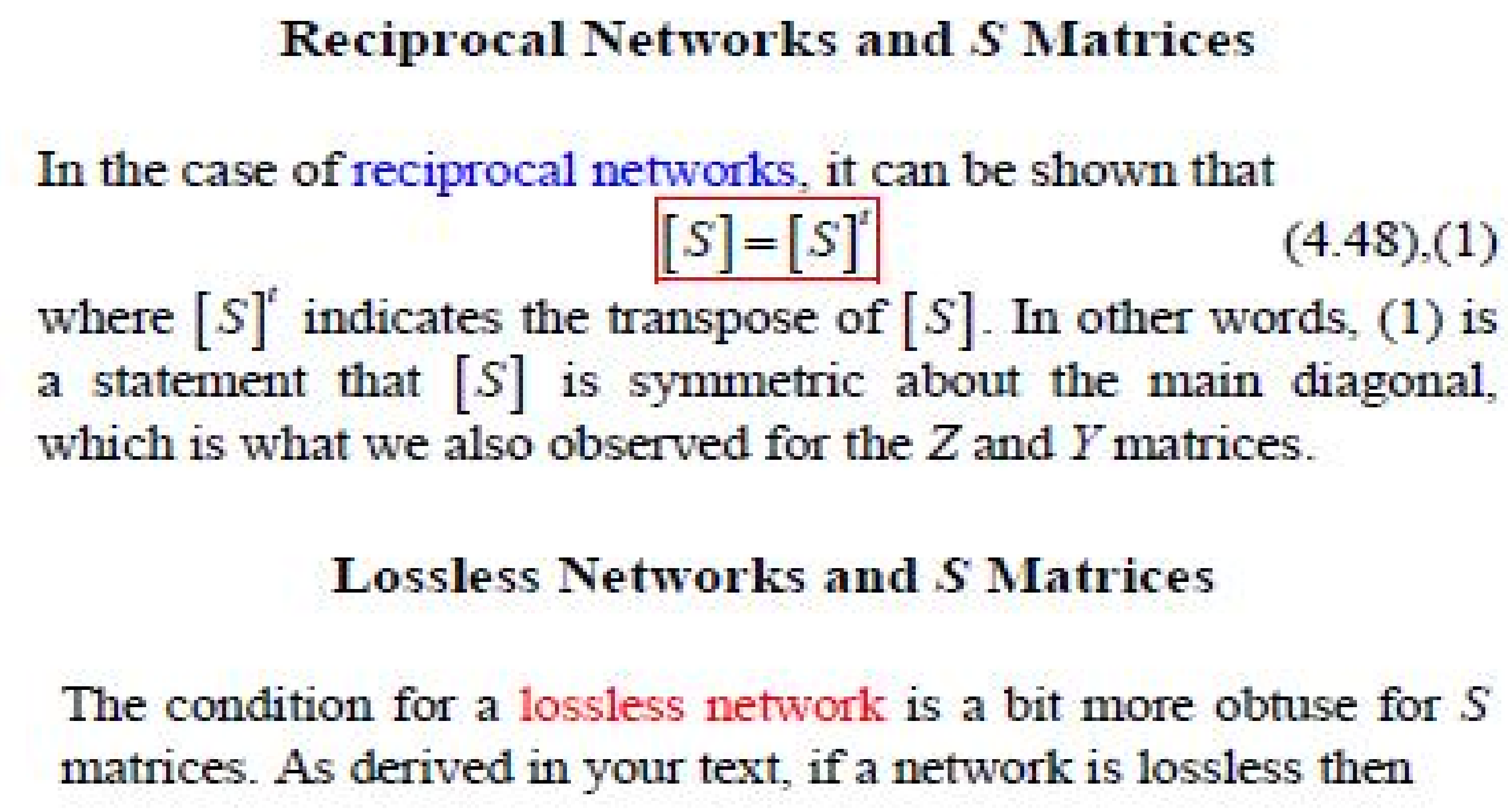
Load impedance = line impedance

Properly terminated port 1 in order to make S_{22} and S_{12} measurements



input impedance = line impedance

Properties of S-parameter



Reciprocal Networks and *S* Matrices

In the case of reciprocal networks, it can be shown that

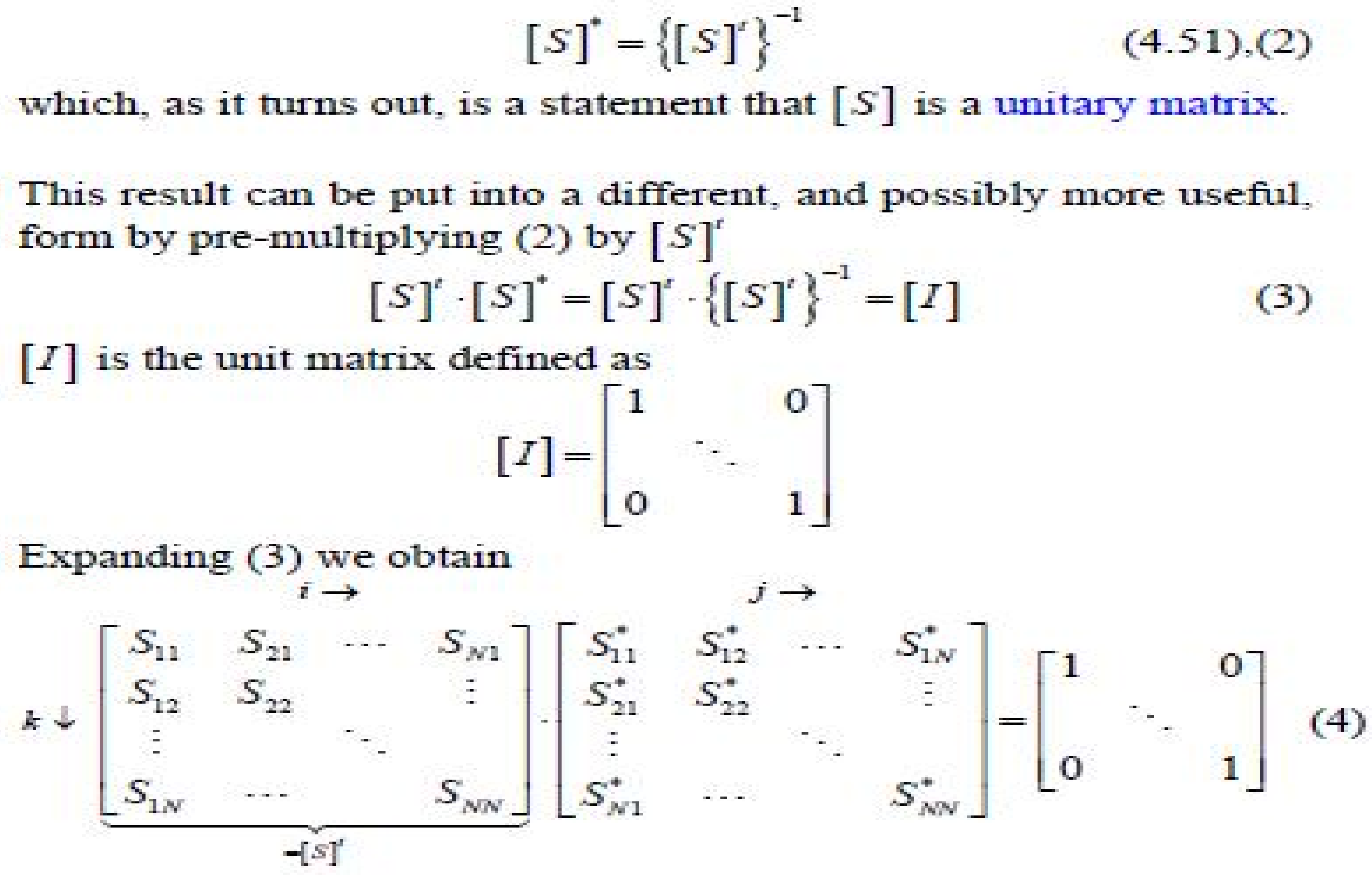
$$\boxed{[S]=[S]^t} \qquad (4.48),(1)$$

where $[S]^t$ indicates the transpose of $[S]$. In other words, (1) is a statement that $[S]$ is symmetric about the main diagonal, which is what we also observed for the *Z* and *Y* matrices.

Lossless Networks and *S* Matrices

The condition for a lossless network is a bit more obtuse for *S* matrices. As derived in your text, if a network is lossless then

Properties of S-parameter



$$[S]^* = \left\{[S]^t\right\}^{-1} \qquad (4.51),(2)$$

which, as it turns out, is a statement that $[S]$ is a unitary matrix.

This result can be put into a different, and possibly more useful, form by pre-multiplying (2) by $[S]^t$

$$[S]^t \cdot [S]^* = [S]^t \cdot \left\{[S]^t\right\}^{-1} = [I] \qquad (3)$$

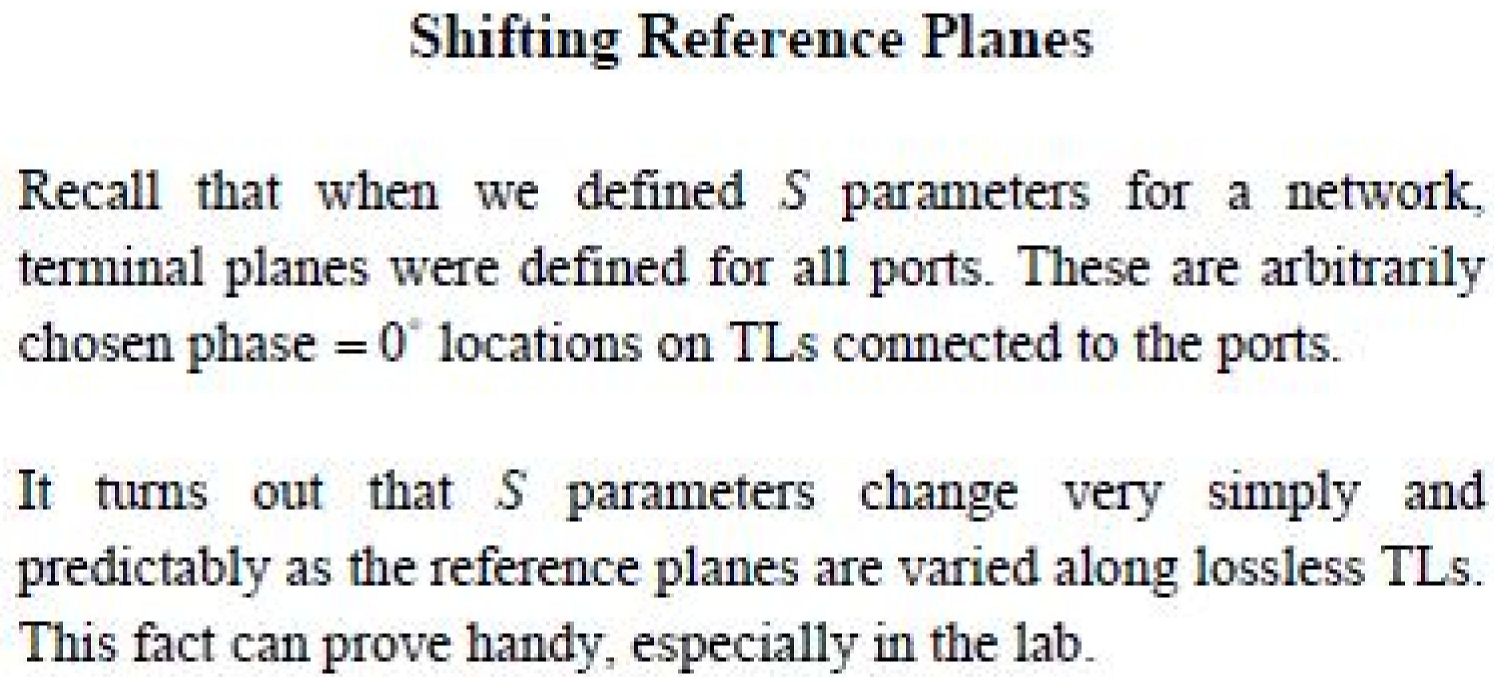
$[I]$ is the unit matrix defined as

$$[I] = \begin{bmatrix} 1 & & 0 \\ & \ddots & \\ 0 & & 1 \end{bmatrix}$$

Expanding (3) we obtain

$$\begin{array}{cccc} & i \rightarrow & & j \rightarrow \\ k \downarrow & \underbrace{\begin{bmatrix} S_{11} & S_{21} & \cdots & S_{N1} \\ S_{12} & S_{22} & & \vdots \\ \vdots & & \ddots & \\ S_{1N} & \cdots & & S_{NN} \end{bmatrix}}_{=[S]^t} & \cdot & \begin{bmatrix} S_{11}^* & S_{12}^* & \cdots & S_{1N}^* \\ S_{21}^* & S_{22}^* & & \vdots \\ \vdots & & \ddots & \\ S_{N1}^* & \cdots & & S_{NN}^* \end{bmatrix} = \begin{bmatrix} 1 & & 0 \\ & \ddots & \\ 0 & & 1 \end{bmatrix} \end{array} \qquad (4)$$

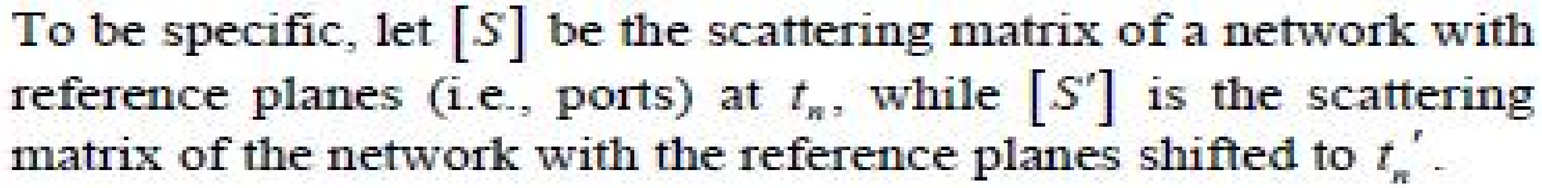
Properties of *S*-parameter



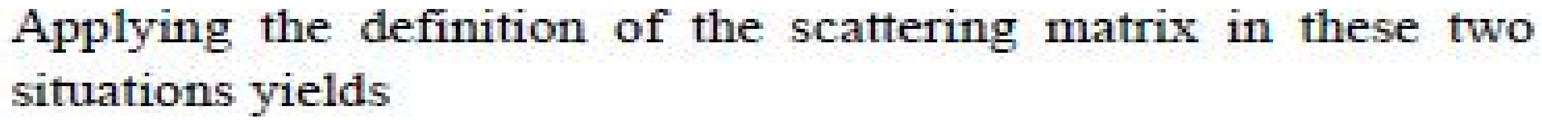
Shifting Reference Planes

Recall that when we defined S parameters for a network, terminal planes were defined for all ports. These are arbitrarily chosen phase $= 0^\circ$ locations on TLs connected to the ports.

It turns out that S parameters change very simply and predictably as the reference planes are varied along lossless TLs. This fact can prove handy, especially in the lab.

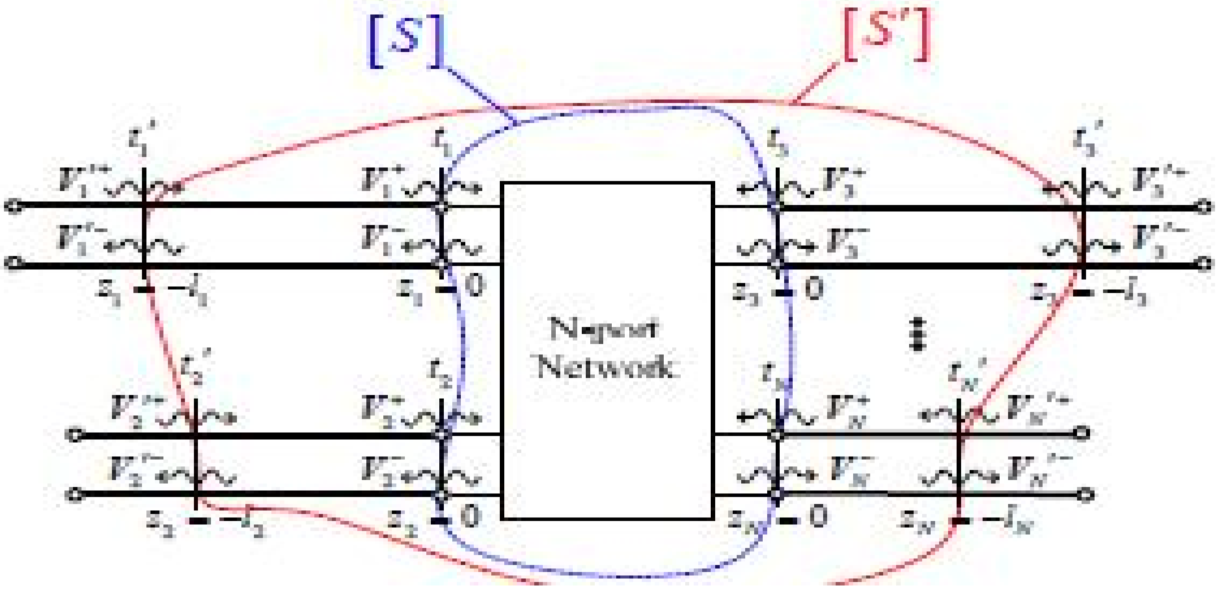


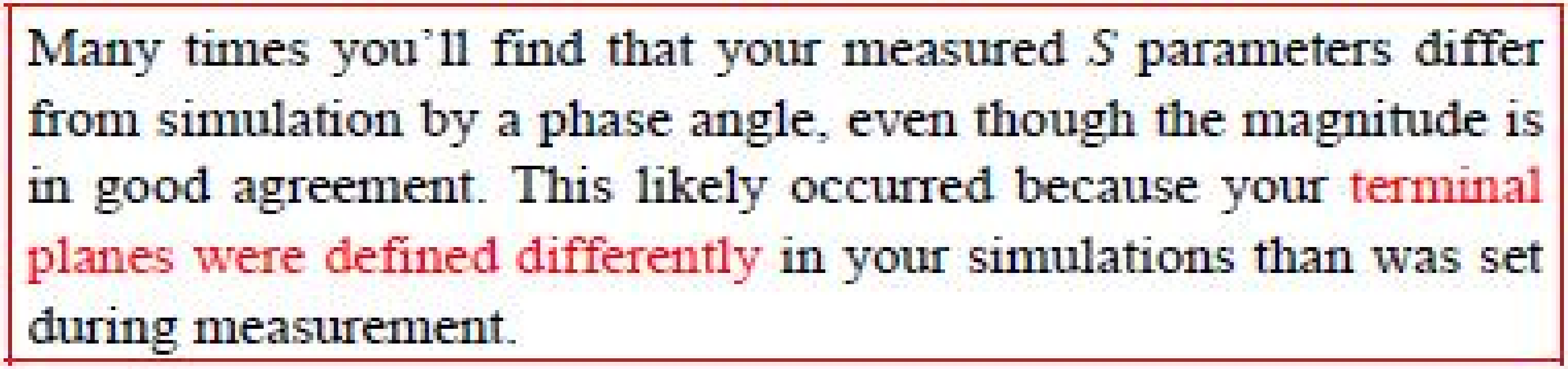
To be specific, let $[S]$ be the scattering matrix of a network with reference planes (i.e., ports) at t_n, while $[S']$ is the scattering matrix of the network with the reference planes shifted to t_n'.



Applying the definition of the scattering matrix in these two situations yields

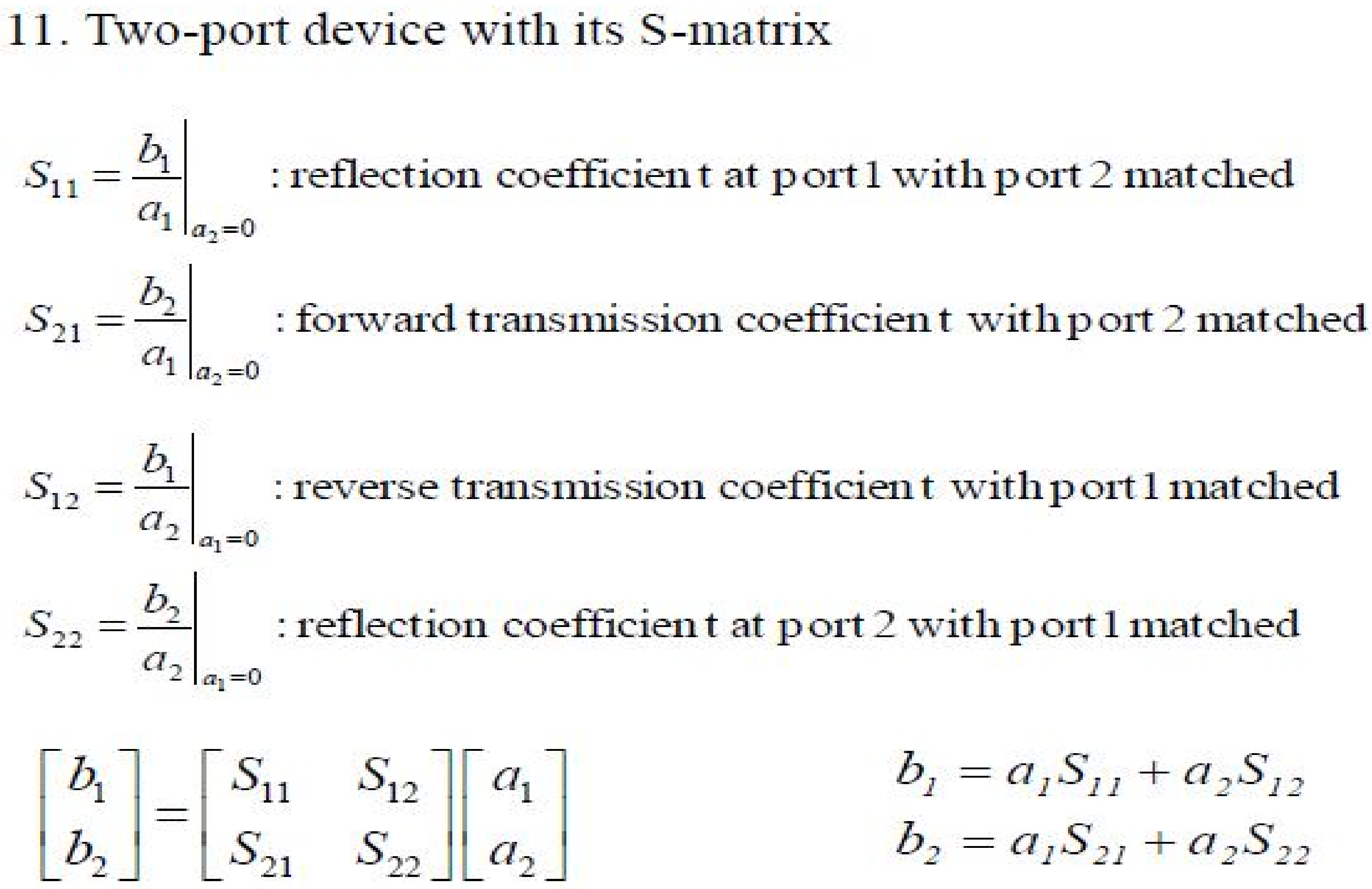
Properties of *S*-parameter





Many times you'll find that your measured *S* parameters differ from simulation by a phase angle, even though the magnitude is in good agreement. This likely occurred because your terminal planes were defined differently in your simulations than was set during measurement.

S matrix of a two port network



11. Two-port device with its S-matrix

$$S_{11} = \left.\frac{b_1}{a_1}\right|_{a_2=0} \quad \text{: reflection coefficient at port 1 with port 2 matched}$$

$$S_{21} = \left.\frac{b_2}{a_1}\right|_{a_2=0} \quad \text{: forward transmission coefficient with port 2 matched}$$

$$S_{12} = \left.\frac{b_1}{a_2}\right|_{a_1=0} \quad \text{: reverse transmission coefficient with port 1 matched}$$

$$S_{22} = \left.\frac{b_2}{a_2}\right|_{a_1=0} \quad \text{: reflection coefficient at port 2 with port 1 matched}$$

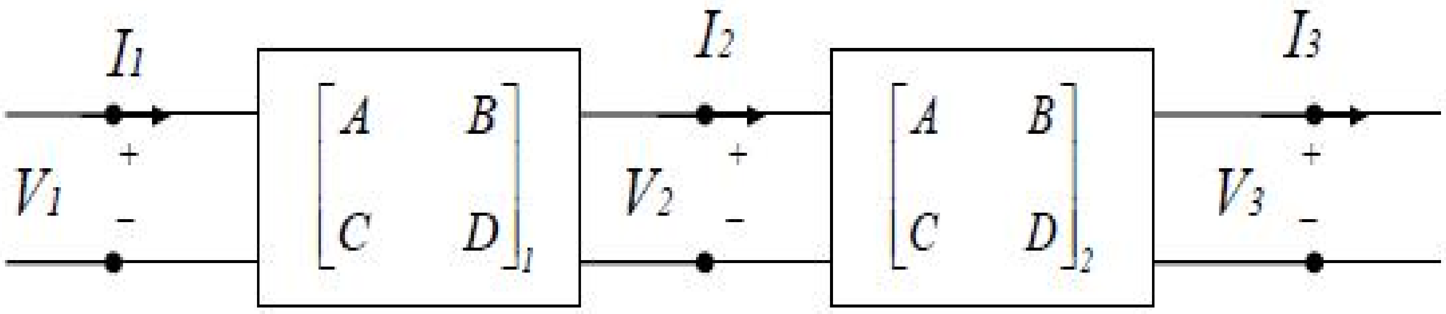
$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

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

ABCD MATRIX

4.4 The transmission (ABCD) matrix

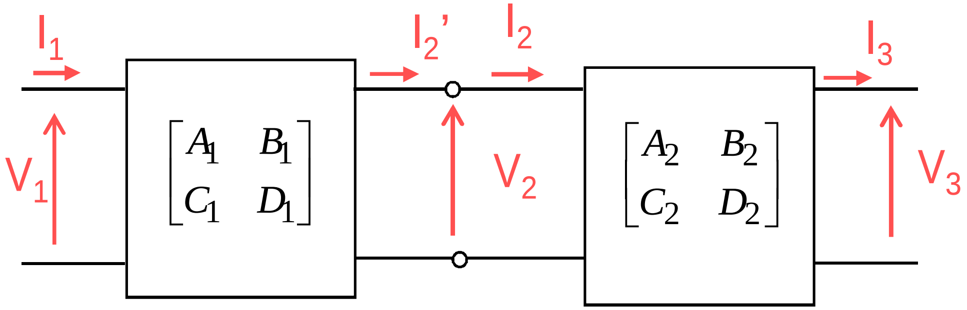
- Cascade network



$$\begin{bmatrix}V_1\\I_1\end{bmatrix}=\begin{bmatrix}A&B\\C&D\end{bmatrix}_1\begin{bmatrix}V_2\\I_2\end{bmatrix}=\begin{bmatrix}A&B\\C&D\end{bmatrix}_1\begin{bmatrix}A&B\\C&D\end{bmatrix}_2\begin{bmatrix}V_3\\I_3\end{bmatrix}$$

ABCD MATRIX

- The ABCD matrix is useful for characterizing the overall response of 2-port networks that are cascaded to each other.



$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} \begin{bmatrix} V_3 \\ I_3 \end{bmatrix}$$

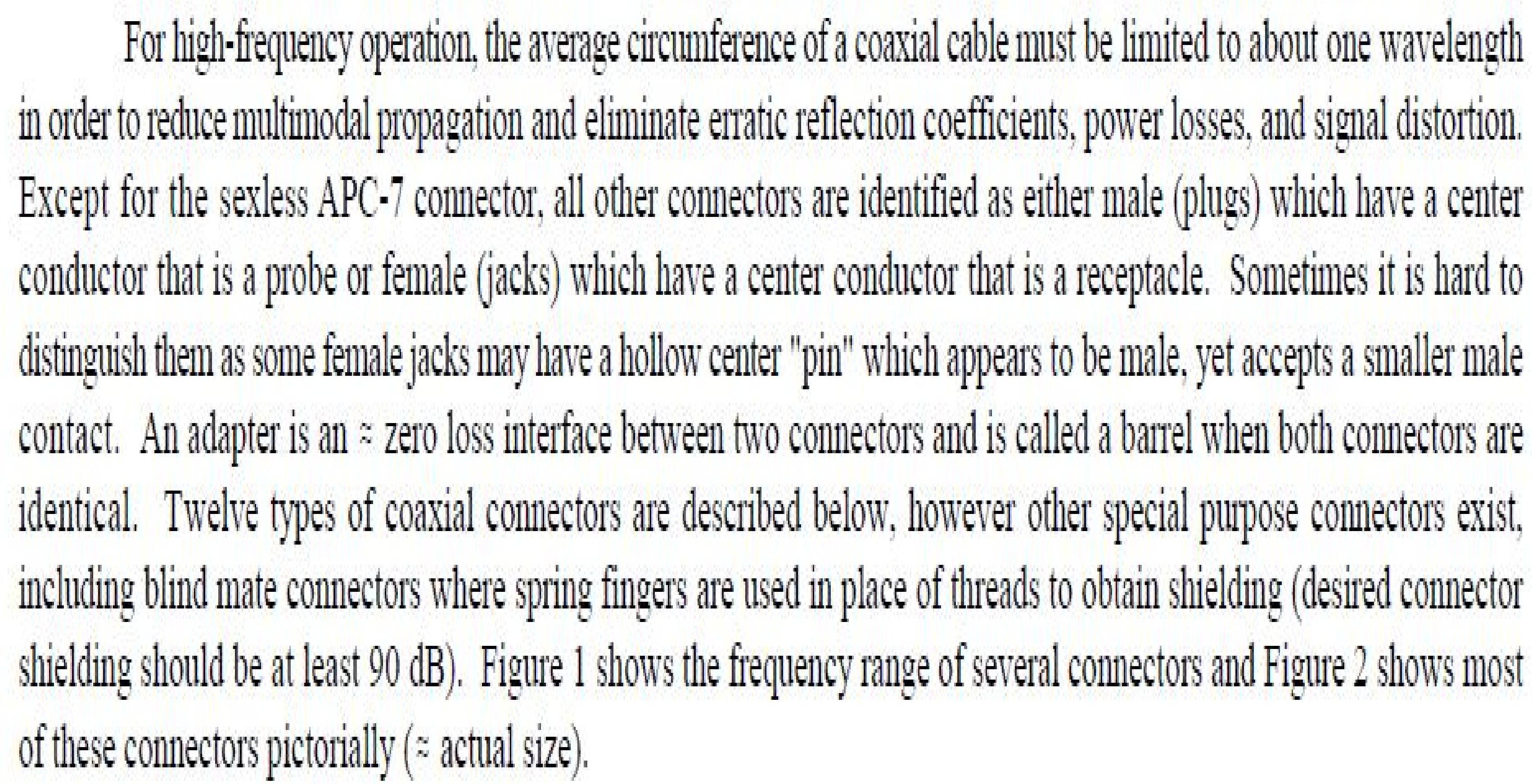
$$\Rightarrow \begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \underset{\Big\uparrow}{\begin{bmatrix} A_3 & B_3 \\ C_3 & D_3 \end{bmatrix}} \begin{bmatrix} V_3 \\ I_3 \end{bmatrix}$$

Overall ABCD matrix

UNIT II MICROWAVE PASSIVE DEVICES

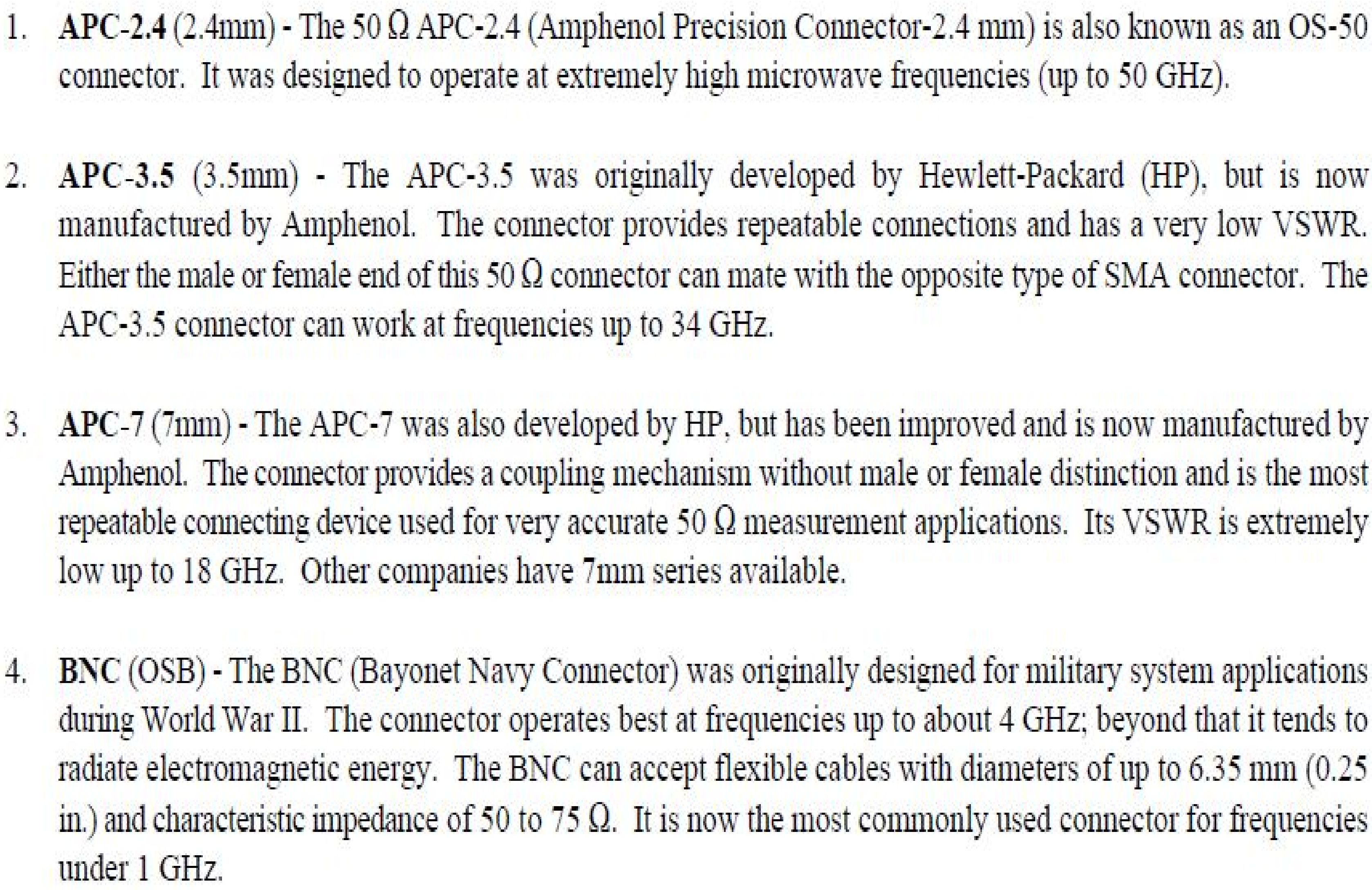
Coaxial cables-connectors and adapters – Wave guides- Matched terminations – Rectangular to circular wave guide transition– Wave guide corners – Bends and twists – Windows –Attenuators – Phase shifters – Wave guide tees– E plane tee – H plane tee – Magic tee – Isolators – Circulators –Directional couplers – scattering matrix derivation for all components .

Microwave coaxial connectors



For high-frequency operation, the average circumference of a coaxial cable must be limited to about one wavelength in order to reduce multimodal propagation and eliminate erratic reflection coefficients, power losses, and signal distortion. Except for the sexless APC-7 connector, all other connectors are identified as either male (plugs) which have a center conductor that is a probe or female (jacks) which have a center conductor that is a receptacle. Sometimes it is hard to distinguish them as some female jacks may have a hollow center "pin" which appears to be male, yet accepts a smaller male contact. An adapter is an ≈ zero loss interface between two connectors and is called a barrel when both connectors are identical. Twelve types of coaxial connectors are described below, however other special purpose connectors exist, including blind mate connectors where spring fingers are used in place of threads to obtain shielding (desired connector shielding should be at least 90 dB). Figure 1 shows the frequency range of several connectors and Figure 2 shows most of these connectors pictorially (≈ actual size).

Microwave coaxial connectors



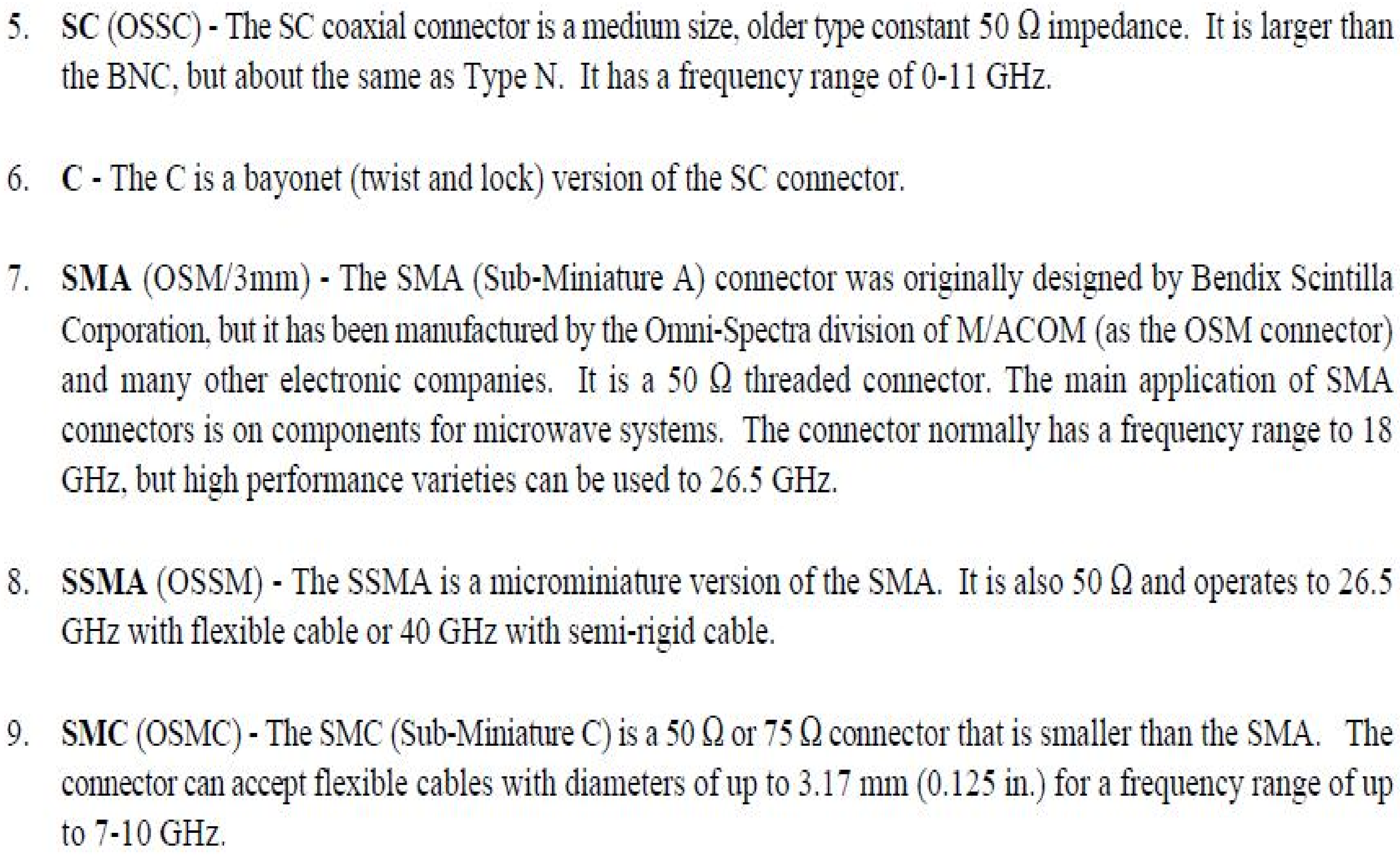
1. **APC-2.4** (2.4mm) **-** The 50 Ω APC-2.4 (Amphenol Precision Connector-2.4 mm) is also known as an OS-50 connector. It was designed to operate at extremely high microwave frequencies (up to 50 GHz).

2. **APC-3.5** (3.5mm) **-** The APC-3.5 was originally developed by Hewlett-Packard (HP), but is now manufactured by Amphenol. The connector provides repeatable connections and has a very low VSWR. Either the male or female end of this 50 Ω connector can mate with the opposite type of SMA connector. The APC-3.5 connector can work at frequencies up to 34 GHz.

3. **APC-7** (7mm) **-** The APC-7 was also developed by HP, but has been improved and is now manufactured by Amphenol. The connector provides a coupling mechanism without male or female distinction and is the most repeatable connecting device used for very accurate 50 Ω measurement applications. Its VSWR is extremely low up to 18 GHz. Other companies have 7mm series available.

4. **BNC** (OSB) **-** The BNC (Bayonet Navy Connector) was originally designed for military system applications during World War II. The connector operates best at frequencies up to about 4 GHz; beyond that it tends to radiate electromagnetic energy. The BNC can accept flexible cables with diameters of up to 6.35 mm (0.25 in.) and characteristic impedance of 50 to 75 Ω. It is now the most commonly used connector for frequencies under 1 GHz.

Microwave coaxial connectors



5. **SC** (OSSC) - The SC coaxial connector is a medium size, older type constant 50 Ω impedance. It is larger than the BNC, but about the same as Type N. It has a frequency range of 0-11 GHz.

6. **C** - The C is a bayonet (twist and lock) version of the SC connector.

7. **SMA** (OSM/3mm) - The SMA (Sub-Miniature A) connector was originally designed by Bendix Scintilla Corporation, but it has been manufactured by the Omni-Spectra division of M/ACOM (as the OSM connector) and many other electronic companies. It is a 50 Ω threaded connector. The main application of SMA connectors is on components for microwave systems. The connector normally has a frequency range to 18 GHz, but high performance varieties can be used to 26.5 GHz.

8. **SSMA** (OSSM) - The SSMA is a microminiature version of the SMA. It is also 50 Ω and operates to 26.5 GHz with flexible cable or 40 GHz with semi-rigid cable.

9. **SMC** (OSMC) - The SMC (Sub-Miniature C) is a 50 Ω or 75 Ω connector that is smaller than the SMA. The connector can accept flexible cables with diameters of up to 3.17 mm (0.125 in.) for a frequency range of up to 7-10 GHz.

Microwave coaxial connectors

APC 2.4 Jack - APC 3.5 Jack

SC Jack - Type N Jack

Type N Jack - TNC Jack

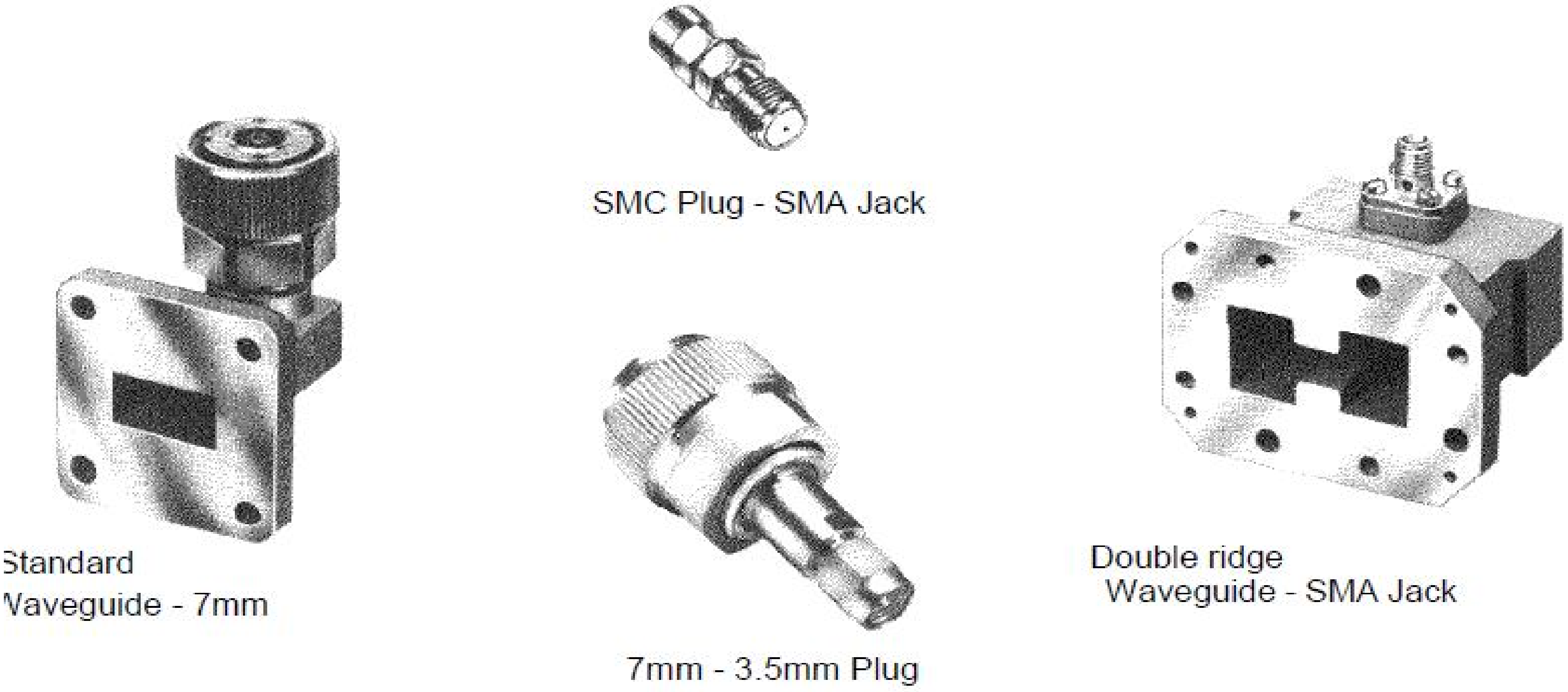
SMA Plug - TNC Plug

SSMA Jack - BNC Jack

Type N Plug - TNC Jack

Figure 2. . Microwave Coaxial Connectors (Connector Orientation Corresponds to Name Below It)

Microwave coaxial connectors


Standard Waveguide - 7mm

SMC Plug - SMA Jack

7mm - 3.5mm Plug

Double ridge Waveguide - SMA Jack

Figure 2. Microwave Coaxial connectors (Continued)

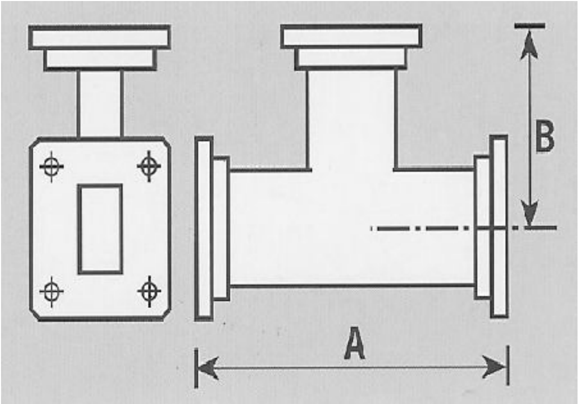
Waveguide tees:

- Waveguide junctions are used in microwave technologies when power in a waveguide needs to be split or some extracted.
- There are a number of different types of waveguide junction that can be used.
- Each type having different properties - the different types of waveguide junction affect the energy contained within the waveguide in different ways.
- When selecting a waveguide junction balances between performance and cost need to be made and therefore an understanding of the different types of waveguide junction is useful.

Types of Waveguide Tee Junctions:

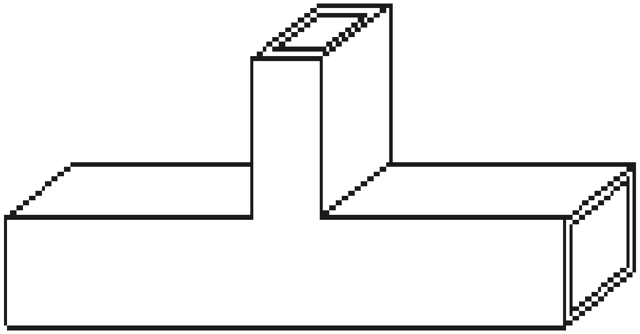
- There are a number of different types of waveguide junction. The major types are listed below:

1. H-type T Junction
2. E-Type T Junction
3. Magic T waveguide junction
4. Hybrid Ring Waveguide Junction



E-Type Waveguide Junction

- It is called an E-type T junction because the junction arm, i.e. the top of the "T" extends from the main waveguide in the same direction as the E field.
- It is characterized by the fact that the outputs of this form of waveguide junction are 180° out of phase with each other.



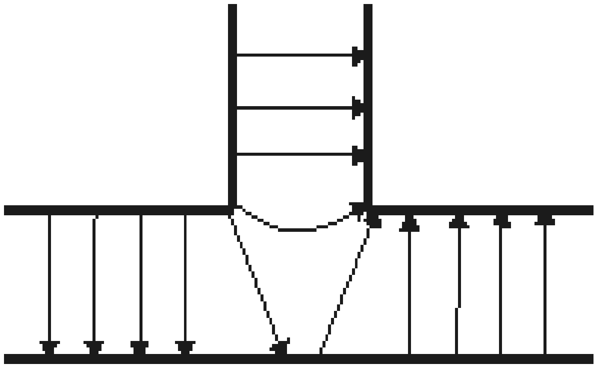
Waveguide E-type junction

E-Type Waveguide Junction:

- The basic construction of the waveguide junction shows the three port waveguide device.
- Although it may be assumed that the input is the single port and the two outputs are those on the top section of the "T", actually any port can be used as the input, the other two being outputs.
- WORKNG:
  - To see how the waveguide junction operates, and how the 180° phase shift occurs, it is necessary to look at the electric field. The magnetic field is omitted from the diagram for simplicity.

Working:

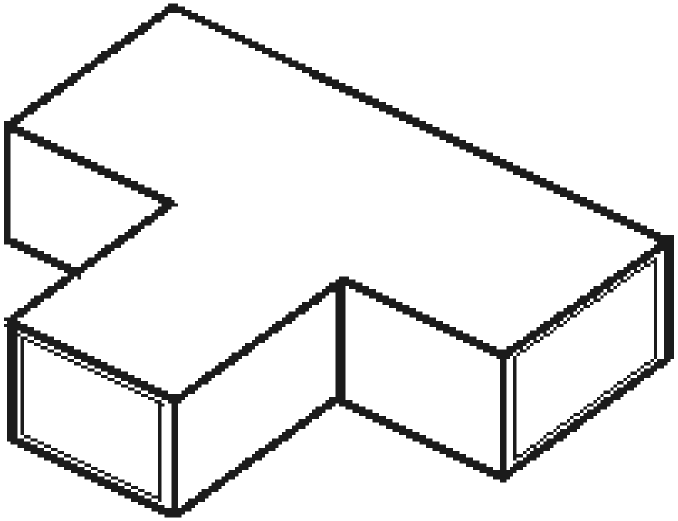
- It can be seen from the electric field that when it approaches the T junction itself, the electric field lines become distorted and bend.
- They split so that the "positive" end of the line remains with the top side of the right hand section in the diagram, but the "negative“ end of the field lines remain with the top side of the left hand section. In this way the signals appearing at either section of the "T" are out of phase.
- These phase relationships are preserved if signals enter from either of the other ports.



Waveguide E-type junction E fields

H-type waveguide junction

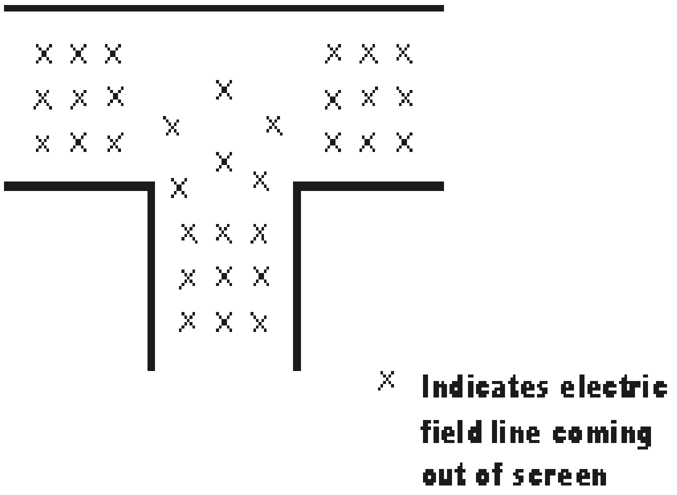
- This type of waveguide junction is called an H-type T junction because the long axis of the main top of the "T" arm is parallel to the plane of the magnetic lines of force in the waveguide.
- It is characterized by the fact that the two outputs from the top of the "T“ section in the waveguide are in phase with each other.



Waveguide H-type junction

Working:

- To see how the waveguide junction operates, the diagram below shows the electric field lines.



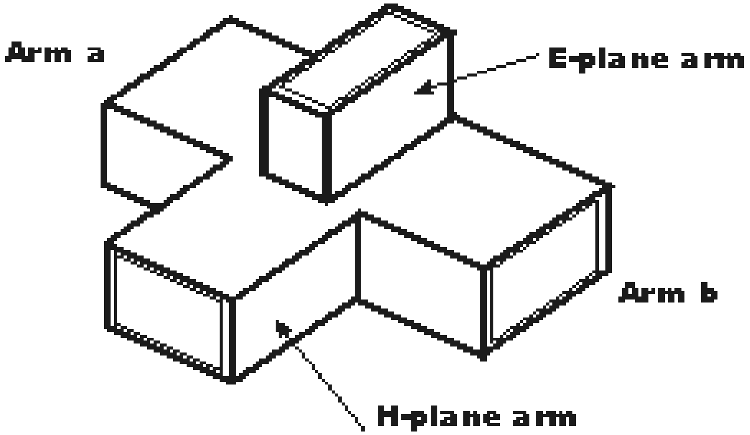
Waveguide H-type junction electric fields

Working

- The electric field lines are shown using the traditional notation - a cross indicates a line coming out of the screen, whereas a dot indicates an electric field line going into the screen.
- It can be seen from the diagram that the signals at all ports are in phase.
- Although it is easiest to consider signals entering from the lower section of the "T", any port can actually be used - the phase relationships are preserved whatever entry port is used.

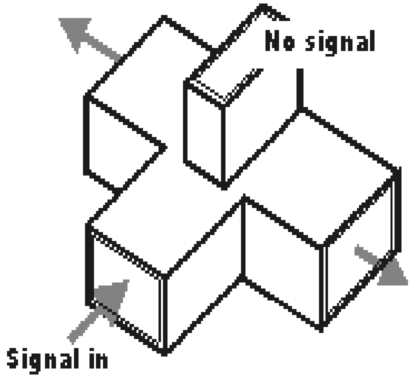
Magic T hybrid waveguide junction

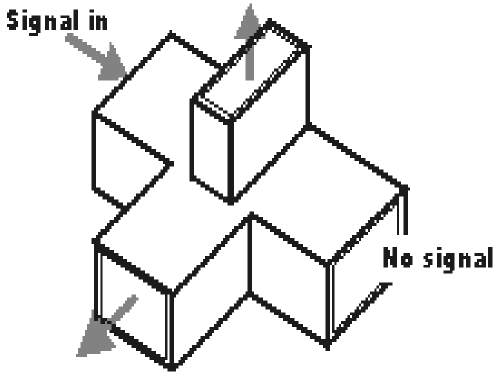
- The magic-T is a combination of the H-type and E-type T junctions. The most common application of this type of junction is as the mixer section for microwave radar receivers.
- The diagram besides gives simplified version of the Magic T waveguide junction with its four ports.



Magic T waveguide junction

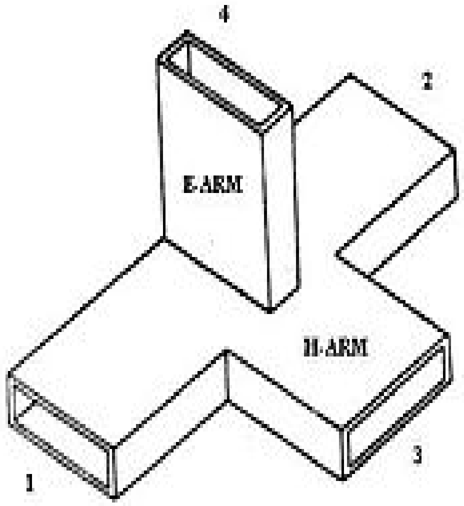
Working:





Working:

- E-plane:
  - To look at the operation of the Magic T waveguide junction, take the example of when a signal is applied into the "E plane" arm.
  - A signal injected into the E-plane port will also be divided equally between ports 1 and 2, but will be 180 degrees out of phase.
- H-plane:
  - A signal injected into the H-plane port will be divided equally between ports 1 and 2, and will be in phase.

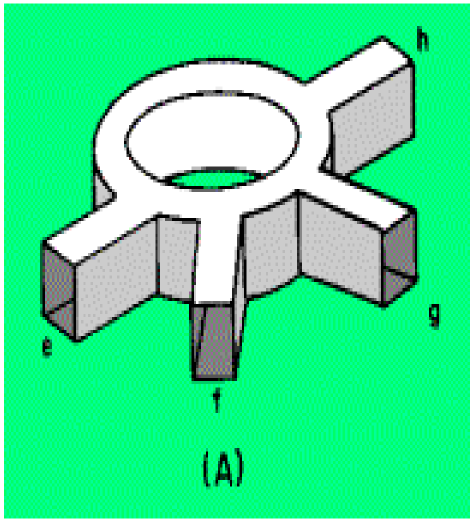


Disadvantage:

- One of the disadvantages of the Magic-T waveguide junction are that reflections arise from the impedance mismatches that naturally occur within it.
- These reflections not only give rise to power loss. The reflections can be reduced by using matching techniques.

Hybrid ring waveguide junction:

- This form of waveguide junction overcomes the power limitation of the magic-T waveguide junction.
- A hybrid ring waveguide junction is a further development of the magic T.
- It is constructed from a circular ring of rectangular waveguide.
- The ports are then joined to the holes at the required points. Again, if signal enters one port, it does not appear at all the others.



Practical Use:

- The hybrid ring is used primarily in high-power radar and communications systems where it acts as a duplexer - allowing the same antenna to be used for transmit and receive functions.
- During the transmit period, the hybrid ring waveguide junction couples microwave energy from the transmitter to the antenna while blocking energy from the receiver input.
- Then as the receive cycle starts, the hybrid ring waveguide junction couples energy from the antenna to the receiver.
- During this period it prevents energy from reaching the transmitter.

Rectangular to circular waveguide transition

FEATURES:

- Minimum VSWR
- Minimum Insertion Loss
- Optional Pressurized Models Available
- Efficient Conversion from TE_{11} Mode Rectangular Waveguide to TE_{11} or TE_{01} Mode Circular Waveguide

APPLICATIONS:

- Radar Systems
- Test Setup

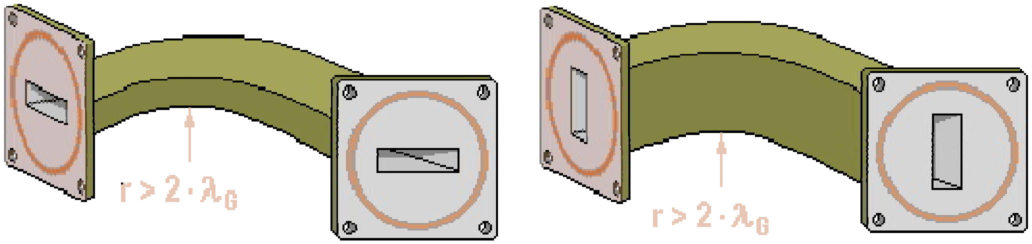
DESCRIPTION: **CRC series**

Cernex's CRC series TE_{01} mode transitions are available for operation from 18.0 to 170.0 GHz. These reciprocal devices have a standard rectangular TE_{11} mode waveguide input and a circular TE_{11} or TE_{01} mode output. Because of the different frequency ranges of circular TE_{11} or TE_{01} mode waveguide, it is possible for a standard sized rectangular waveguide input to have one of several different circular waveguide size outputs. The CRC series circular mode waveguide features low VSWR and insertion loss. For maximum mode purity, filtering is recommended for al TE_{01} propagation (please refer to Table 1-1).

Waveguides Bends and Twists

- The size, shape, and dielectric material of a waveguide must be constant throughout its length for energy to move from one end to the other without reflections. Any abrupt change in its size or shape can cause reflections and a loss in overall efficiency. When such a change is necessary, the bends, twists, and joints of the waveguides must meet certain conditions to prevent reflections.
- ***Bends***
- Waveguides may be bent in several ways that do not cause reflections. One way is the gradual bend shown in the right part of the following figure. This gradual bend is known as an E bend because it distorts the E fields. The E bend must have a radius greater than two wavelengths to prevent reflections.

Waveguides Bends



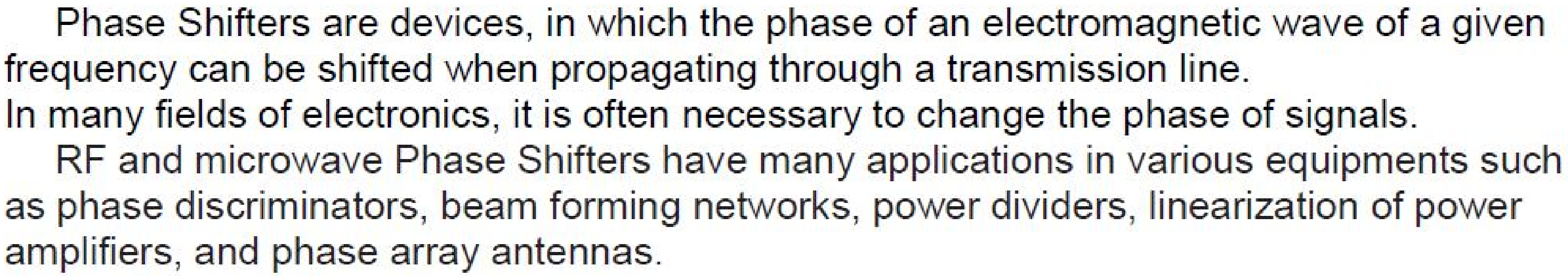
- **H** - bend
- **E** - bend
- *Figure 1: Waveguide bends*
- Another common bend is the gradual H bend shown in the leftt part of the figure. It is called an H bend because the H fields are distorted when a waveguide is bent in this manner. Again, the radius of the bend must be greater than two wavelengths to prevent reflections.
- A sharp bend in either dimension may be used if it meets certain requirements. Notice the two 45-degree bends in figure; the bends are 1/4·λ apart. The reflections that occur at the 45-degree bends cancel each other, leaving the fields as though no reflections have occurred.

Waveguide ***Twists***

- Sometimes the electromagnetic fields must be rotated so that they are in the proper phase to match the phase of the load. This may be accomplished by twisting the waveguide as shown in the figure. The twist must be gradual and greater than two wavelengths (2·λ).

- *Figure 3: Waveguide twist*
- The flexible waveguide allows special bends which some equipment applications might require. It consists of a specially wound ribbon of conductive material, most commonly brass, with the inner surface plated with chromium. Power losses are greater in the flexible waveguide because the inner surfaces are not perfectly smooth. Therefore, it is only used in short sections where no other reasonable solution is available.

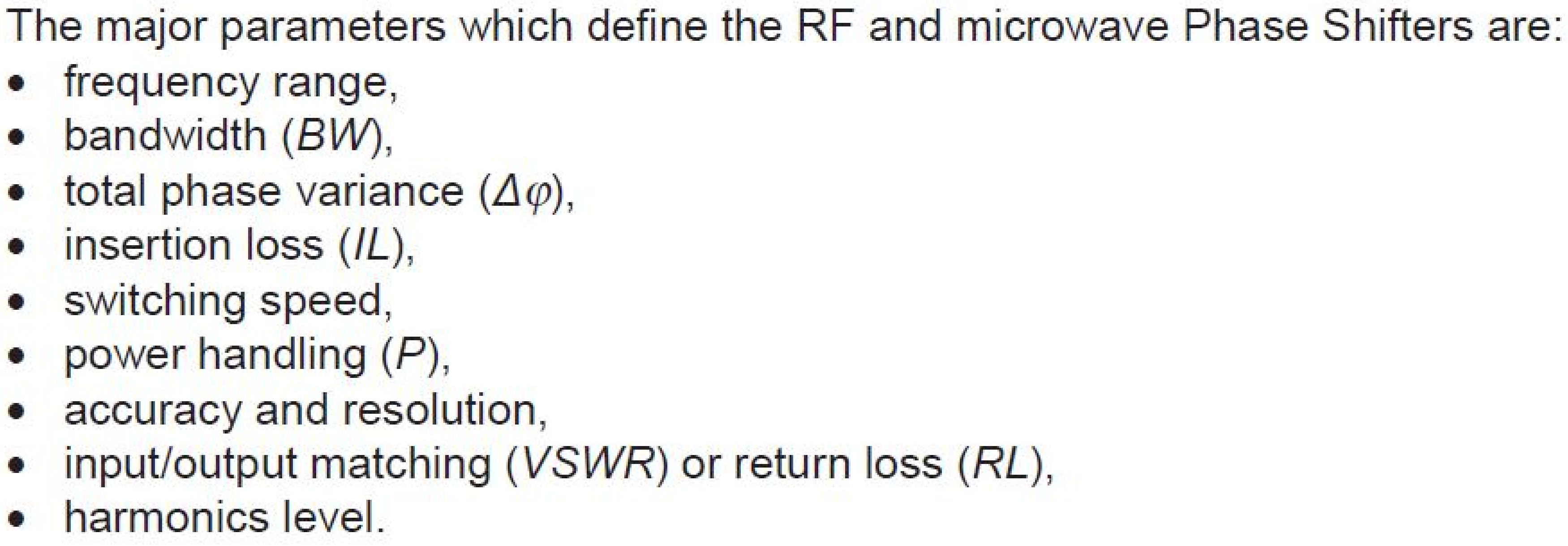
Phase shifters



Phase Shifters are devices, in which the phase of an electromagnetic wave of a given frequency can be shifted when propagating through a transmission line.

In many fields of electronics, it is often necessary to change the phase of signals.

RF and microwave Phase Shifters have many applications in various equipments such as phase discriminators, beam forming networks, power dividers, linearization of power amplifiers, and phase array antennas.



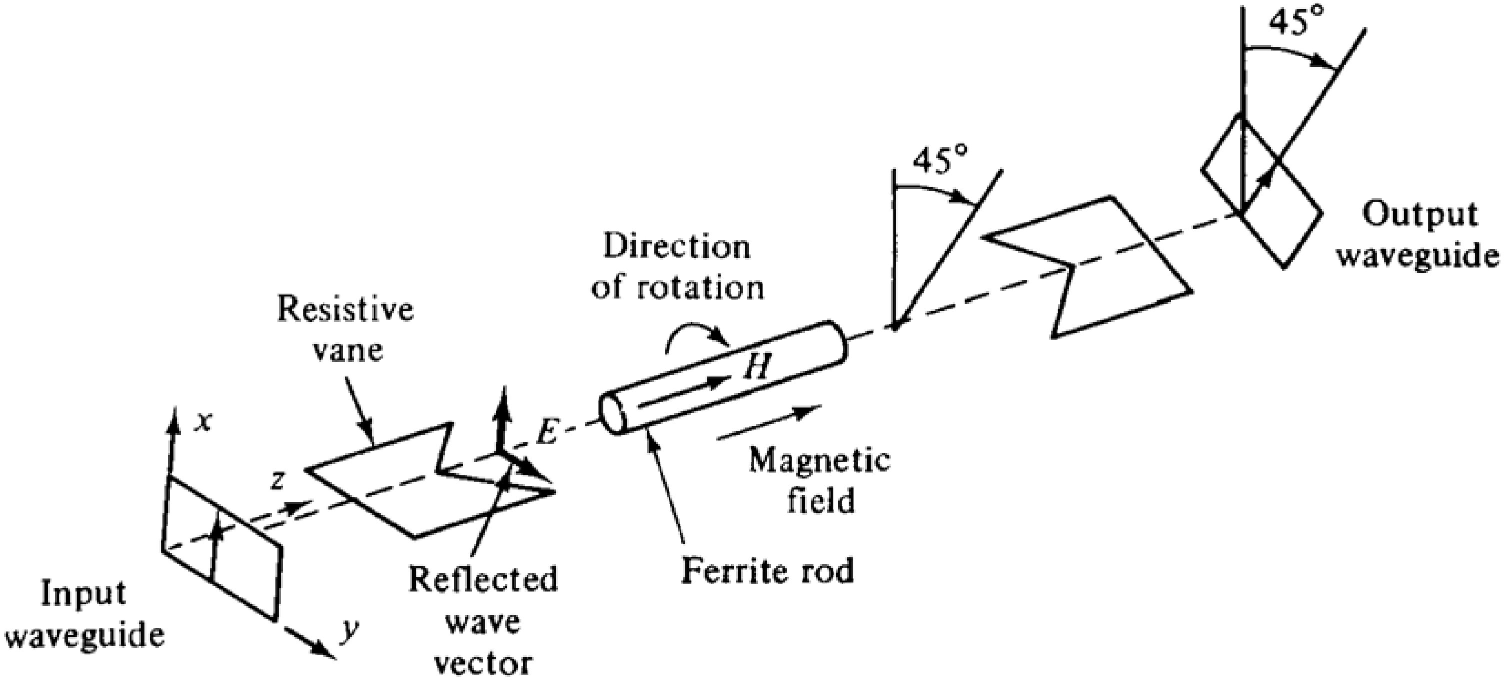
The major parameters which define the RF and microwave Phase Shifters are:

- frequency range,
- bandwidth (*BW*),
- total phase variance ($\Delta\varphi$),
- insertion loss (*IL*),
- switching speed,
- power handling (*P*),
- accuracy and resolution,
- input/output matching (*VSWR*) or return loss (*RL*),
- harmonics level.

Isolator

- An isolator is a non reciprocal transmission device that is used to isolate one component from reflections of the other in a transmission line.
- An ideal isolator completely absorbs the power from propagation in one direction and provide loss less transmission in opposite direction
- It is also known as UNILINE
- It is used to improve the frequency stability.
- One type of isolator is Faraday rotation Isolator, the input resistive card is in y-z plane, the output resistive card is displaced 45° with respect to the input card.
- The magnetic field which is applied longitudinally to the ferrite rod rotates the wave plane by 45°.
- This is normal to the output resistive card
- As the result of rotation the wave arrives at the out put end without attenuation at all.
- On the other end a reflected wave from the output end is similarly rotated clockwise 45° by the ferrite rod, since the reflected wave is parallel to the input resistive card the wave is absorbed by the input card.

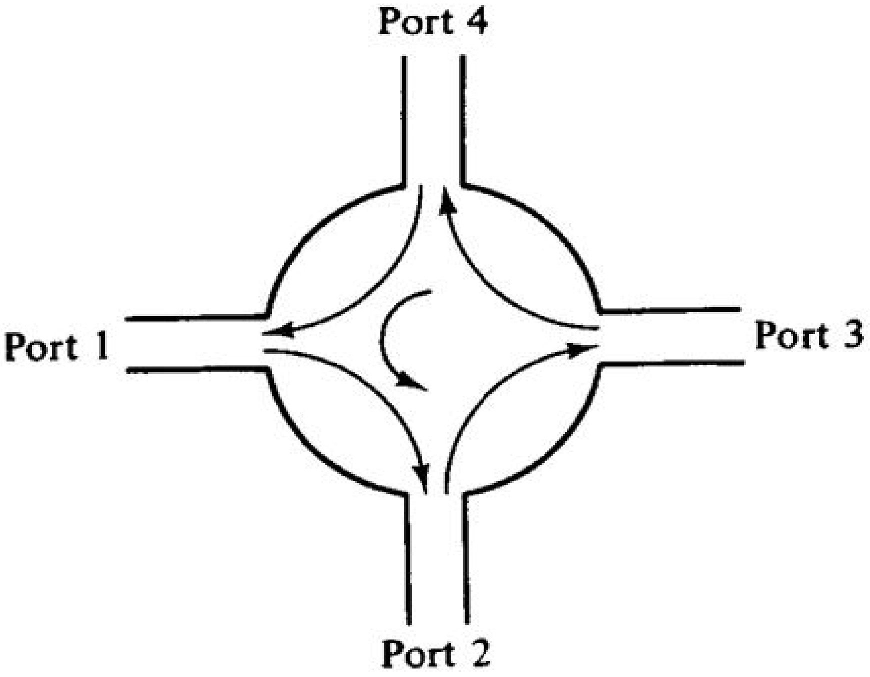
Isolator



Isolator

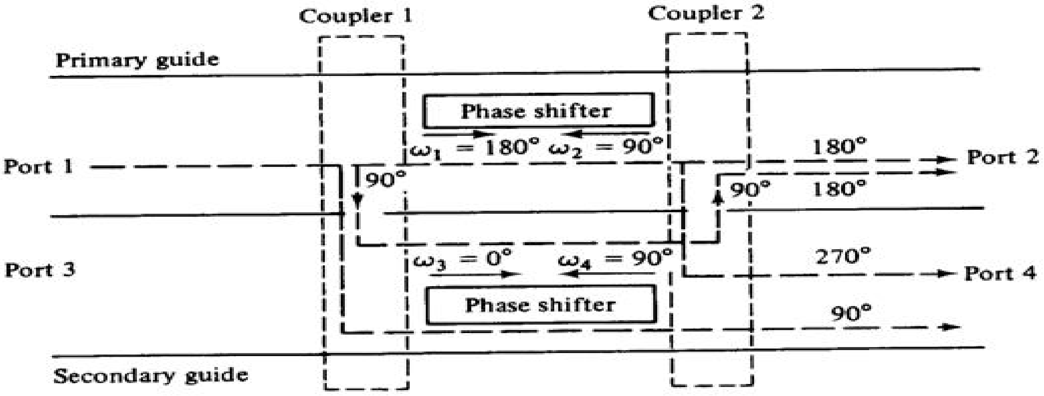
circulator

- A circulator is a multiport wave guide junction in which wave can flow only from nth port to n+1th port in one direction.
- There is no restriction on number of ports.



Circulator

- The operating principle of a microwave circulator can be analyzed with the help of figure below.



- Each of the two 3dB couplers in circulator introduces a phase shift of 90° and each of the two phase shifters produce a certain phase change, the wave is split in to two components by the coupler 1.
- The wave in primary guide arrives at port 2 with a relative phase change of 180° . The second wave propagates through the two couplers & secondary guide arrives at port 2 with relative phase shift of 180° , since the two waves reaching port 2 are in phase , the power transmitted is obtained fron port 1 to port 2.
- The waves propagating through primary guide , phase shifter, & coupler 2 arrives at port 4 with a 270o phase change.

Circulator

➢The wave travelling through coupler 1 & secondary guide arrives at port 4 with a phase shift of 90o.

➢Since the two waves reaching port 4 are opposite in phase the power transmission from 1-4 is zero.

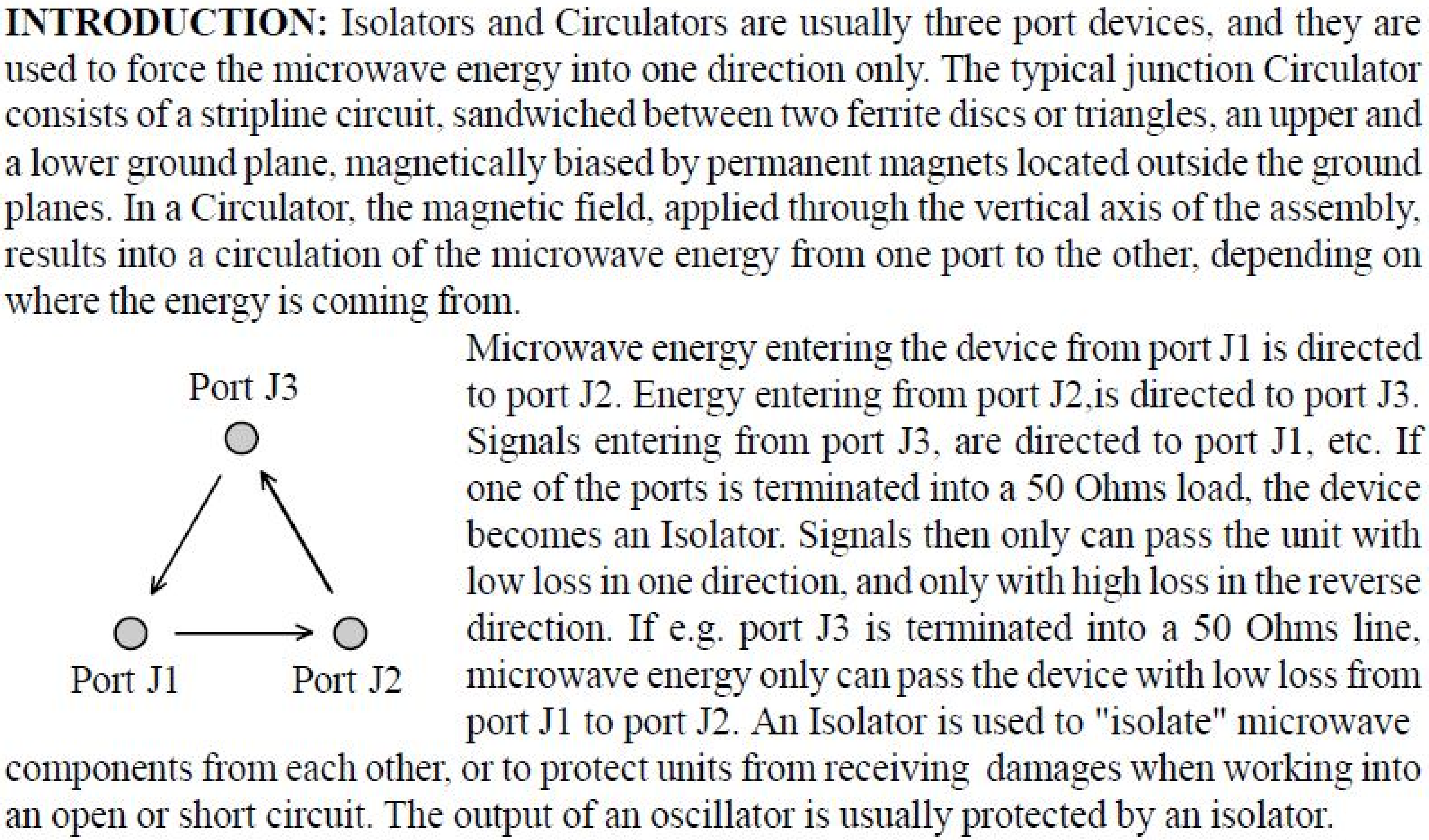
➢A perfectly matched lossless nonreciprocal four port circulator has an S matrix of the form.

$$\mathbf{S} = \begin{bmatrix} 0 & S_{12} & S_{13} & S_{14} \\ S_{21} & 0 & S_{23} & S_{24} \\ S_{31} & S_{32} & 0 & S_{34} \\ S_{41} & S_{42} & S_{43} & 0 \end{bmatrix}$$

➢Using the parameters of S parameters the above matrix is simplifies as

$$\mathbf{S} = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

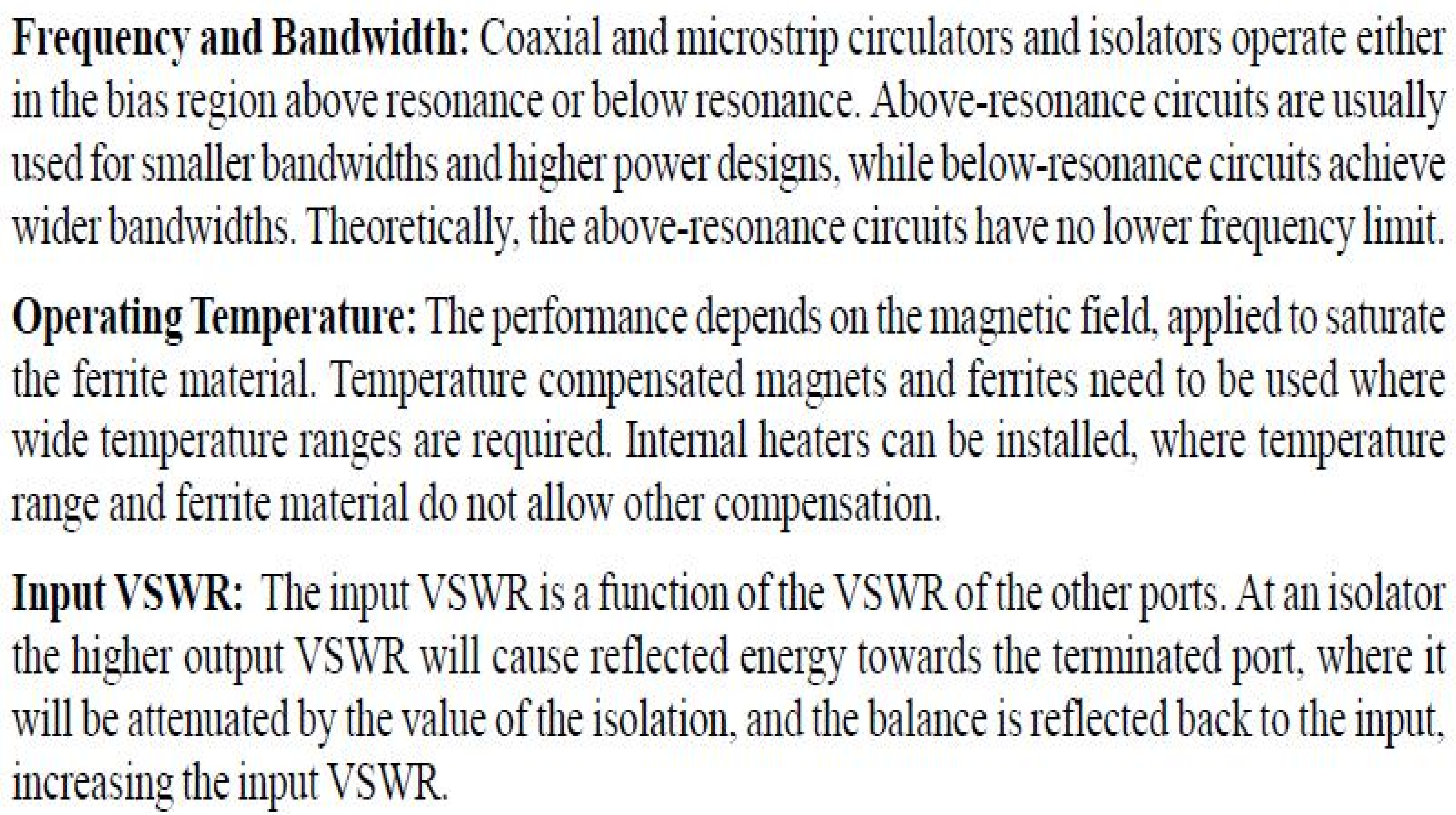
Isolators and circulators



INTRODUCTION: Isolators and Circulators are usually three port devices, and they are used to force the microwave energy into one direction only. The typical junction Circulator consists of a stripline circuit, sandwiched between two ferrite discs or triangles, an upper and a lower ground plane, magnetically biased by permanent magnets located outside the ground planes. In a Circulator, the magnetic field, applied through the vertical axis of the assembly, results into a circulation of the microwave energy from one port to the other, depending on where the energy is coming from.

Microwave energy entering the device from port J1 is directed to port J2. Energy entering from port J2,is directed to port J3. Signals entering from port J3, are directed to port J1, etc. If one of the ports is terminated into a 50 Ohms load, the device becomes an Isolator. Signals then only can pass the unit with low loss in one direction, and only with high loss in the reverse direction. If e.g. port J3 is terminated into a 50 Ohms line, microwave energy only can pass the device with low loss from port J1 to port J2. An Isolator is used to "isolate" microwave components from each other, or to protect units from receiving damages when working into an open or short circuit. The output of an oscillator is usually protected by an isolator.

Isolators and circulators

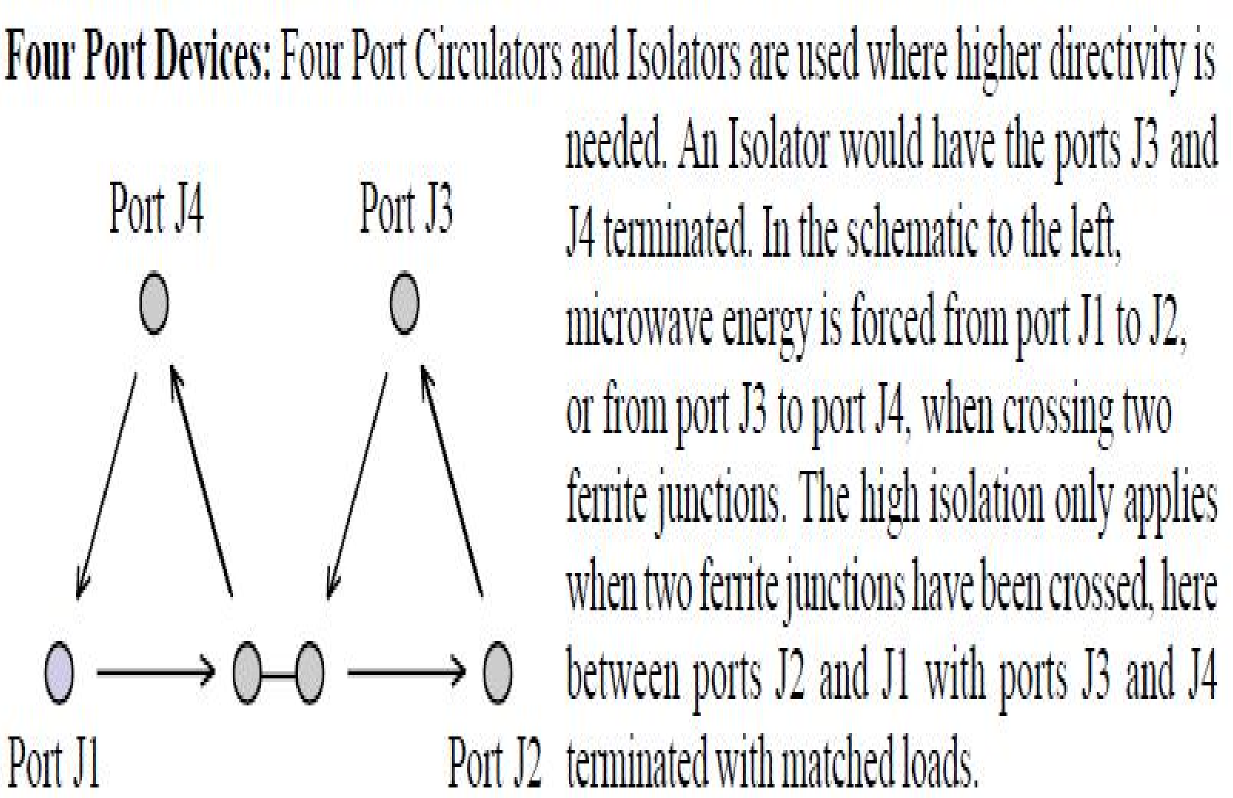


Frequency and Bandwidth: Coaxial and microstrip circulators and isolators operate either in the bias region above resonance or below resonance. Above-resonance circuits are usually used for smaller bandwidths and higher power designs, while below-resonance circuits achieve wider bandwidths. Theoretically, the above-resonance circuits have no lower frequency limit.

Operating Temperature: The performance depends on the magnetic field, applied to saturate the ferrite material. Temperature compensated magnets and ferrites need to be used where wide temperature ranges are required. Internal heaters can be installed, where temperature range and ferrite material do not allow other compensation.

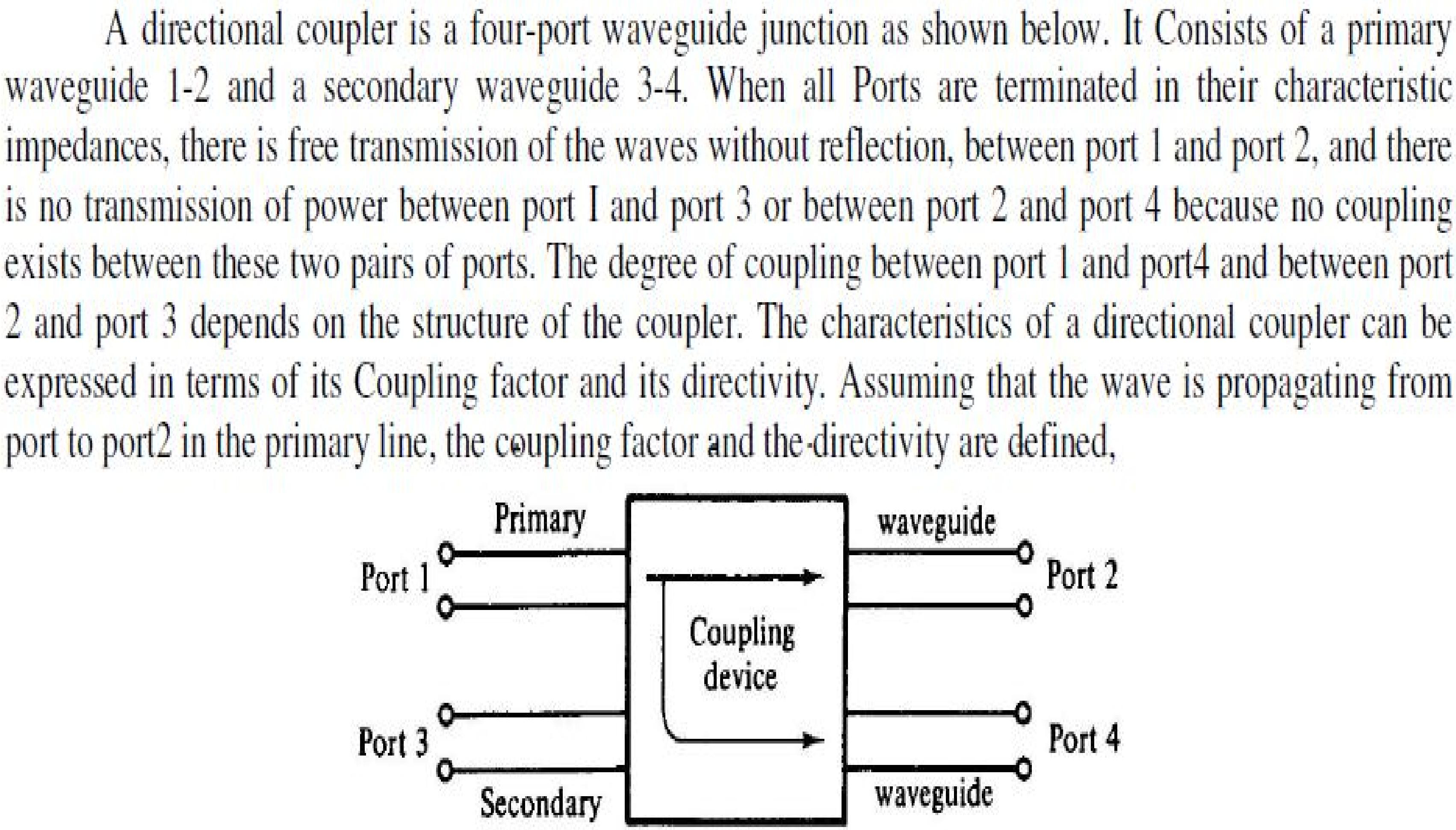
Input VSWR: The input VSWR is a function of the VSWR of the other ports. At an isolator the higher output VSWR will cause reflected energy towards the terminated port, where it will be attenuated by the value of the isolation, and the balance is reflected back to the input, increasing the input VSWR.

Isolators and circulators



Four Port Devices: Four Port Circulators and Isolators are used where higher directivity is needed. An Isolator would have the ports J3 and J4 terminated. In the schematic to the left, microwave energy is forced from port J1 to J2, or from port J3 to port J4, when crossing two ferrite junctions. The high isolation only applies when two ferrite junctions have been crossed, here between ports J2 and J1 with ports J3 and J4 terminated with matched loads.

Directional Coupler



A directional coupler is a four-port waveguide junction as shown below. It Consists of a primary waveguide 1-2 and a secondary waveguide 3-4. When all Ports are terminated in their characteristic impedances, there is free transmission of the waves without reflection, between port 1 and port 2, and there is no transmission of power between port I and port 3 or between port 2 and port 4 because no coupling exists between these two pairs of ports. The degree of coupling between port 1 and port4 and between port 2 and port 3 depends on the structure of the coupler. The characteristics of a directional coupler can be expressed in terms of its Coupling factor and its directivity. Assuming that the wave is propagating from port to port2 in the primary line, the coupling factor and the directivity are defined,

Directional Coupler

$$\text{Coupling factor (dB)} = 10 \log_{10} \frac{P_1}{P_4}$$

$$\text{Directivity (dB)} = 10 \log_{10} \frac{P_4}{P_3}$$

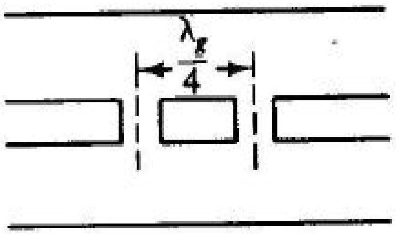
Where PI = power input to port I
P3 = power output from port 3
P4 = power output from port 4

It should be noted that port 2, port 3, and port 4 are terminated in their characteristic impedances. The coupling factor is a measure of the ratio of power levels in the primary and secondary lines. Hence if the coupling factor is known, a fraction of power measured at port 4 may be used to determine the power input at port 1.

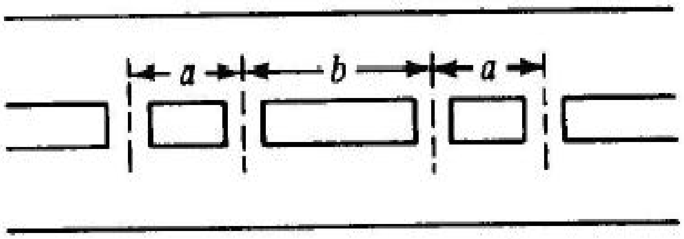
This significance is desirable for microwave power measurements because no disturbance, which may be caused by the power measurements, occurs in the primary line. The directivity is a measure of how well the forward traveling wave in the primary waveguide couples only to a specific port of the secondary waveguide ideal directional coupler should have infinite directivity. In other words, the power at port 3 must be zero because port 2 and portA are perfectly matched. Actually well-designed directional couplers have a directivity of only 30 to 35 dB.

Directional Coupler

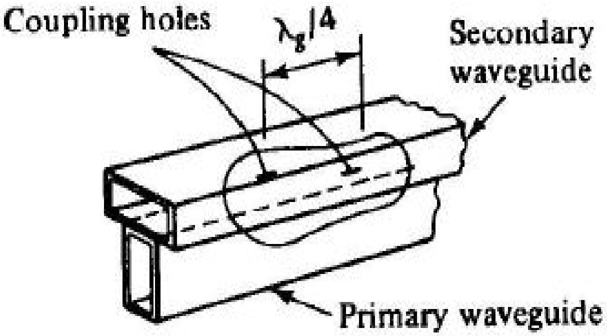
Several types of directional couplers exist, such as a two-hole direct couler, four-hole directional coupler, reverse-coupling directional coupler , and Bethe-hole directional coupler the very commonly used two-hole directional coupler is described here.



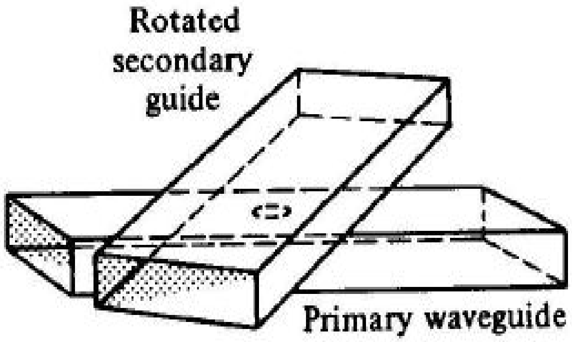
(a)



(b)



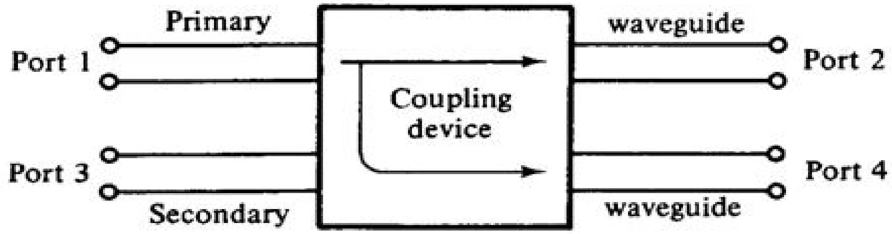
(c)



(d)

Directional Coupler

- A Directional coupler is a four port wave guide junction as shown in igure.



- The primary waveguide is 1-2
- Secondary waveguide is 3-4

- When all ports are terminated there is a free transmission of power ithout reflection between ports 1 & 2.
- There is no transmission between 1 - 3 & 2 – 4 because of no oupling.
- The characteristics of directional coupler can be expressed in terms f C

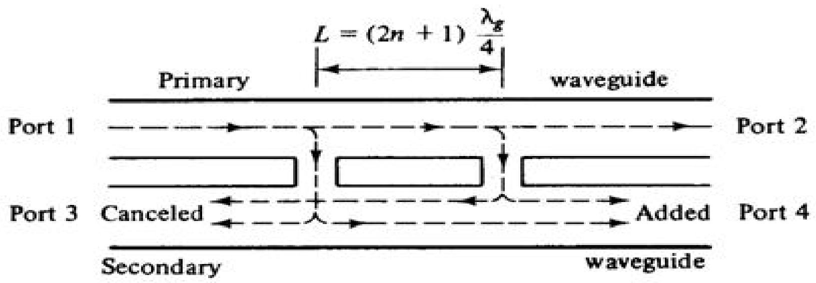
$$\text{Coupling factor (dB)} = 10 \log_{10} \frac{P_1}{P_4}$$

$$\text{Directivity (dB)} = 10 \log_{10} \frac{P_4}{P_3}$$

where P_1 = power input to port 1
P_3 = power output from port 3
P_4 = power output from port 4

Directional Coupler

- A two hole directional coupler with travelling wave propagation in it is illustrated in the figure given.



- The spacing between the centre of two holes should be

$$L = (2n+1)\frac{\lambda_g}{4}$$

- In directional Coupler all four ports are completely matched. So

$$S_{11} = S_{22} = S_{33} = S_{44} = 0$$

- There is no coupling between port 2 & 4, thus

$$S_{13} = S_{31} = S_{24} = S_{42} = 0$$

- Consequently, the S matrix of Directional Coupler i

$$\mathbf{S} = \begin{bmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{21} & 0 & S_{23} & 0 \\ 0 & S_{32} & 0 & S_{34} \\ S_{41} & 0 & S_{43} & 0 \end{bmatrix}$$

This equation can be reduced using zero property

$$S_{12}S_{14}^* + S_{32}S_{34}^* = 0$$

$$S_{21}S_{23}^* + S_{41}S_{43}^* = 0$$

Unitary Property

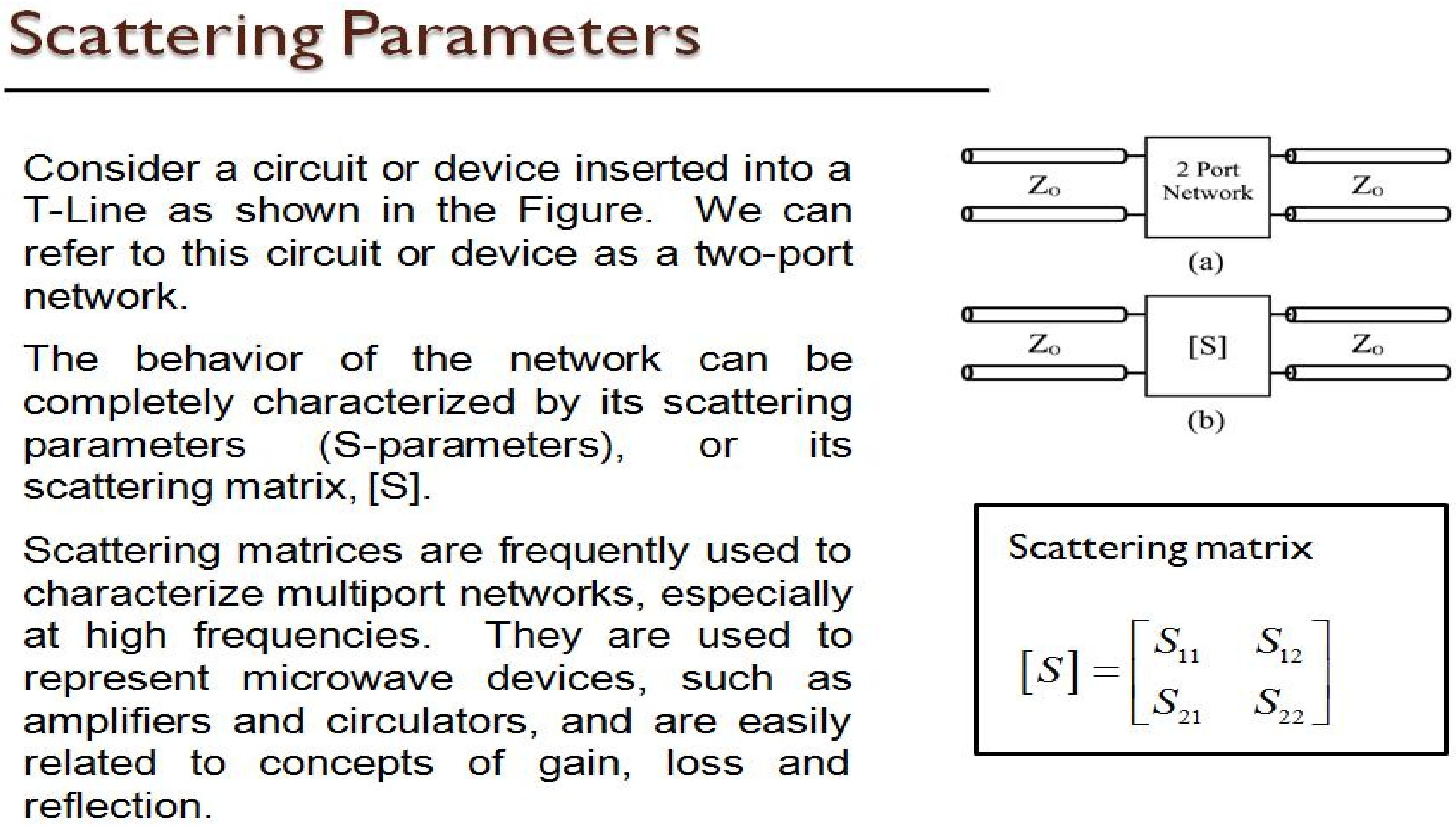
$$S_{12}S_{12}^* + S_{14}S_{14}^* = 1$$

We have

$$|S_{12}||S_{14}| = |S_{32}||S_{34}|$$

$$|S_{21}||S_{23}| = |S_{41}||S_{43}|$$

scattering matrix derivation for all components .



Scattering Parameters

Consider a circuit or device inserted into a T-Line as shown in the Figure. We can refer to this circuit or device as a two-port network.

The behavior of the network can be completely characterized by its scattering parameters (S-parameters), or its scattering matrix, [S].

Scattering matrices are frequently used to characterize multiport networks, especially at high frequencies. They are used to represent microwave devices, such as amplifiers and circulators, and are easily related to concepts of gain, loss and reflection.

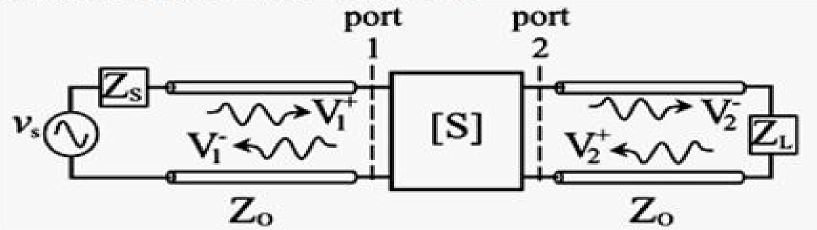
Scattering matrix

$$[S] = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}$$

scattering matrix derivation for all components .

Scattering Parameters (S-Parameters)

The scattering parameters represent ratios of voltage waves entering and leaving the ports (If the same characteristic impedance, Zo, at all ports in the network are the same).

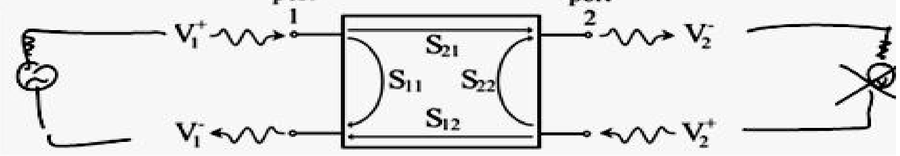


$$V_1^- = S_{11}V_1^+ + S_{12}V_2^+ .$$

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

In matrix form this is written

$$\begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix}, \ [V]^- = [S][V]^+$$



Where,

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

Reflection Coefficient at port 1

$$S_{12} = \left.\frac{V_1^-}{V_2^+}\right|_{V_1^+=0}$$

Transmission coefficient from port 2 to port 1

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

Transmission coefficient from port 1 to port 2

$$S_{22} = \left.\frac{V_2^-}{V_2^+}\right|_{V_1^+=0}$$

Reflection coefficient at port 2

UNIT III MICROWAVE VACCUM TUBE DEVICES

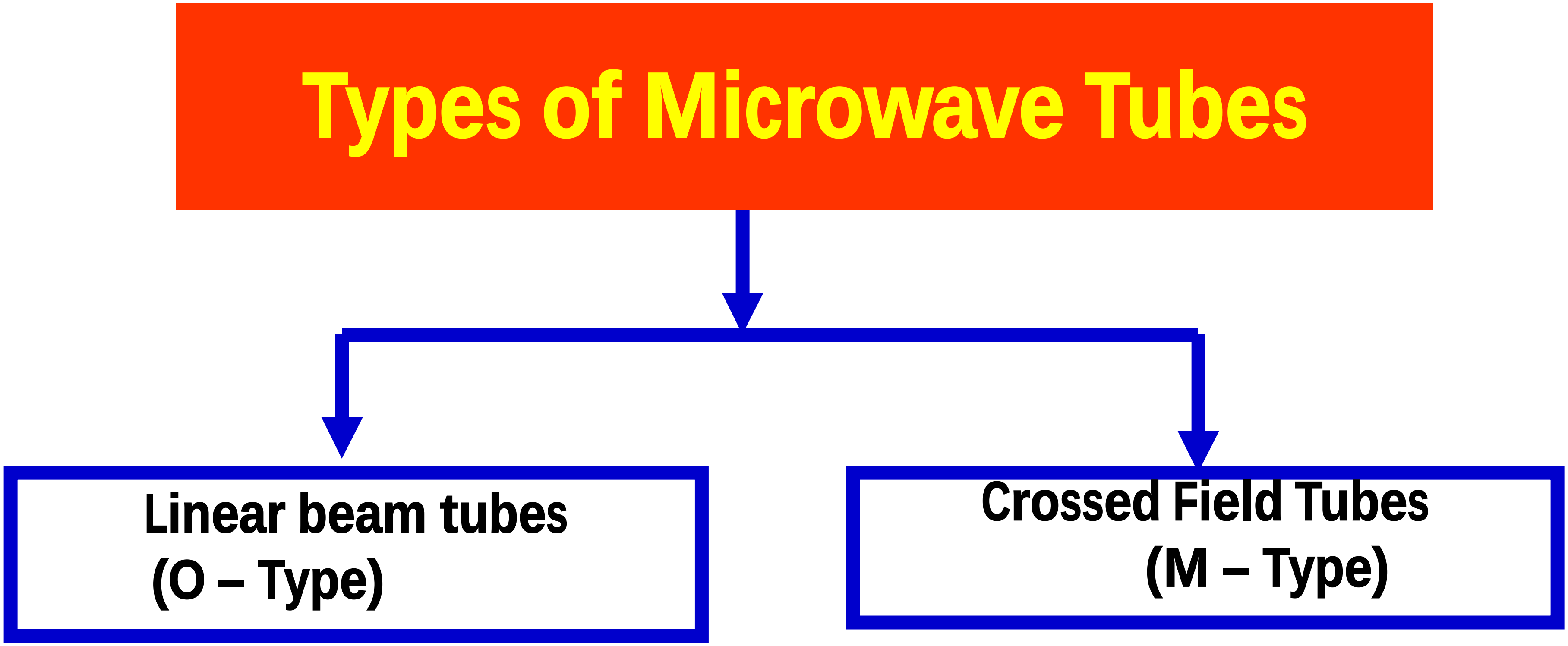
Introduction – Two cavity klystron amplifier – Mechanism and mode of operation –Power output and efficiency -Applications – Reflex klystron oscillator – Mechanism and mode of operation-Power output – Efficiency – Mode curve –Applications – TWT amplifier – Principle of operation-gain and applications – Magnetron oscillator – Hull cut-off voltage mechanism of operation– Power output and efficiency – Applications – Numerical problems.

WHY MICROWAVE VACUUM TUBES?

- Because of
  - The electron transit from the cathode to the grid become comparable to time period of the sinusoidal signal.
  - Appearance of stray reactance's due to the lead wire inductances and the inter-electrode capacitances.

MICROWAVE OSCILLATIONS OR AMPLIFICATION

- The principles uses an electron beam on which space-charge waves
  - interact with EM fields in the microwave cavities to transfer energy to the output circuit of the cavity or
  - interact with EM fields in a slow-wave structure to give amplification through transfer of energy.



Types of Microwave Tubes

Linear beam tubes
(O – Type)

Crossed Field Tubes
(M – Type)

Eg:

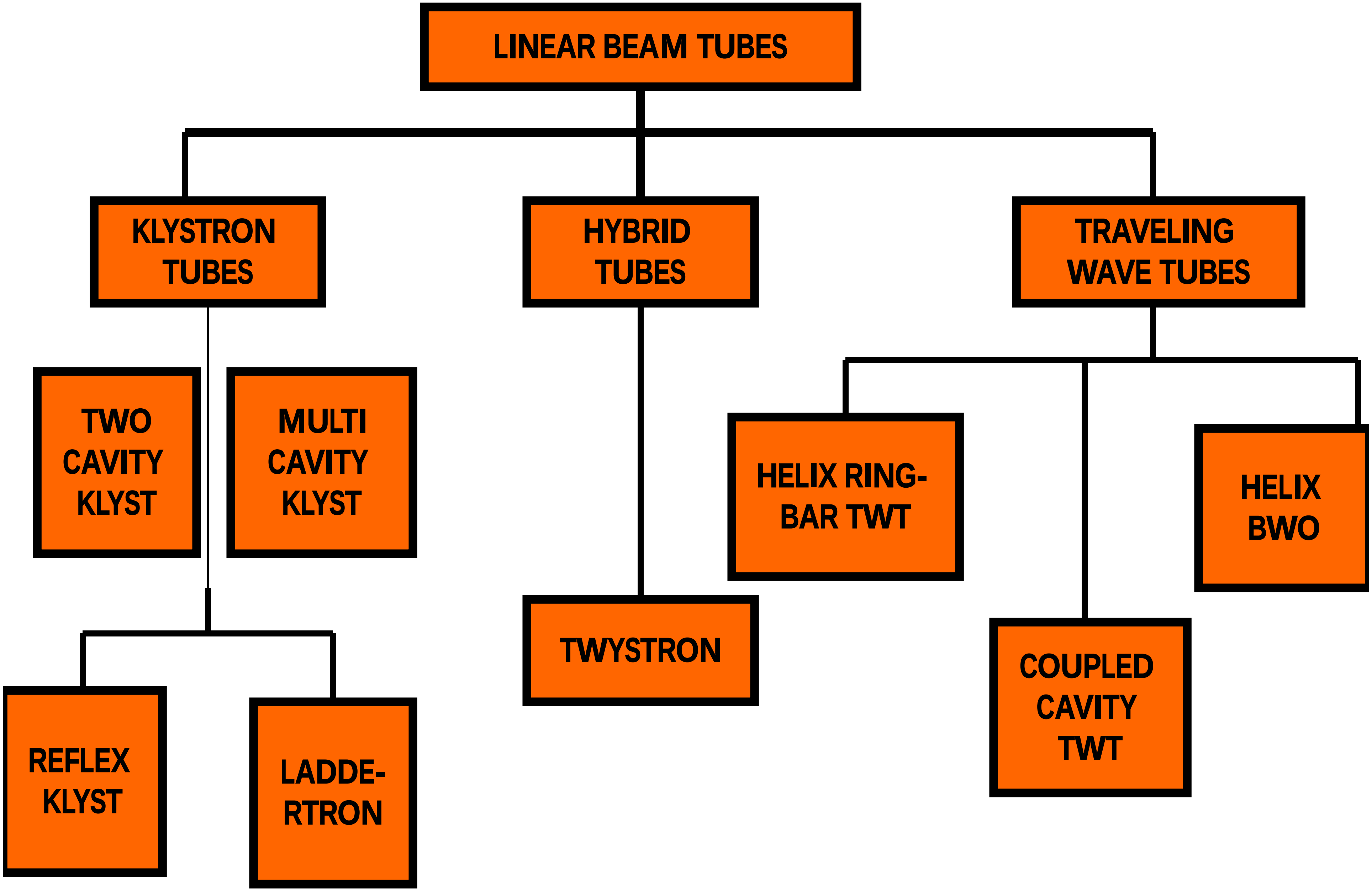
- **Klystron**
- **Reflex klystron**
- **TWT**

Eg:

- **Magnetron**

Linear beam devices	Crossed field devices
(I) Straight path taken by the electron beam	A principle feature of such tubes is that electrons travel in a curved path
(i) DC magnetic field is in parallel with DC electric field to focus the electron beam	DC magnetic field is perpendicular to DC electric field

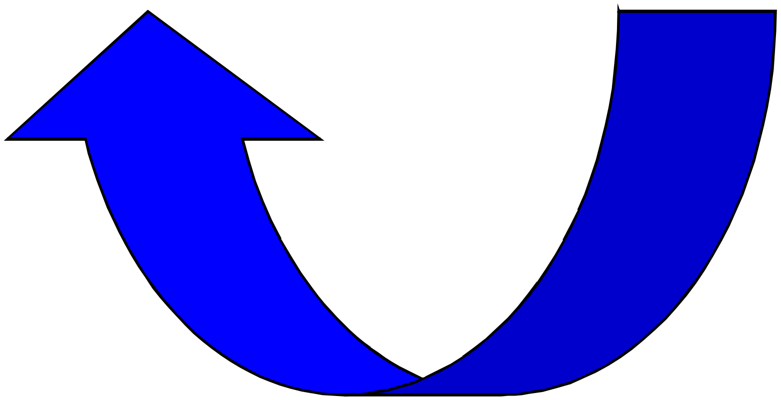
Types of Linear Beam Tubes



- LINEAR BEAM TUBES
  - KLYSTRON TUBES
    - TWO CAVITY KLYST
    - MULTI CAVITY KLYST
    - REFLEX KLYST
    - LADDE-RTRON
  - HYBRID TUBES
    - TWYSTRON
  - TRAVELING WAVE TUBES
    - HELIX RING-BAR TWT
    - COUPLED CAVITY TWT
    - HELIX BWO

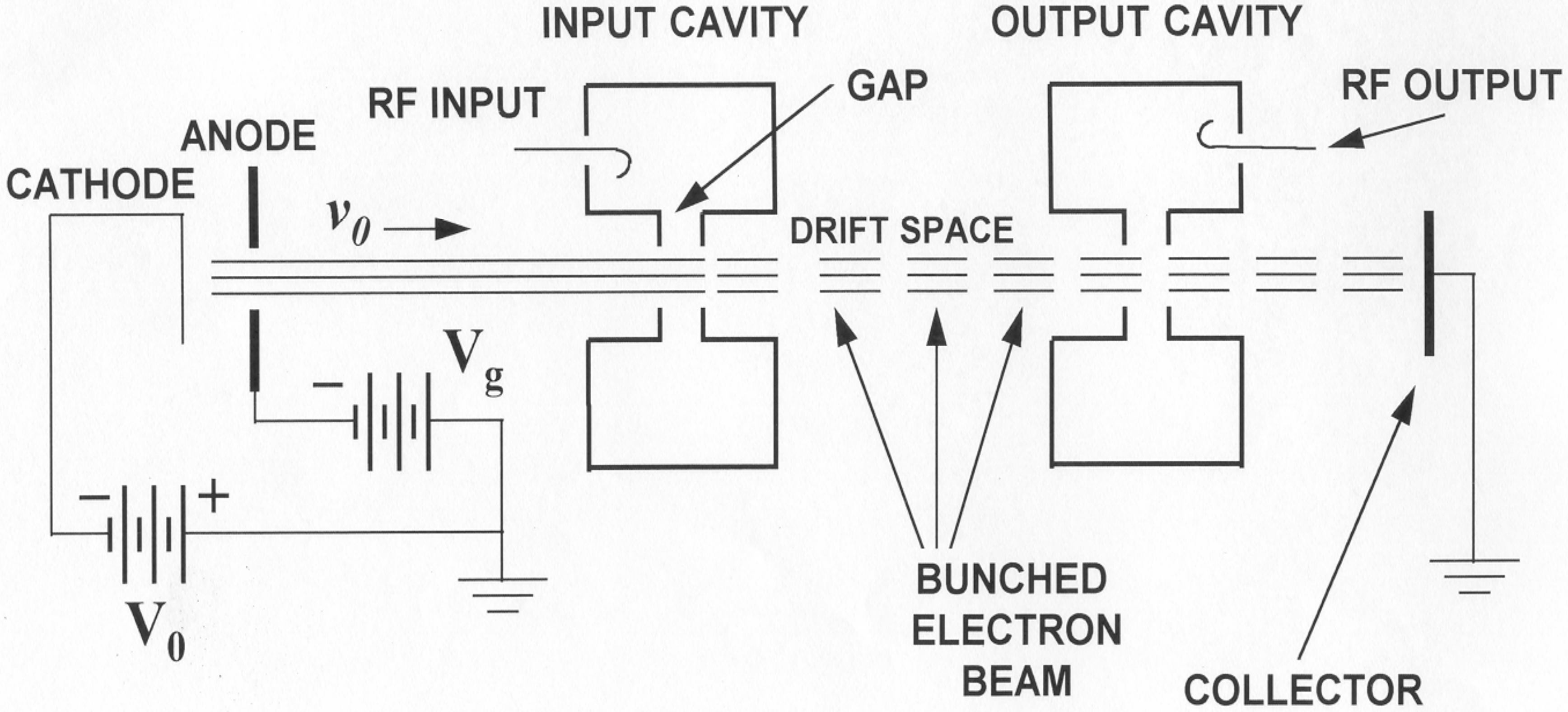
TWYSTRON

- **KL**YSTRON + **TW**T = **TWYSTRON**



- **It is hybrid amplifier that uses the combinations of klystron and TWT components**

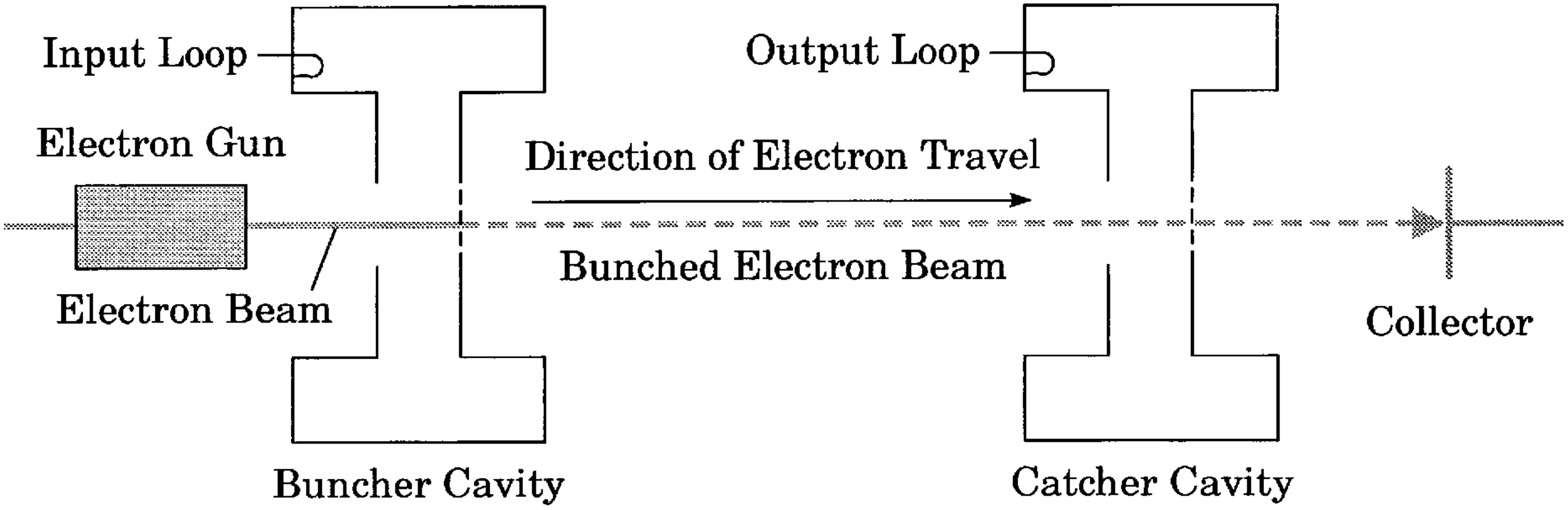
KLYSTRON STRUCTURE



Klystron

- Used in high-power amplifiers
- Electron beam moves down tube past several cavities.
- Input cavity is the *buncher*, output cavity is the *catcher.*
- *Buncher* modulates the velocity of the electron beam

Klystron Cross Section



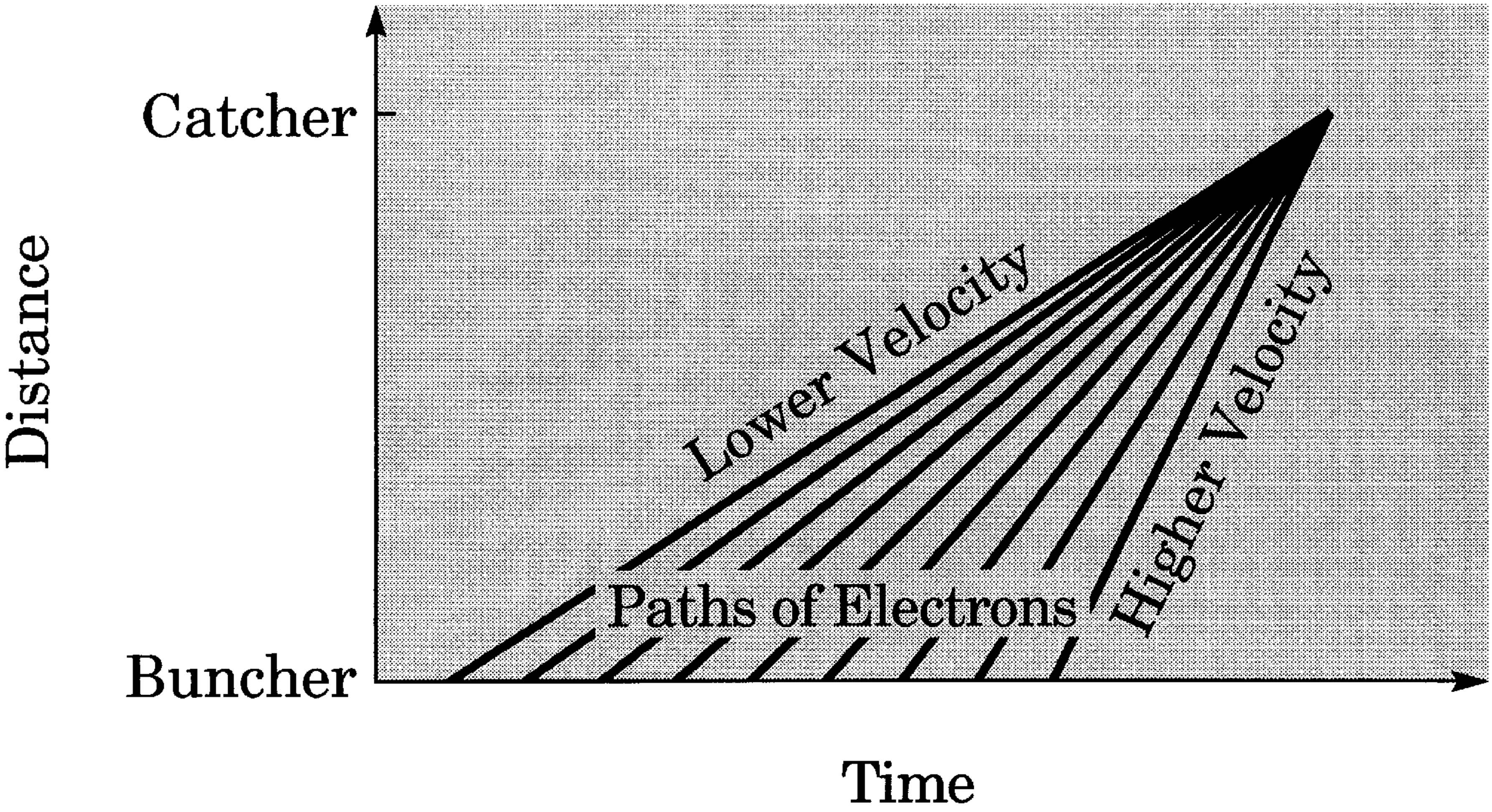
Transparency 271 (Figure 19.39b)

PRINCIPLE

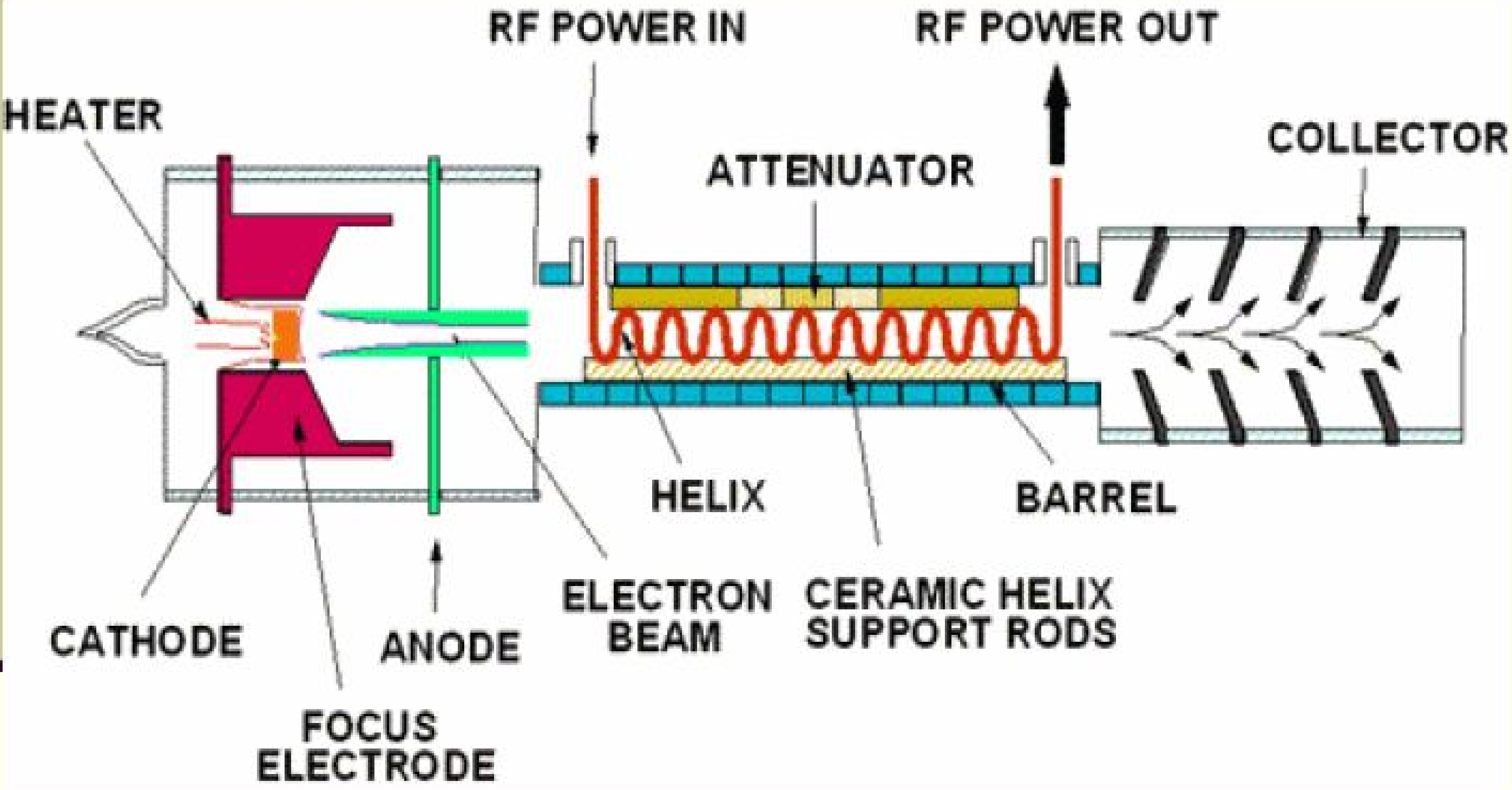
Velocity Modulation

- Electric field from microwaves at buncher alternately speeds and slows electron beam .
- This causes electrons to bunch up Electron bunches at catcher induce microwaves with more energy.
- The cavities form a slow-wave structure

Velocity Modulation



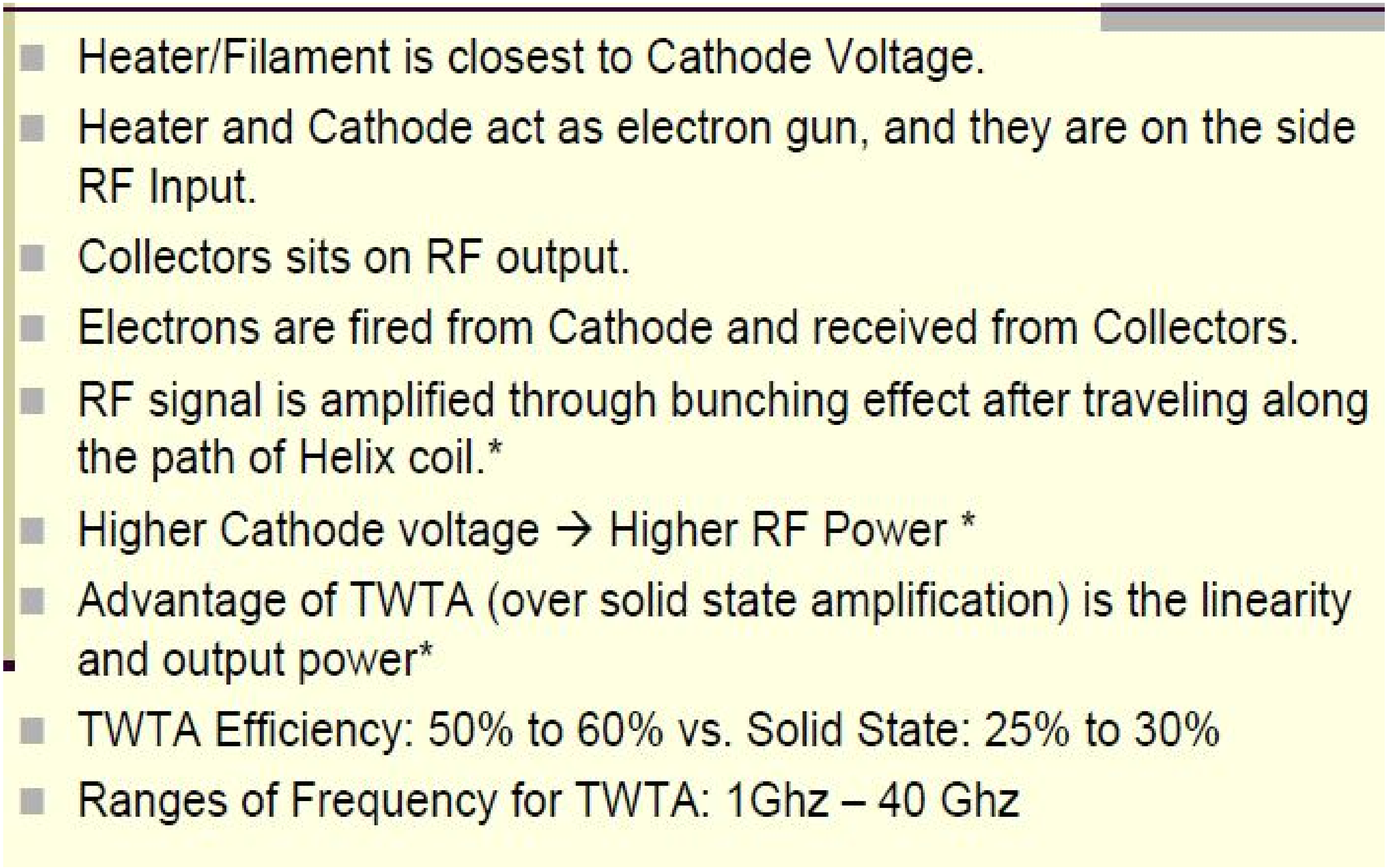
BASICS of Traveling Wave Tube (TWT) Amplifier



Traveling-Wave Tube (TWT)

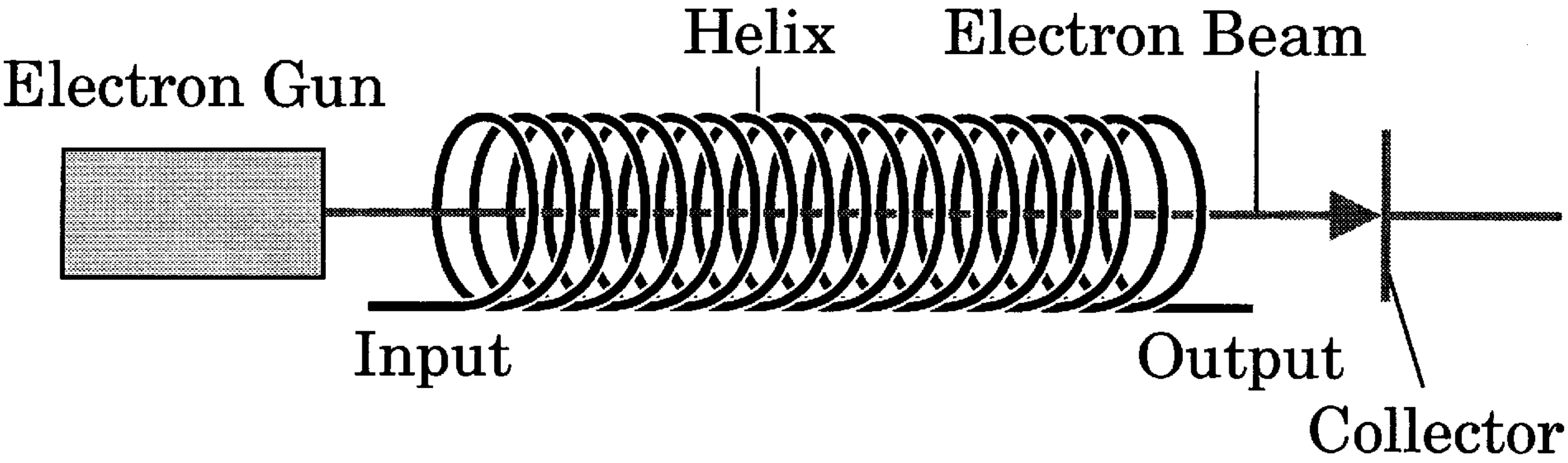
- Uses a helix as a slow-wave structure
- Microwaves input at cathode end of helix, output at anode end
- Energy is transferred from electron beam to microwaves

Traveling-Wave Tube (TWT)



- Heater/Filament is closest to Cathode Voltage.
- Heater and Cathode act as electron gun, and they are on the side RF Input.
- Collectors sits on RF output.
- Electrons are fired from Cathode and received from Collectors.
- RF signal is amplified through bunching effect after traveling along the path of Helix coil.*
- Higher Cathode voltage → Higher RF Power *
- Advantage of TWTA (over solid state amplification) is the linearity and output power*
- TWTA Efficiency: 50% to 60% vs. Solid State: 25% to 30%
- Ranges of Frequency for TWTA: 1Ghz – 40 Ghz

Traveling-Wave Tube

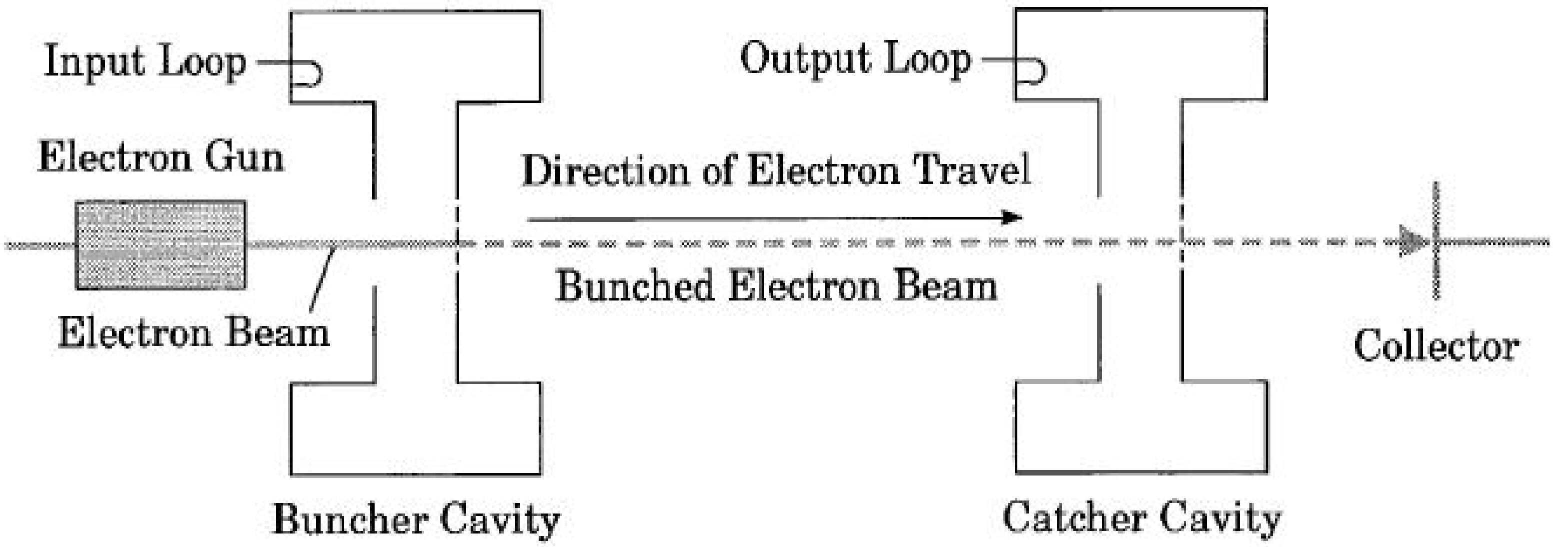


Application of TWT

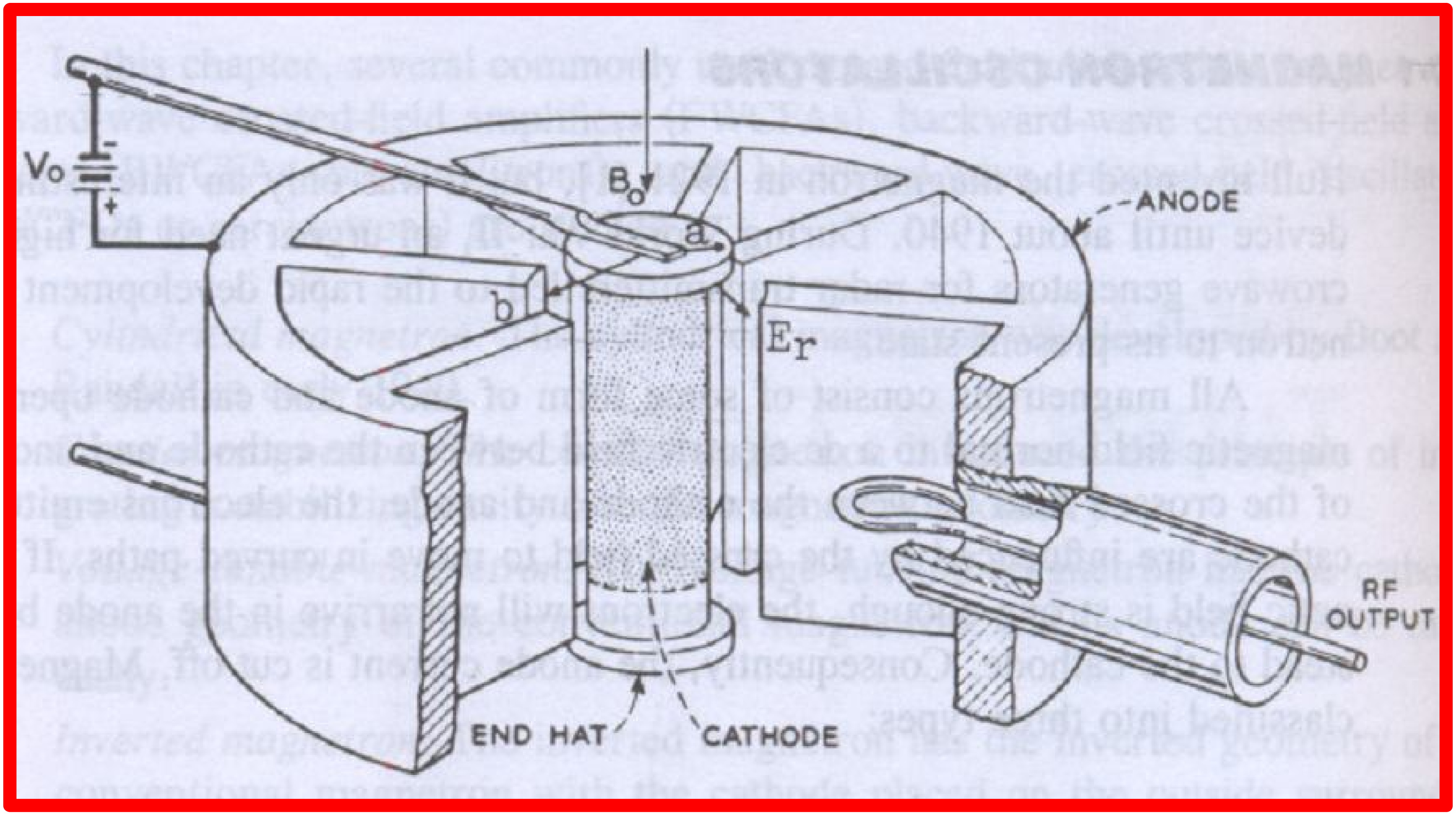
- Point to Point Communication
- Satellite communication and Rader Appz
- Missile tracking application for military
- Television live broadcasting
  - LIVE news vans with satellite dishes on the roof carry TWTA inside

MULTI-CAVITY KLYSTRON

- Electron beam moves down tube past several cavities.
- Input cavity is the *buncher*, output cavity is the *catcher*.
- *Buncher* modulates the velocity of the electron beam



Magnetron Oscillator

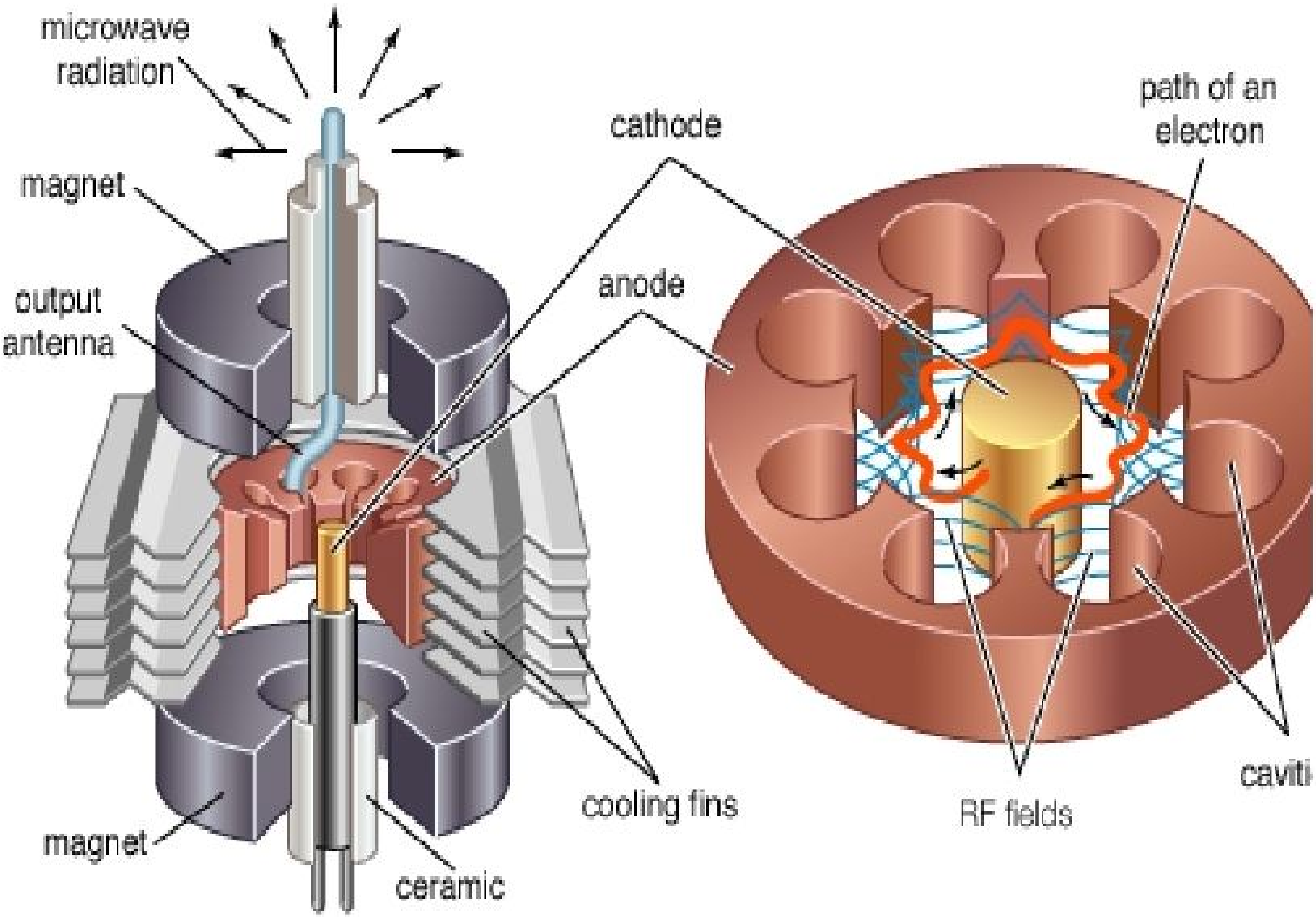


MAGNETRON

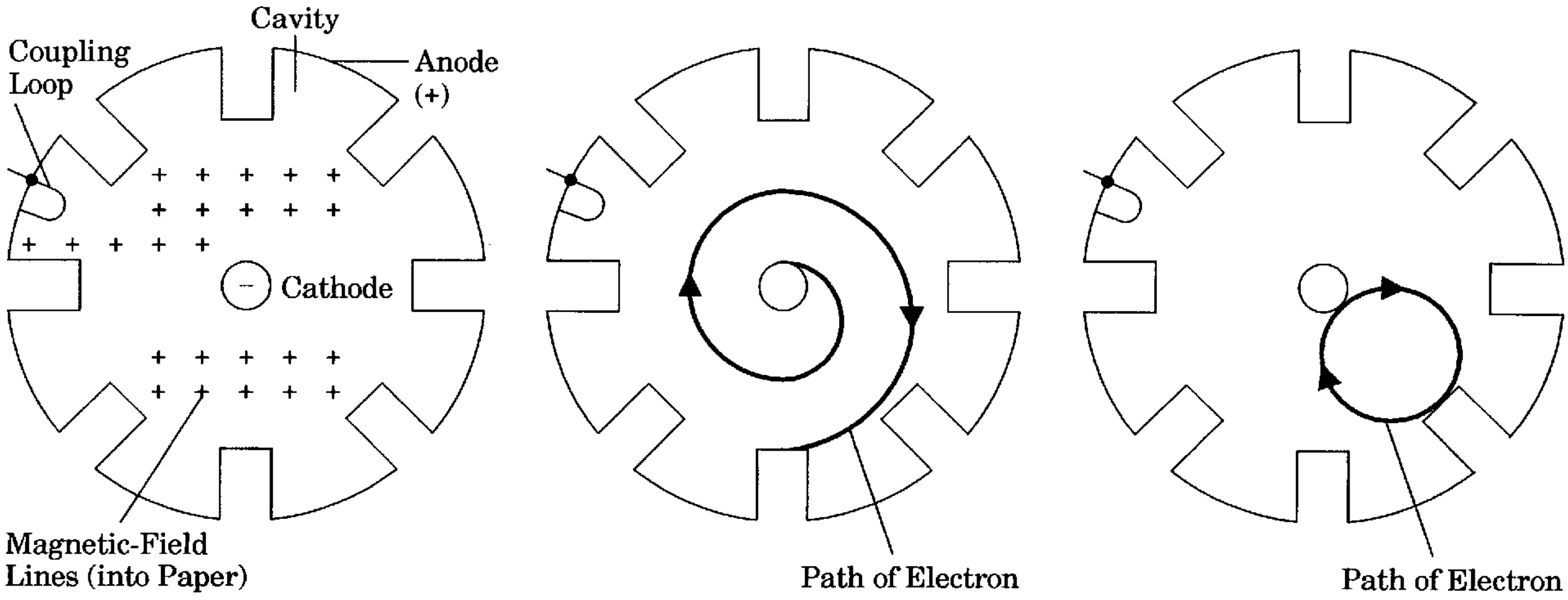
- High-power oscillator
- Common in radar and microwave ovens
- Cathode in center, anode around outside
- Strong dc magnetic field around tube causes electrons from cathode to spiral as they move toward anode
- Current of electrons generates microwaves in cavities around outside

SLOW-WAVE STRUCTURE

- Magnetron has cavities all around the outside
- Wave circulates from one cavity to the next around the outside
- Each cavity represents one-half period
- Wave moves around tube at a velocity much less than that of light
- Wave velocity approximately equals electron velocity


microwave radiation
magnet
output antenna
cathode
anode
path of an electron
cooling fins
RF fields
caviti
magnet
ceramic

Cavity Magnetron



(a) Cross Section

(b) Electron Paths in Normal Operation

(c) Electron Paths at Cutoff

Transparency 270 (Figure 19.38)

UNIT IV MICROWAVE SEMICONDUCTOR DEVICES AND CIRCUITS

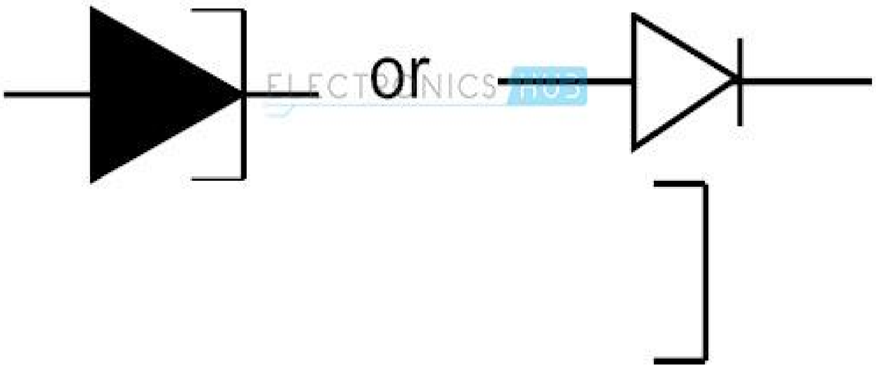
Principles of tunnel diodes - Varactor and Step recovery diodes – Transferred Electron Devices -Gunn diode- Avalanche Transit time devices- IMPATT and TRAPATT Devices- Parametric Amplifiers – Introduction to Micro strip Lines, & Monolithic Microwave Integrated circuits-Materials, MMIC Fabrication Techniques.

Tunnel Diode

- It is used as high speed switch, of order nano-seconds. Due to tunneling effect it has very fast operation in microwave frequency region. It is a two terminal device in which concentration of dopants is too high.
- The transient response is being limited by junction capacitance plus stray wiring capacitance. Mostly used in microwave oscillators and amplifiers. It acts as most negative conductance device. Tunnel diodes can be tuned in both mechanically and electrically. The symbol of tunnel diode is as shown below.

Tunnel Diode Applications

- Oscillatory circuits.
- Microwave circuits.
- Resistant to nuclear radiation.

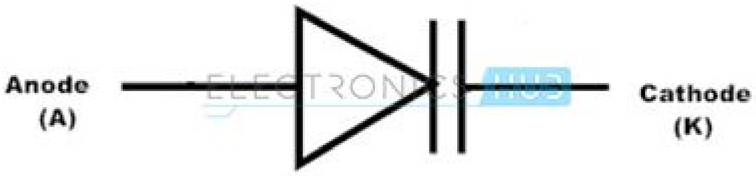


Varactor Diode

- These are also known as Varicap diodes. It acts like the variable capacitor. Operations are performed mainly at reverse bias state only. These diodes are very famous due to its capability of changing the capacitance ranges within the circuit in the presence of constant voltage flow.
- They can able to vary capacitance up to high values. In varactor diode by changing the reverse bias voltage we can decrease or increase the depletion layer. These diodes have many applications as voltage controlled oscillator for cell phones, satellite pre-filters etc. The symbol of varactor diode is given below.

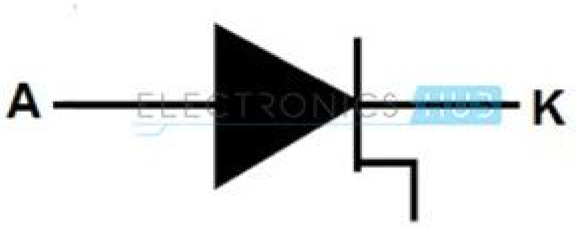
Varactor Diode Applications

- Voltage-controlled capacitors.
- Voltage-controlled oscillators.
- Parametric amplifiers.
- Frequency multipliers.
- FM transmitters and Phase locked loops in radio, television sets and cellular telephone.

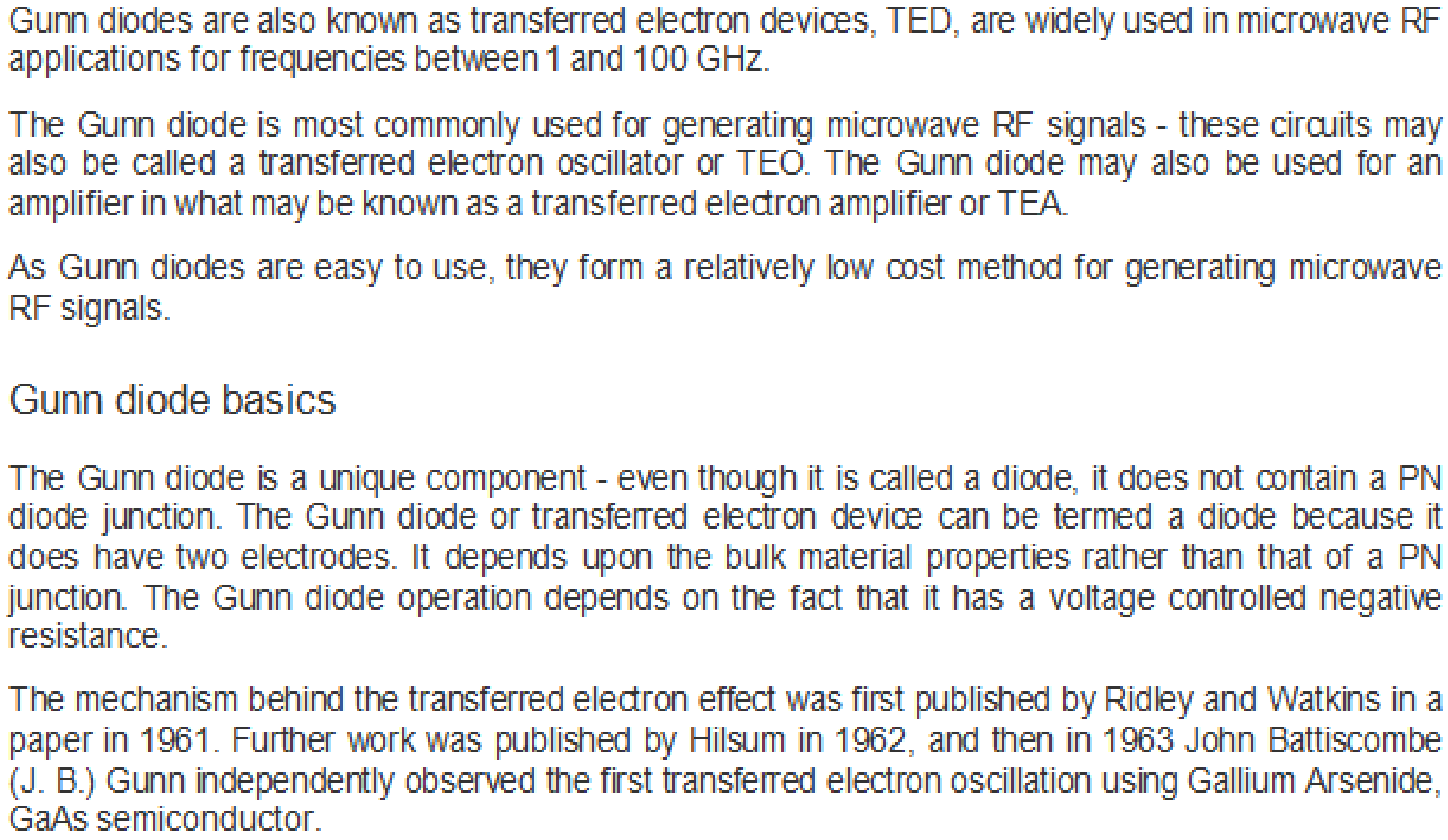


Step Recovery Diodes

- It is also called as snap-off diode or charge-storage diode. These are the special type of diodes which stores the charge from positive pulse and uses in the negative pulse of the sinusoidal signals. The rise time of the current pulse is equal to the snap time. Due to this phenomenon it has speed recovery pulses.
- The applications of these diodes are in higher order multipliers and in pulse shaper circuits. The cut-off frequency of these diodes is very high which are nearly at Giga hertz order.
- As multiplier this diode has the cut-off frequency range of 200 to 300 GHz. In the operations which are performing at 10 GHz range these diodes plays a vital role. The efficiency is high for lower order multipliers. The symbol for this diode is as shown below.



Transferred Electron Devices



Gunn diodes are also known as transferred electron devices, TED, are widely used in microwave RF applications for frequencies between 1 and 100 GHz.

The Gunn diode is most commonly used for generating microwave RF signals - these circuits may also be called a transferred electron oscillator or TEO. The Gunn diode may also be used for an amplifier in what may be known as a transferred electron amplifier or TEA.

As Gunn diodes are easy to use, they form a relatively low cost method for generating microwave RF signals.

Gunn diode basics

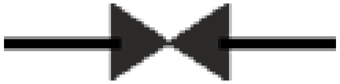
The Gunn diode is a unique component - even though it is called a diode, it does not contain a PN diode junction. The Gunn diode or transferred electron device can be termed a diode because it does have two electrodes. It depends upon the bulk material properties rather than that of a PN junction. The Gunn diode operation depends on the fact that it has a voltage controlled negative resistance.

The mechanism behind the transferred electron effect was first published by Ridley and Watkins in a paper in 1961. Further work was published by Hilsum in 1962, and then in 1963 John Battiscombe (J. B.) Gunn independently observed the first transferred electron oscillation using Gallium Arsenide, GaAs semiconductor.

Gunn Diode

Gunn diode symbol for circuit diagrams

The Gunn diode symbol used in circuit diagrams varies. Often a standard diode is seen in the diagram, however this form of Gunn diode symbol does not indicate the fact that the Gunn diode is not a PN junction. Instead another symbol showing two filled in triangles with points touching is used as shown below.



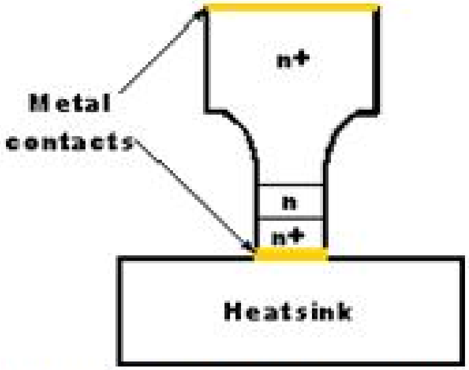
Gunn diode symbol

Gunn diode construction

Gunn diodes are fabricated from a single piece of n-type semiconductor. The most common materials are gallium Arsenide, GaAs and Indium Phosphide, InP. However other materials including Ge, CdTe, InAs, InSb, ZnSe and others have been used. The device is simply an n-type bar with n+ contacts. It is necessary to use n-type material because the transferred electron effect is only applicable to electrons and not holes found in a p-type material.

Within the device there are three main areas, which can be roughly termed the top, middle and bottom areas.

Gunn Diode



A discrete Gunn diode with the active layer mounted onto a heatsink for efficient heat transfer

The most common method of manufacturing a Gunn diode is to grow and epitaxial layer on a degenerate n+ substrate. The active region is between a few microns and a few hundred micron thick. This active layer has a doping level between $10^{14}cm^{-3}$ and $10^{16}cm^{-3}$ - this is considerably less than that used for the top and bottom areas of the device. The thickness will vary according to the frequency required.

The top n+ layer can be deposited epitaxially or doped using ion implantation. Both top and bottom areas of the device are heavily doped to give n+ material. This provides the required high conductivity areas that are needed for the connections to the device.

Devices are normally mounted on a conducting base to which a wire connection is made. The base also acts as a heat sink which is critical for the removal of heat. The connection to the other terminal of the diode is made via a gold connection deposited onto the top surface. Gold is required because of its relative stability and high conductivity.

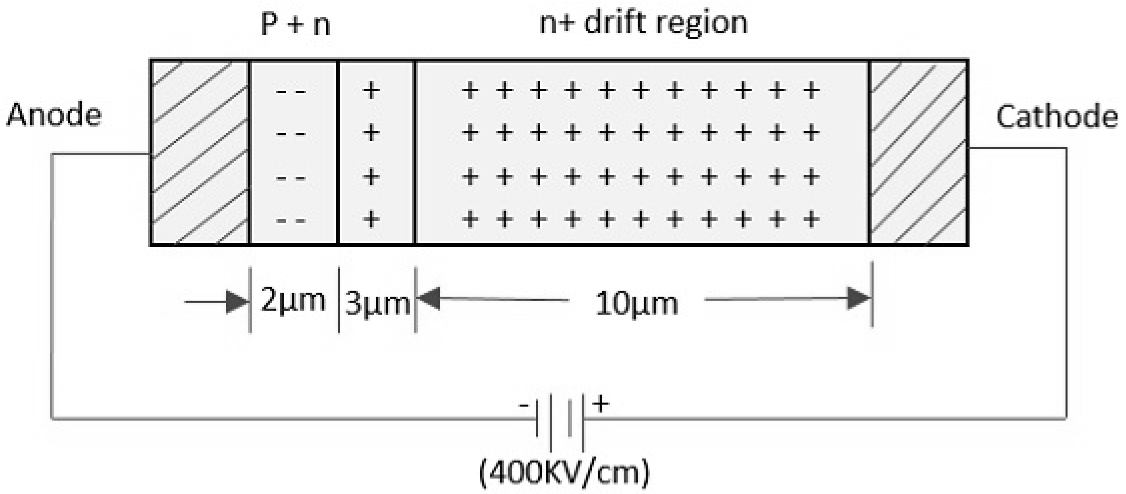
Avalanche transit time devices

- The process of having a delay between voltage and current, in avalanche together with transit time, through the material is said to be Negative resistance. The devices that helps to make a diode exhibit this property are called as **Avalanche transit time devices**.
- The examples of the devices that come under this category are IMPATT, TRAPATT and BARITT diodes. Let us take a look at each of them, in detail.

IMPATT Diode

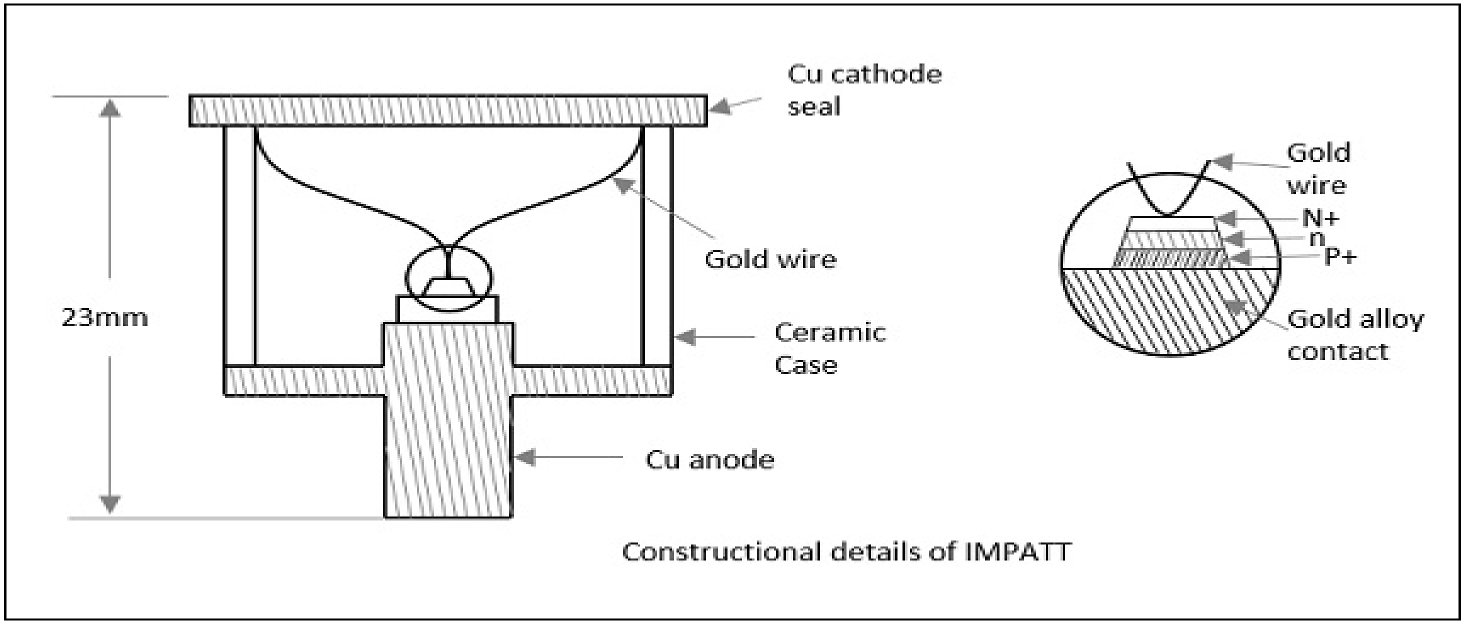
- This is a high-power semiconductor diode, used in high frequency microwave applications. The full form IMPATT is **IMPact ionization Avalanche Transit Time diode**.
- A voltage gradient when applied to the IMPATT diode, results in a high current. A normal diode will eventually breakdown by this. However, IMPATT diode is developed to withstand all this. A high potential gradient is applied to back bias the diode and hence minority carriers flow across the junction.
- Application of a RF AC voltage if superimposed on a high DC voltage, the increased velocity of holes and electrons results in additional holes and electrons by thrashing them out of the crystal structure by Impact ionization. If the original DC field applied was at the threshold of developing this situation, then it leads to the avalanche current multiplication and this process continues. This can be understood by the following figure.

IMPATT Diode



- Due to this effect, the current pulse takes a phase shift of 90°. However, instead of being there, it moves towards cathode due to the reverse bias applied. The time taken for the pulse to reach cathode depends upon the thickness of **n+** layer, which is adjusted to make it 90° phase shift. Now, a dynamic RF negative resistance is proved to exist. Hence, IMPATT diode acts both as an oscillator and an amplifier.

IMPATT Diode



Constructional details of IMPATT

The efficiency of IMPATT diode is represented as
η=[PacPdc]=VaVd[IaId]η=[PacPdc]=VaVd[IaId]
Where,

- PacPac = AC power   Vd&IdVd&Id = DC voltage & current

- PdcPdc = DC power   Va&IaVa&Ia = AC voltage & current

IMPATT Diode

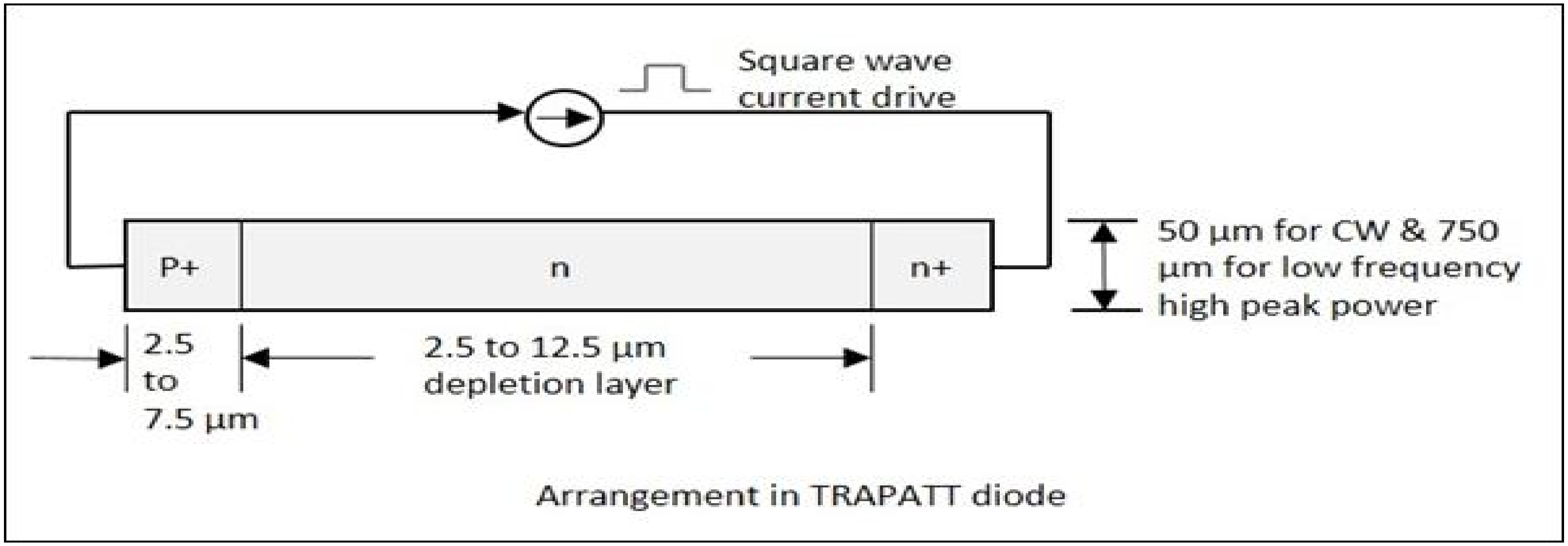
Disadvantages

- Following are the disadvantages of IMPATT diode.
- It is noisy as avalanche is a noisy process
- Tuning range is not as good as in Gunn diodes

Applications

- Following are the applications of IMPATT diode.
- Microwave oscillator
- Microwave generators
- Modulated output oscillator
- Receiver local oscillator
- Negative resistance amplifications
- Intrusion alarm networks (high Q IMPATT)
- Police radar (high Q IMPATT)
- Low power microwave transmitter (high Q IMPATT)
- FM telecom transmitter (low Q IMPATT)
- CW Doppler radar transmitter (low Q IMPATT)

TRAPATT Diode

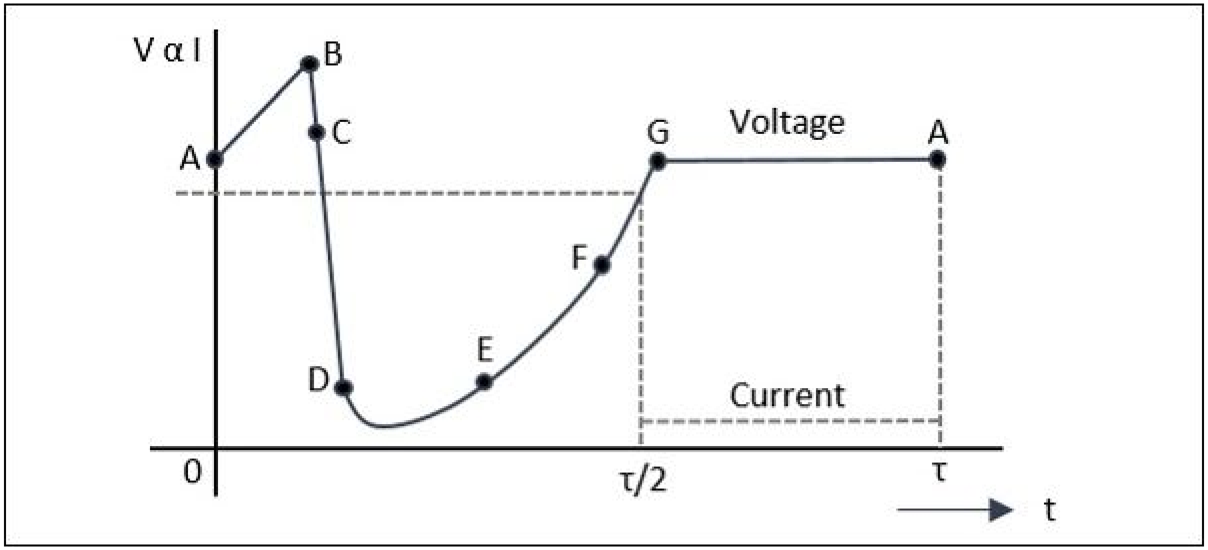


Arrangement in TRAPATT diode

The full form of TRAPATT diode is **TRApped Plasma Avalanche Triggered Transit diode**. A microwave generator which operates between hundreds of MHz to GHz. These are high peak power diodes usually **n+- p-p+** or **p+-n-n+** structures with n-type depletion region, width varying from 2.5 to 1.25 Âµm. The following figure depicts this.

TRAPATT Diode

- The electrons and holes trapped in low field region behind the zone, are made to fill the depletion region in the diode. This is done by a high field avalanche region which propagates through the diode.
- The following figure shows a graph in which AB shows charging, BC shows plasma formation, DE shows plasma extraction, EF shows residual extraction, and FG shows charging. Let us see what happens at each of the points.



TRAPATT Diode

- **A:** The voltage at point A is not sufficient for the avalanche breakdown to occur. At A, charge carriers due to thermal generation results in charging of the diode like a linear capacitance.
- **A-B:** At this point, the magnitude of the electric field increases. When a sufficient number of carriers are generated, the electric field is depressed throughout the depletion region causing the voltage to decrease from B to C.
- **C:** This charge helps the avalanche to continue and a dense plasma of electrons and holes is created. The field is further depressed so as not to let the electrons or holes out of the depletion layer, and traps the remaining plasma.
- **D:** The voltage decreases at point D. A long time is required to clear the plasma as the total plasma charge is large compared to the charge per unit time in the external current.
- **E:** At point E, the plasma is removed. Residual charges of holes and electrons remain each at one end of the deflection layer.

TRAPATT Diode

- **E to F:** The voltage increases as the residual charge is removed.
- **F:** At point F, all the charge generated internally is removed.
- **F to G:** The diode charges like a capacitor.
- **G:** At point G, the diode current comes to zero for half a period. The voltage remains constant as shown in the graph above. This state continues until the current comes back on and the cycle repeats.

The avalanche zone velocity VsVs is represented as

Vs=dxdt=JqNAVs=dxdt=JqNA

Where

JJ = Current density

qq = Electron charge 1.6 x 10^{-19}

NANA = Doping concentration

TRAPATT Diode

The avalanche zone will quickly sweep across most of the diode and the transit time of the carriers is represented as

τs=LVsτs=LVs

Where

VsVs = Saturated carrier drift velocity

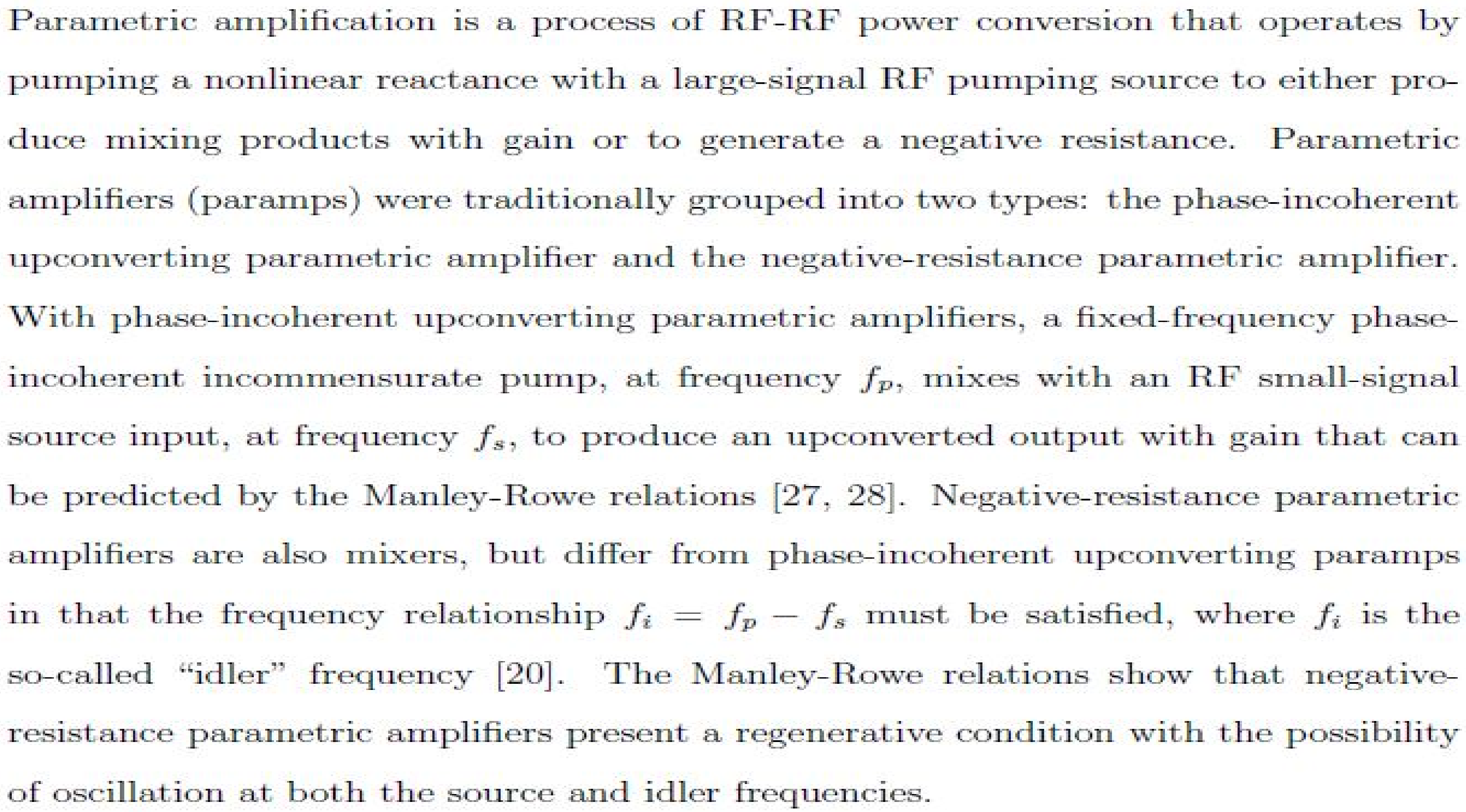
LL = Length of the specimen

The transit time calculated here is the time between the injection and the collection. The repeated action increases the output to make it an amplifier, whereas a microwave low pass filter connected in shunt with the circuit can make it work as an oscillator.

Applications

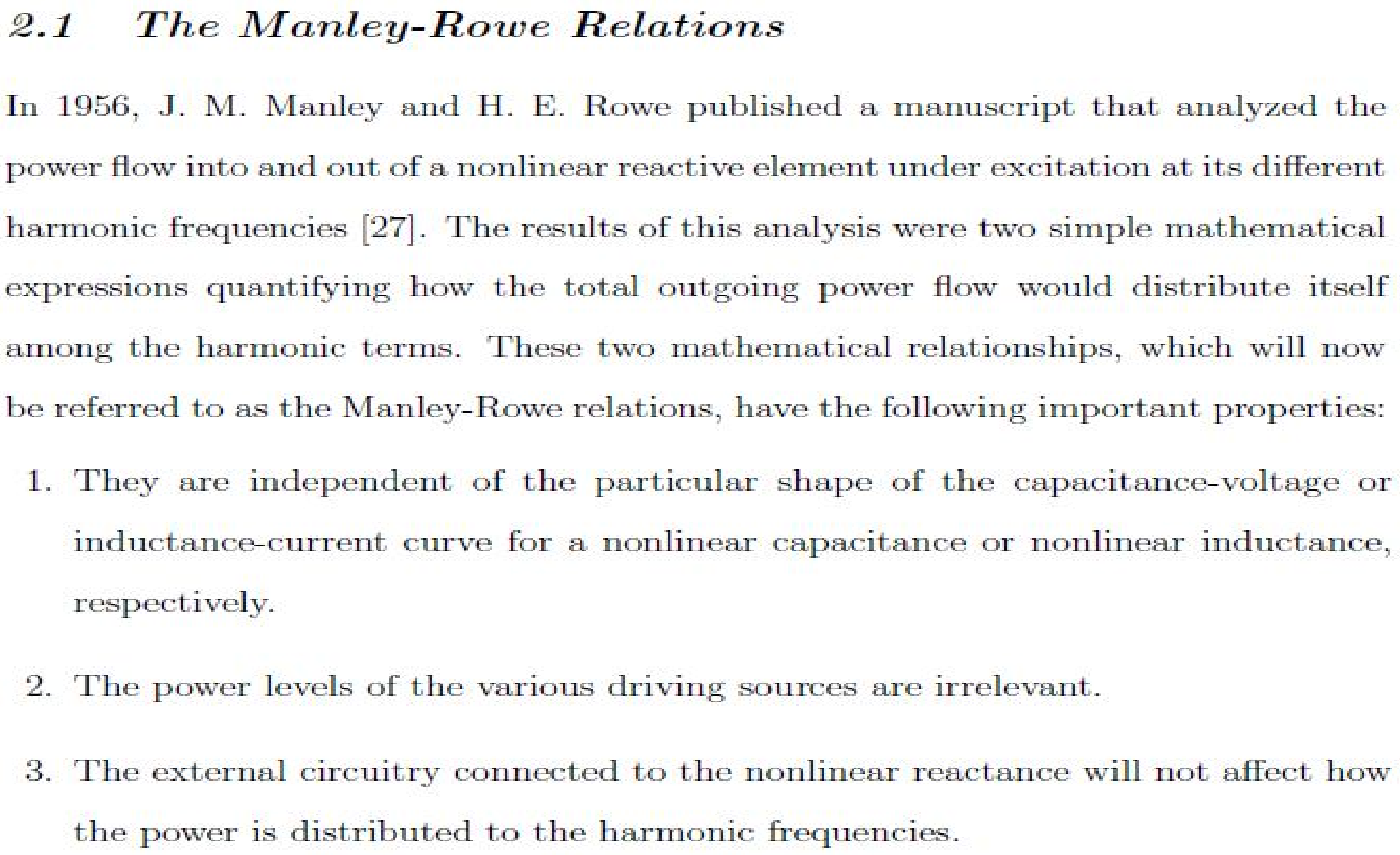
- There are many applications of this diode.
- Low power Doppler radars
- Local oscillator for radars
- Microwave beacon landing system
- Radio altimeter
- Phased array radar, etc.

Parametric Amplifier



Parametric amplification is a process of RF-RF power conversion that operates by pumping a nonlinear reactance with a large-signal RF pumping source to either produce mixing products with gain or to generate a negative resistance. Parametric amplifiers (paramps) were traditionally grouped into two types: the phase-incoherent upconverting parametric amplifier and the negative-resistance parametric amplifier. With phase-incoherent upconverting parametric amplifiers, a fixed-frequency phase-incoherent incommensurate pump, at frequency f_p, mixes with an RF small-signal source input, at frequency f_s, to produce an upconverted output with gain that can be predicted by the Manley-Rowe relations [27, 28]. Negative-resistance parametric amplifiers are also mixers, but differ from phase-incoherent upconverting paramps in that the frequency relationship $f_i = f_p - f_s$ must be satisfied, where f_i is the so-called "idler" frequency [20]. The Manley-Rowe relations show that negative-resistance parametric amplifiers present a regenerative condition with the possibility of oscillation at both the source and idler frequencies.

Parametric Amplifier

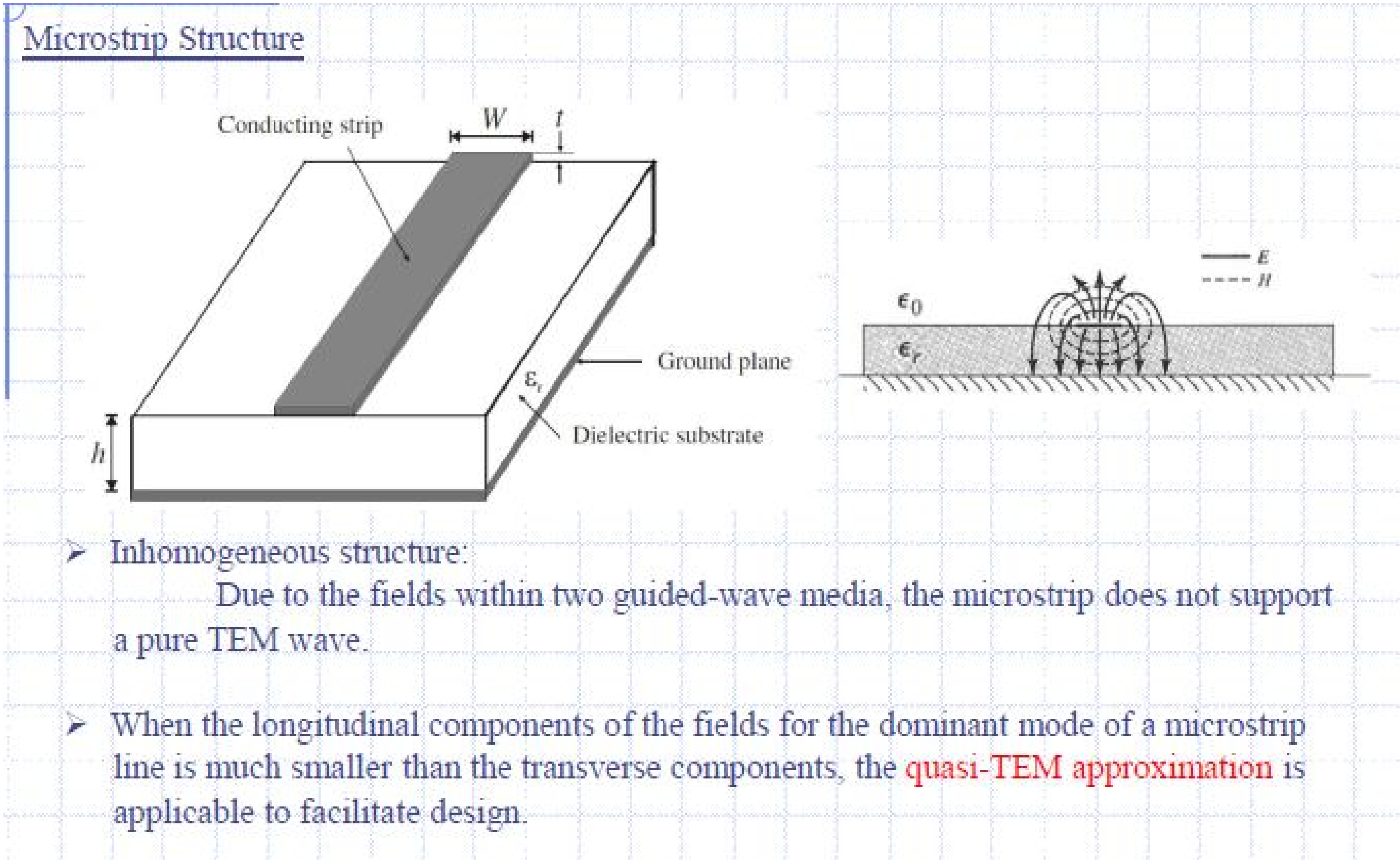


2.1 *The Manley-Rowe Relations*

In 1956, J. M. Manley and H. E. Rowe published a manuscript that analyzed the power flow into and out of a nonlinear reactive element under excitation at its different harmonic frequencies [27]. The results of this analysis were two simple mathematical expressions quantifying how the total outgoing power flow would distribute itself among the harmonic terms. These two mathematical relationships, which will now be referred to as the Manley-Rowe relations, have the following important properties:

1. They are independent of the particular shape of the capacitance-voltage or inductance-current curve for a nonlinear capacitance or nonlinear inductance, respectively.
2. The power levels of the various driving sources are irrelevant.
3. The external circuitry connected to the nonlinear reactance will not affect how the power is distributed to the harmonic frequencies.

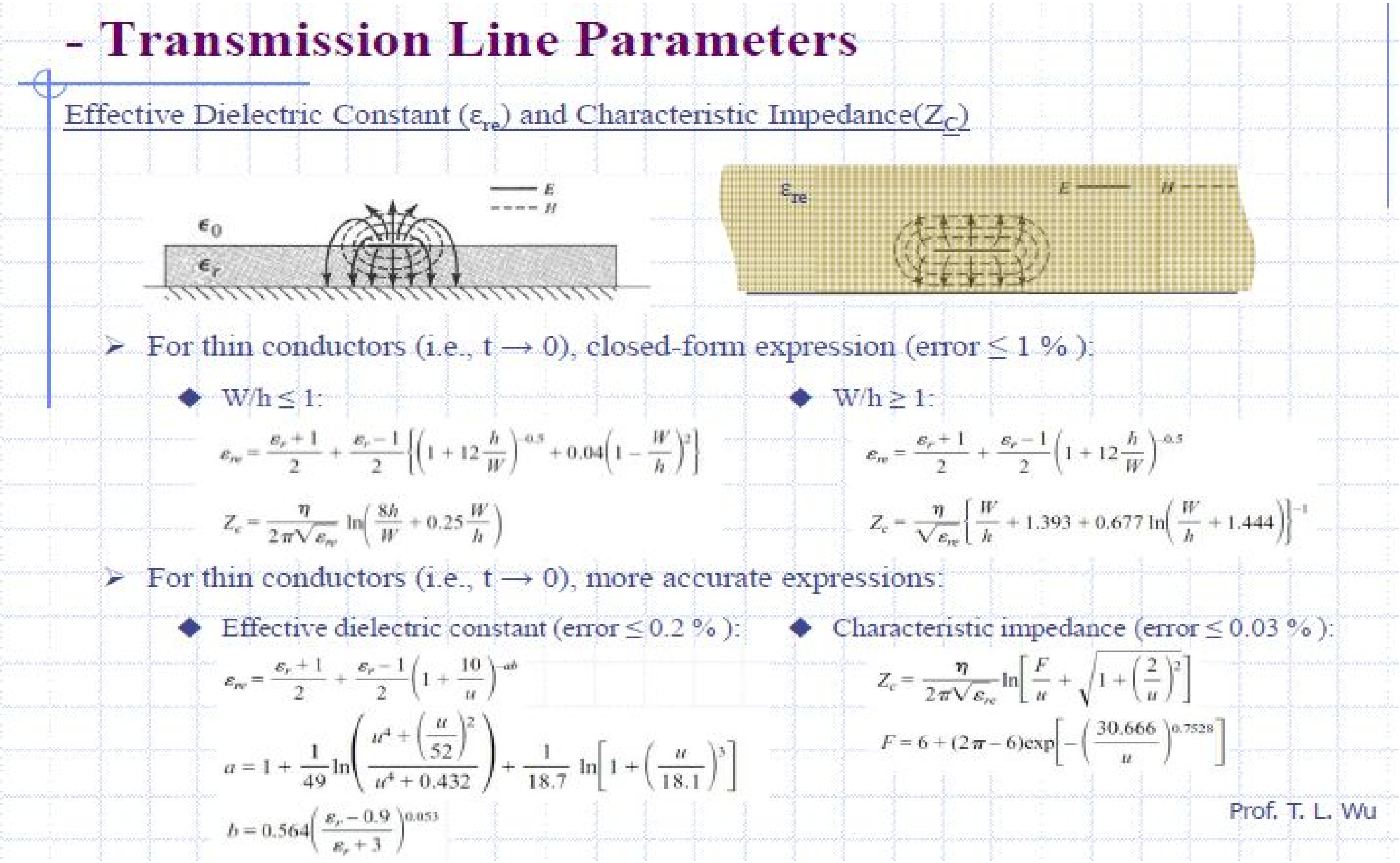
Microstrip lines



Microstrip Structure

- Inhomogeneous structure:
  Due to the fields within two guided-wave media, the microstrip does not support a pure TEM wave.
- When the longitudinal components of the fields for the dominant mode of a microstrip line is much smaller than the transverse components, the quasi-TEM approximation is applicable to facilitate design.

Microstrip lines



- Transmission Line Parameters

Effective Dielectric Constant (ε_{re}) and Characteristic Impedance(Z_C)

- For thin conductors (i.e., t → 0), closed-form expression (error ≤ 1 %):
  - W/h ≤ 1:

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left\{\left(1 + 12\frac{h}{W}\right)^{-0.5} + 0.04\left(1 - \frac{W}{h}\right)^2\right\}$$

$$Z_c = \frac{\eta}{2\pi\sqrt{\varepsilon_{re}}}\ln\left(\frac{8h}{W} + 0.25\frac{W}{h}\right)$$

  - W/h ≥ 1:

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-0.5}$$

$$Z_c = \frac{\eta}{\sqrt{\varepsilon_{re}}}\left\{\frac{W}{h} + 1.393 + 0.677\ln\left(\frac{W}{h} + 1.444\right)\right\}^{-1}$$

- For thin conductors (i.e., t → 0), more accurate expressions:
  - Effective dielectric constant (error ≤ 0.2 %):

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{10}{u}\right)^{-ab}$$

$$a = 1 + \frac{1}{49}\ln\left(\frac{u^4 + \left(\frac{u}{52}\right)^2}{u^4 + 0.432}\right) + \frac{1}{18.7}\ln\left[1 + \left(\frac{u}{18.1}\right)^3\right]$$

$$b = 0.564\left(\frac{\varepsilon_r - 0.9}{\varepsilon_r + 3}\right)^{0.053}$$

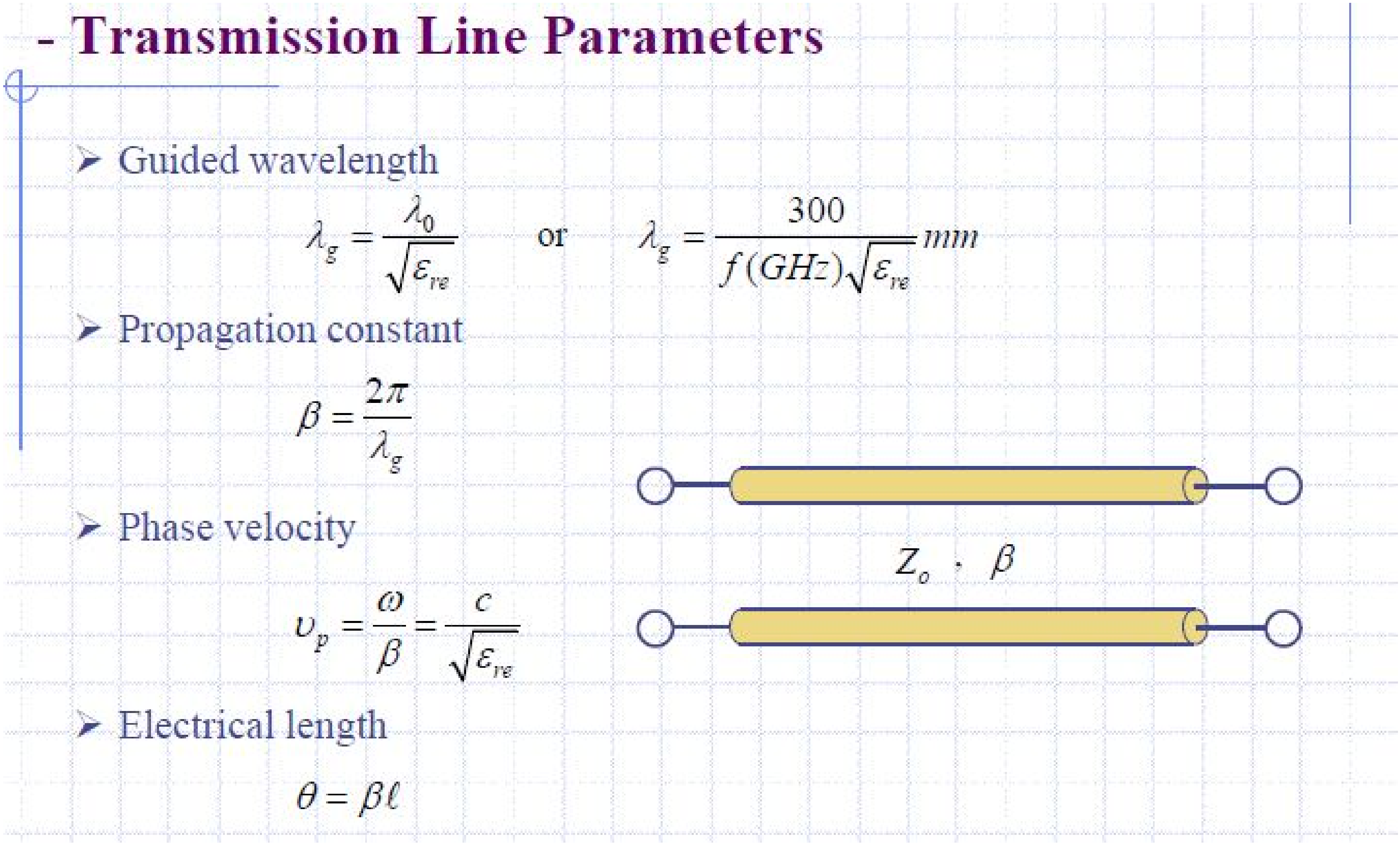
  - Characteristic impedance (error ≤ 0.03 %):

$$Z_c = \frac{\eta}{2\pi\sqrt{\varepsilon_{re}}}\ln\left[\frac{F}{u} + \sqrt{1 + \left(\frac{2}{u}\right)^2}\right]$$

$$F = 6 + (2\pi - 6)\exp\left[-\left(\frac{30.666}{u}\right)^{0.7528}\right]$$

Prof. T. L. Wu

Microstrip lines



- Transmission Line Parameters

- Guided wavelength

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{re}}} \qquad \text{or} \qquad \lambda_g = \frac{300}{f(GHz)\sqrt{\varepsilon_{re}}}\,mm$$

- Propagation constant

$$\beta = \frac{2\pi}{\lambda_g}$$

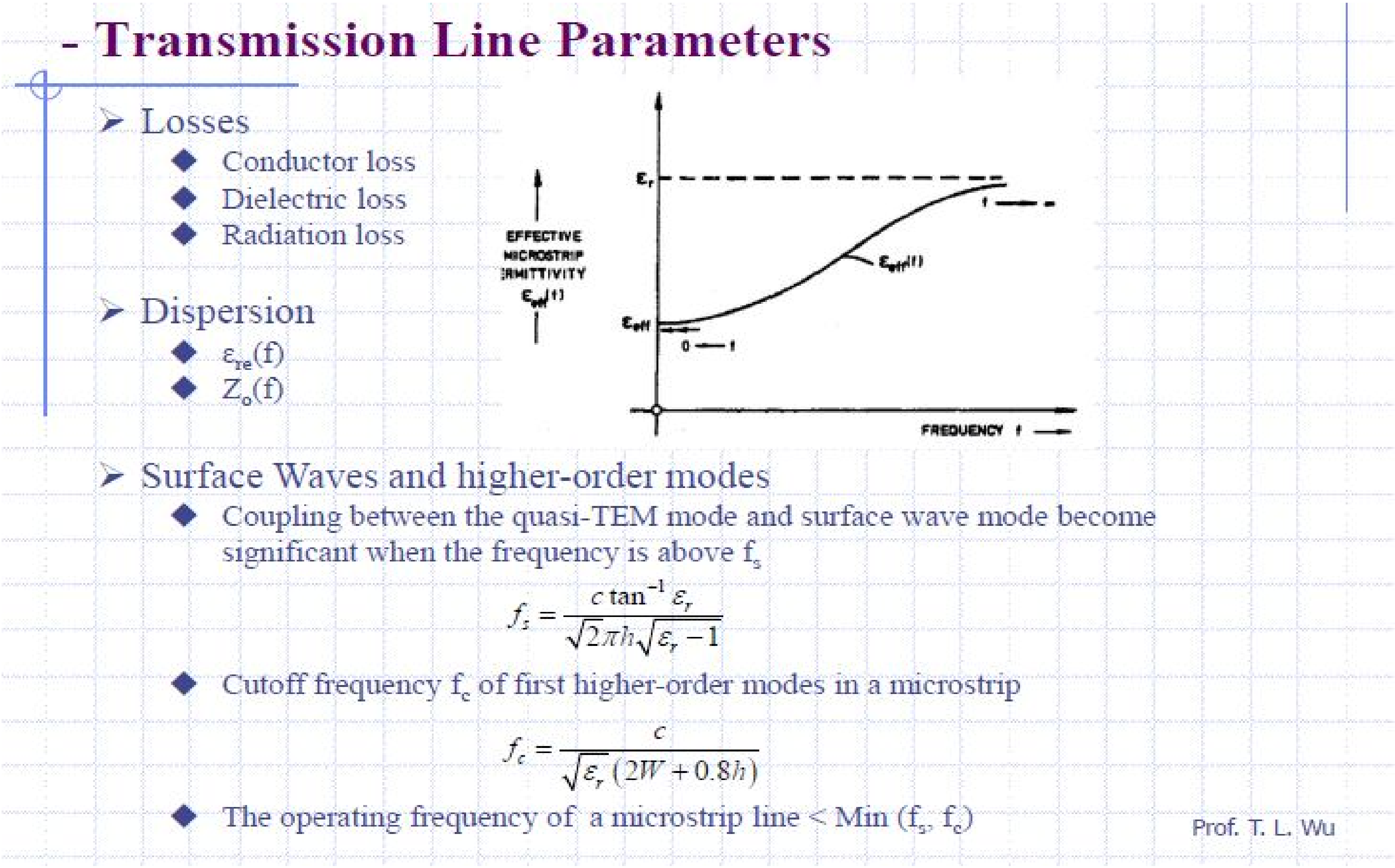
- Phase velocity

$$\upsilon_p = \frac{\omega}{\beta} = \frac{c}{\sqrt{\varepsilon_{re}}}$$

- Electrical length

$$\theta = \beta\ell$$

Microstrip lines



- Transmission Line Parameters

- Losses
  - Conductor loss
  - Dielectric loss
  - Radiation loss
- Dispersion
  - $\varepsilon_{re}(f)$
  - $Z_o(f)$
- Surface Waves and higher-order modes
  - Coupling between the quasi-TEM mode and surface wave mode become significant when the frequency is above f_s

$$f_s = \frac{c \tan^{-1} \varepsilon_r}{\sqrt{2}\pi h \sqrt{\varepsilon_r - 1}}$$

  - Cutoff frequency f_c of first higher-order modes in a microstrip

$$f_c = \frac{c}{\sqrt{\varepsilon_r}(2W + 0.8h)}$$

  - The operating frequency of a microstrip line < Min (f_s, f_c)

Prof. T. L. Wu

Monolithic Microwave Integrated Circuit (MMIC)

- Microwave ICs are the best alternative to conventional waveguide or coaxial circuits, as they are low in weight, small in size, highly reliable and reproducible. The basic materials used for monolithic microwave integrated circuits are −
- Substrate material
- Conductor material
- Dielectric films
- Resistive films
- These are so chosen to have ideal characteristics and high efficiency. The substrate on which circuit elements are fabricated is important as the dielectric constant of the material should be high with low dissipation factor, along with other ideal characteristics. The substrate materials used are GaAs, Ferrite/garnet, Aluminum, beryllium, glass and rutile.

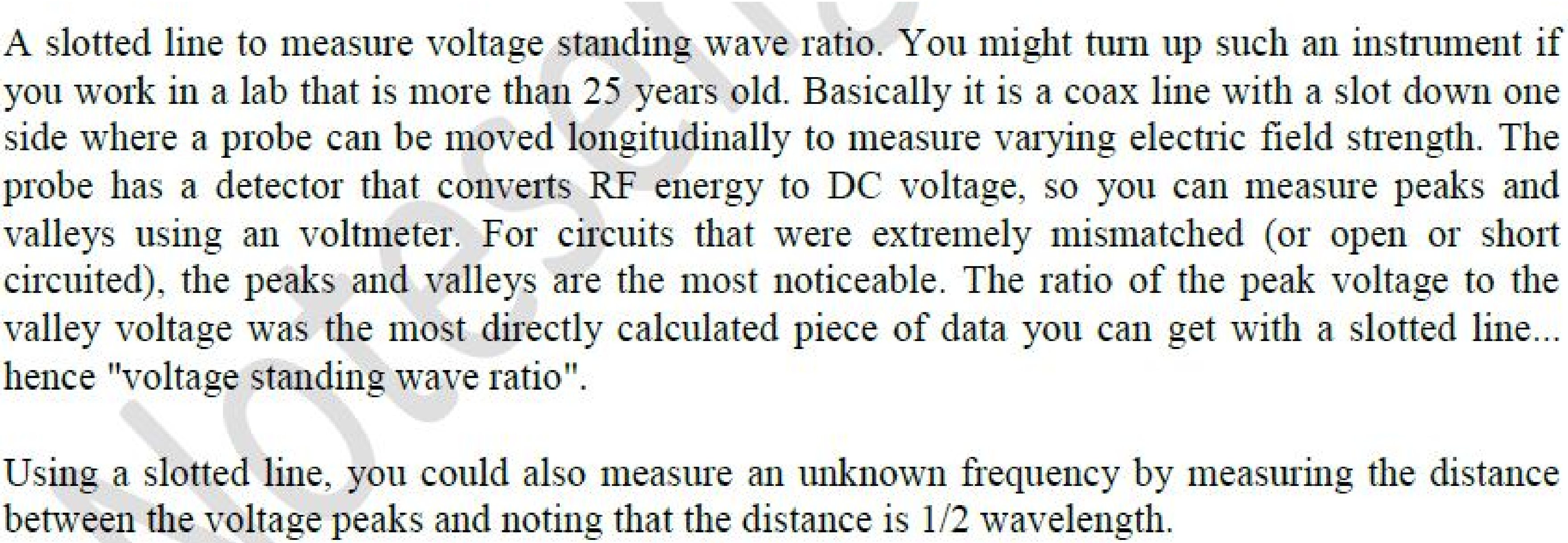
Monolithic Microwave Integrated Circuit (MMIC)

- The conductor material is so chosen to have high conductivity, low temperature coefficient of resistance, good adhesion to substrate and etching, etc. Aluminum, copper, gold, and silver are mainly used as conductor materials. The dielectric materials and resistive materials are so chosen to have low loss and good stability.
- Fabrication Technology
- In hybrid integrated circuits, the semiconductor devices and passive circuit elements are formed on a dielectric substrate. The passive circuits are either distributed or lumped elements, or a combination of both.
- Hybrid integrated circuits are of two types.
- Hybrid IC
- Miniature Hybrid IC
- In both the above processes, Hybrid IC uses the distributed circuit elements that are fabricated on IC using a single layer metallization technique, whereas Miniature hybrid IC uses multi-level elements.
- Most analog circuits use meso-isolation technology to isolate active n-type areas used for FETs and diodes. Planar circuits are fabricated by implanting ions into semi-insulating substrate, and to provide isolation the areas are masked off.

UNIT V MICROWAVE MEASUREMENTS

Introduction – Slotted line carriage — Spectrum analyzer – Network analyzer – Power measurements – Schottky barrier diode sensor –Bolometer sensor – Power sensor – High power measurement – Insertion loss and attenuation measurement – VSWR measurement – Low and high VSWR – Impedance measurement – Frequency measurement – Measurement of cavity Q – Dielectric measurement of a solid by wave-guide method – Antenna measurement – Radiation pattern – Phase and gain.

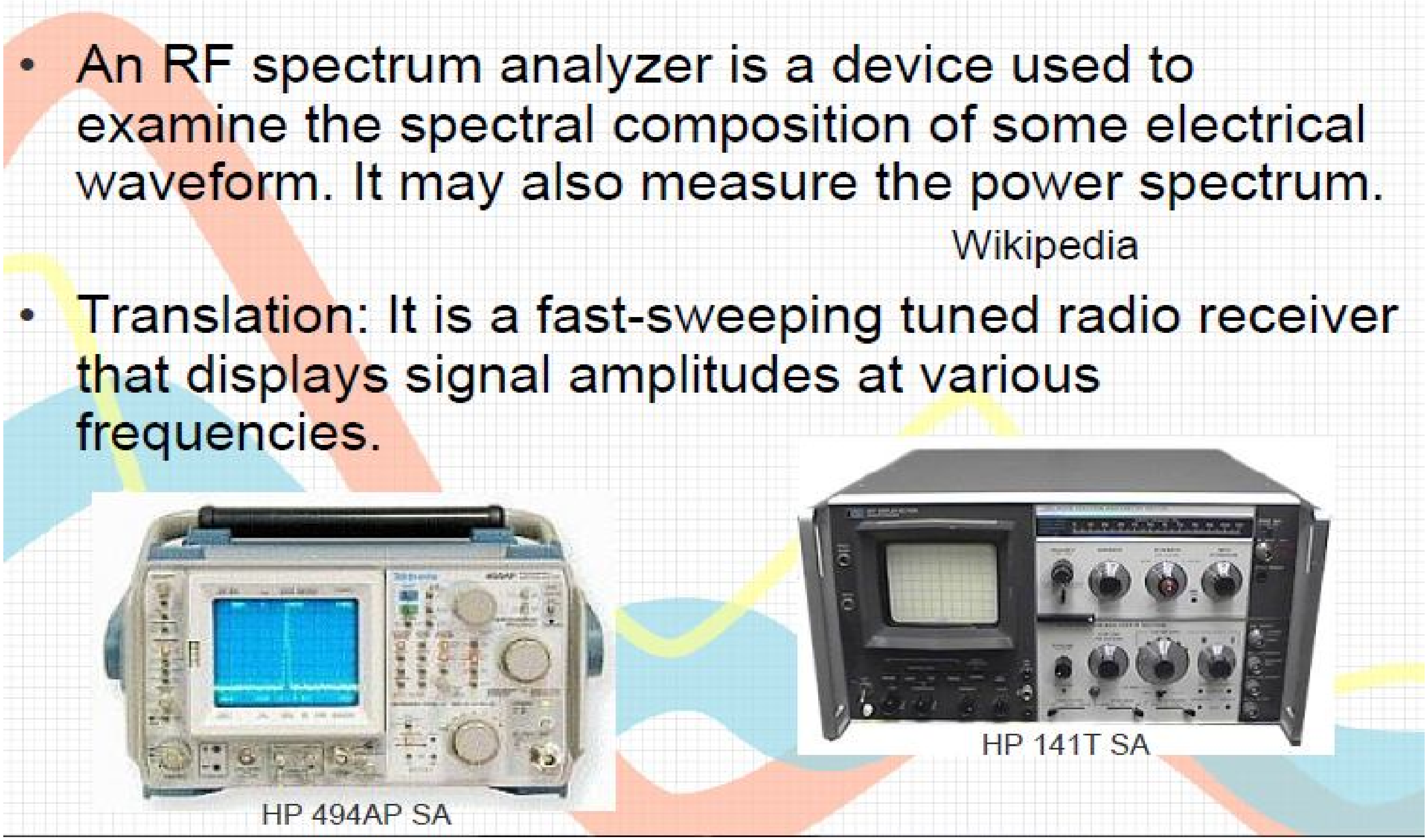
Slotted Line carriage



A slotted line to measure voltage standing wave ratio. You might turn up such an instrument if you work in a lab that is more than 25 years old. Basically it is a coax line with a slot down one side where a probe can be moved longitudinally to measure varying electric field strength. The probe has a detector that converts RF energy to DC voltage, so you can measure peaks and valleys using an voltmeter. For circuits that were extremely mismatched (or open or short circuited), the peaks and valleys are the most noticeable. The ratio of the peak voltage to the valley voltage was the most directly calculated piece of data you can get with a slotted line... hence "voltage standing wave ratio".

Using a slotted line, you could also measure an unknown frequency by measuring the distance between the voltage peaks and noting that the distance is 1/2 wavelength.

Spectrum Analyzer



- An RF spectrum analyzer is a device used to examine the spectral composition of some electrical waveform. It may also measure the power spectrum.

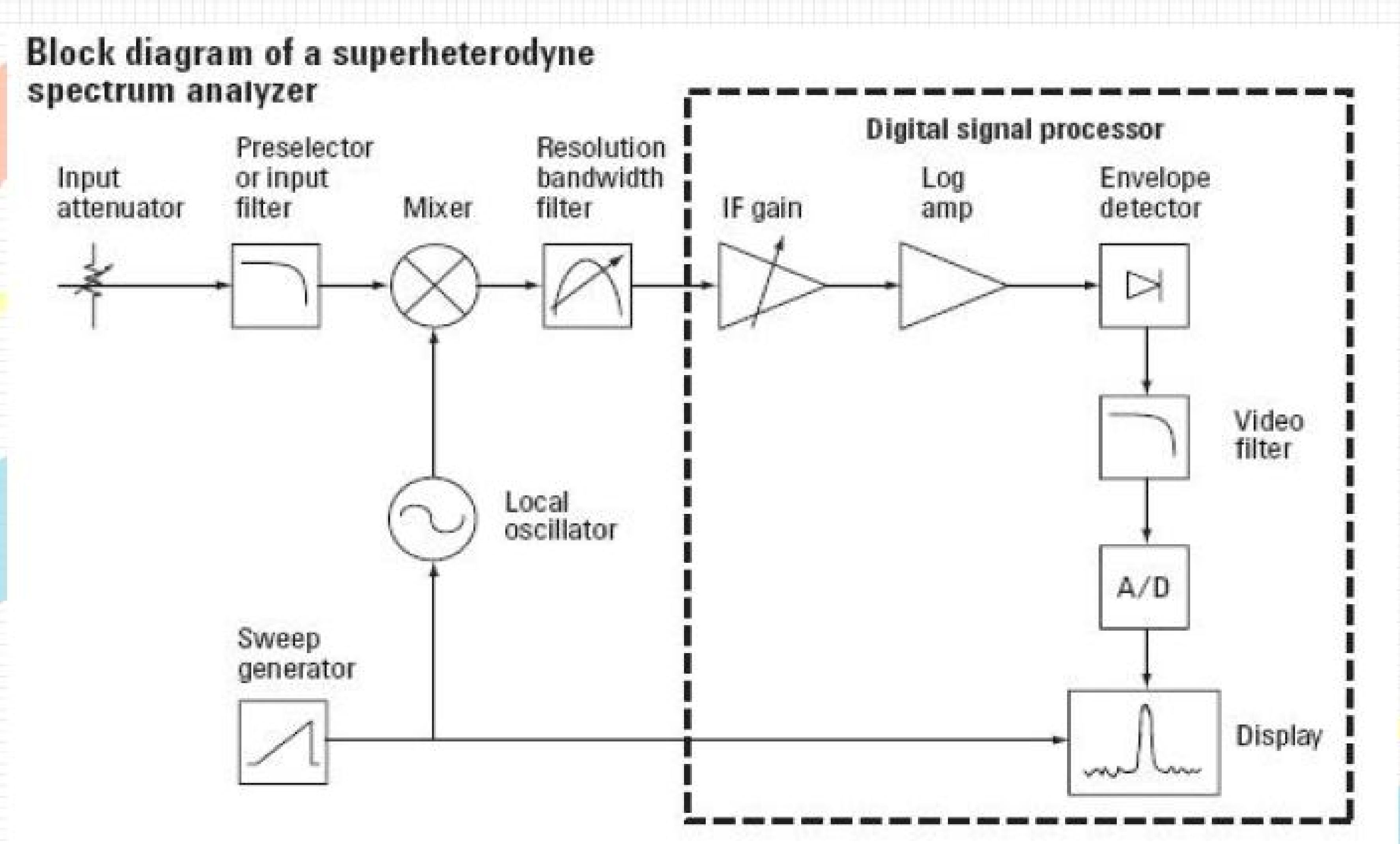
  Wikipedia

- Translation: It is a fast-sweeping tuned radio receiver that displays signal amplitudes at various frequencies.

HP 494AP SA

HP 141T SA

Spectrum Analyzer



Buying a Spectrum Analyzer?

- Prices vary from ~ hundreds$ to thousands$.
- Good for general purpose experimenting and test. For example, required for cavity duplexer adjustment.
- CRT Trace Storage capability is a must.
- Addition of Tracking generator is a wise move.
- It is nice to be able to capture the plots. Need 1980's grade (GP-IB bus). Otherwise take screen pictures.
- The HP-141T mainframe SA is good entry point.
- Lab-Grade units keep their value.

Two Types of Spectrum Analyzers

- Swept
  - Traditional Heterodyne design.
  - The most popular and least costly
  - Has wider frequency coverage (GHz...)
  - Has limitations in capturing bursty or complex events
  - Provides only amplitude information
- Real-Time (Fourier Transform)
  - RF samples are taken by ADC in the time domain
  - Fourier Transform and other post-processing (math) is applied to the samples at various frequency bins.
  - Is much better in capturing complex or fast changing signals
  - Provides both amplitude and phase info, thanks to FFT
  - Has frequency range limited by ADC.
  - More costly

Network Analyzer - Definition

- An instrument used to analyze the properties of electrical networks, especially those properties associated with the reflection and transmission of electrical signals known as scattering parameters (S-parameters). Wikipedia
- Translation: It is a fast-sweeping tuned or wideband radio receiver that displays relative signal amplitudes (and optionally phases) when compared to a reference at various frequencies.

HP 8505A VNA

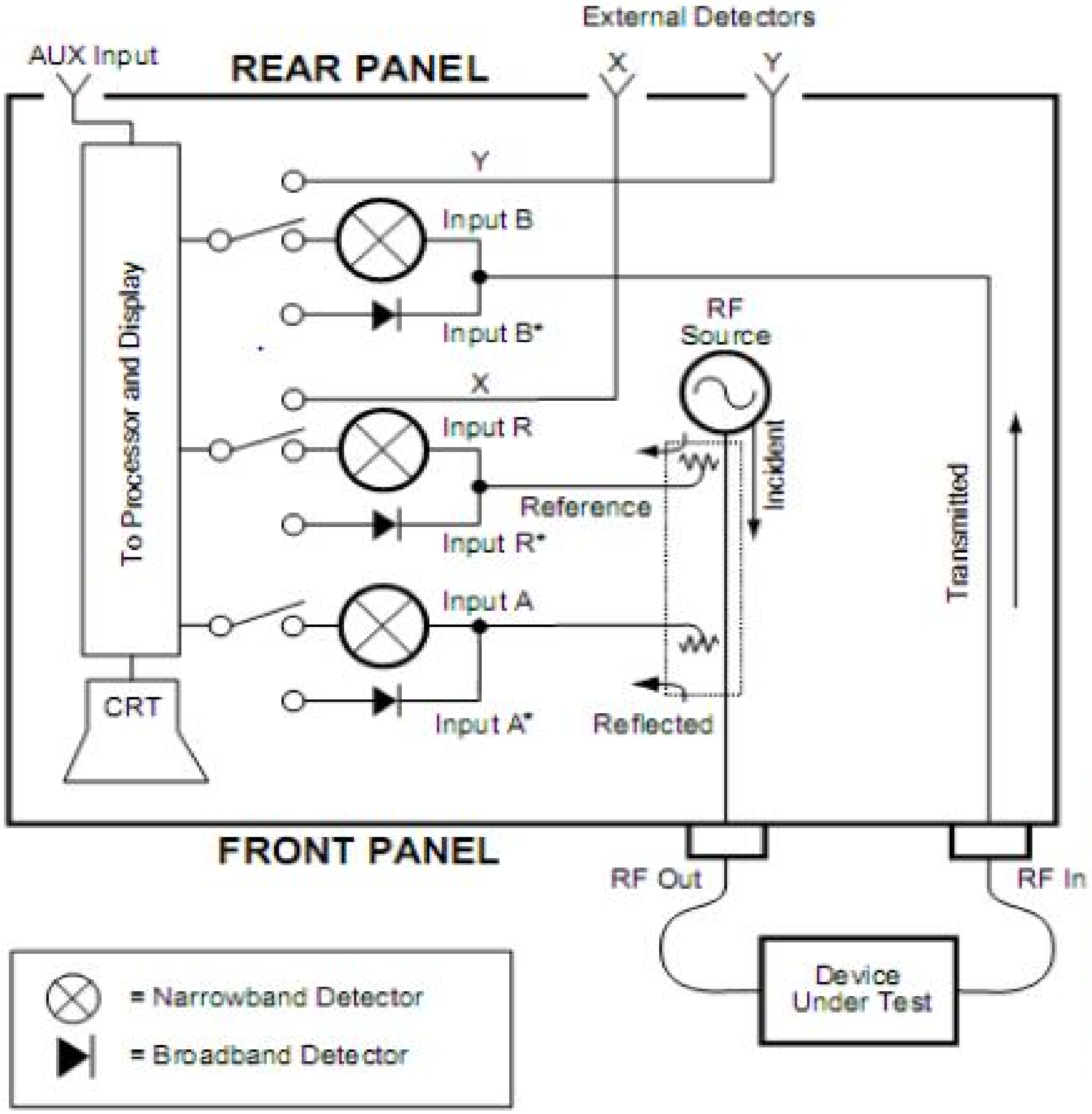
Network Analyzer – Two Types

- Scalar Network Analyzer (SNA)
  - Measures amplitude properties only. Simpler design ($)
  - Usually requires an external sweeping RF source
  - May have external RF detectors
- Vector Network Analyzer (VNA)
  - Measures both amplitude and phase properties with greater dynamic range and accuracy. Complex unit ($$$)
  - Has built-in sweeping RF source (generally)
  - Has built-in Tuned RF receiver

Wiltron 560 SNA

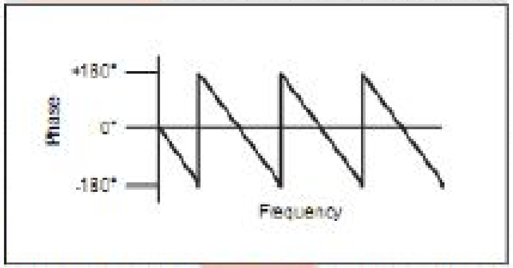
HP 8753C VNA

Network Analyzer – Block Diagram

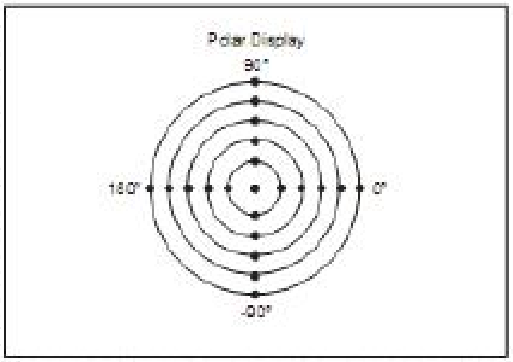


Vector Network Analyzers

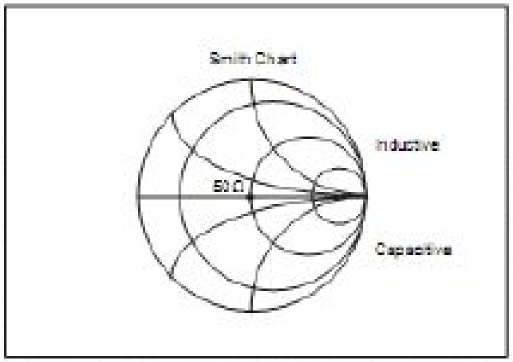
- Can display data in various forms



Linear Phase with Frequency

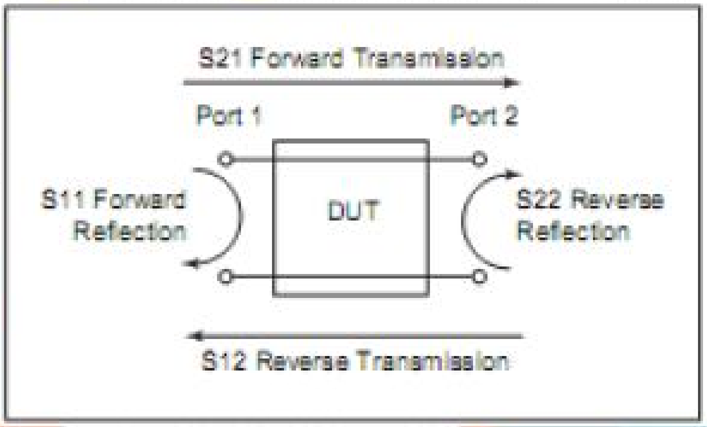


Polar Plot



Smith Chart

- Can usually express results in the form of S-parameters directly.
  - Completely characterize a one-port or two-port linear or passive device



Buying a Network Analyzer?

- Classic VNAs are expensive (min. 1000$). Keep their value.
- SNA....Better off with SA and Tracking Generator.
- Cheaper newer models available (use the computer for display/control). Not as broadband, not as accurate as classic lab-grade VNAs. Require a PC.
  - MiniVNA, max. 180MHz
  - N2PK Vector Network Analyzer, max. 60MHz, a kit.
  - VNA 2180, max. 180MHz
- Antenna Analyzers, a possibility...Limited in frequency and measurement range, accuracy, but are small and can be connected up at the antenna feedpoint.
  - MFJ-269, HF, VHF, UHF
  - AEA CIA-HF, HF
  - Autek RF-1, HF only

POWER MEASUREMENT

- Power is defined as the quantity of energy dissipated or stored per unit time.
- Methods of measurement of power depend on the frequency of operation, levels of power and whether the power is continuous or pulsed.
- The range of microwave power is divided into three categories :-

  i. Low power (< 10mW @ 0dBm)

  ii. Medium power (from 10 mW - 10 W @ 0 – 40 dBm)

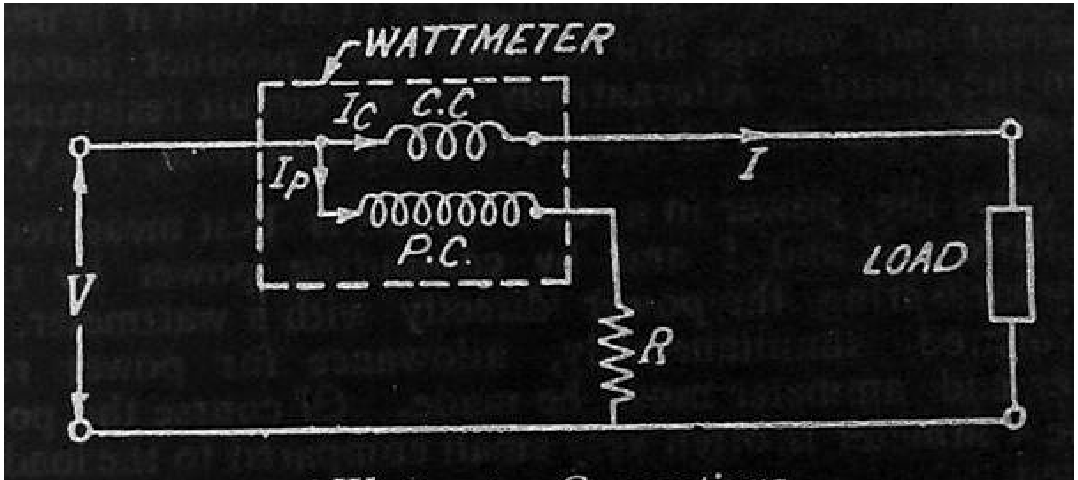
  iii. High power (> 10 W @ 40 dBm)
- The microwave power meter consists of a power sensor, which converts the microwave power to heat energy.
- The sensors used for power measurements are the Schottky barrier diode, bolometer and the thermocouple.

Power Measurement

- Power may be defined as the rate at which energy is transformed oe made available
- In almost all cases the power in a d.c. circuit is best measured by separately measuring quantities, V and I and by computing P=VI
- In case of a.c. circuits the instantaneous power varies continuously as the current and voltage go through a cycle of values
- The fact that the power factor is involved in the expression for the power means that a wattmeter must be used instead of merely an ammeter and voltmeter.

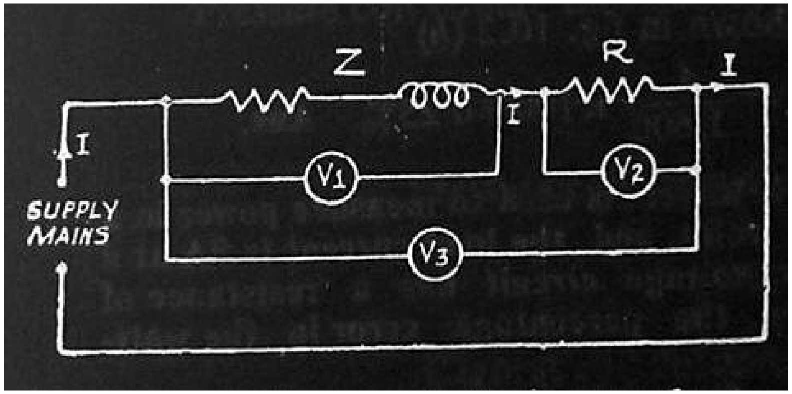
Wattmeter

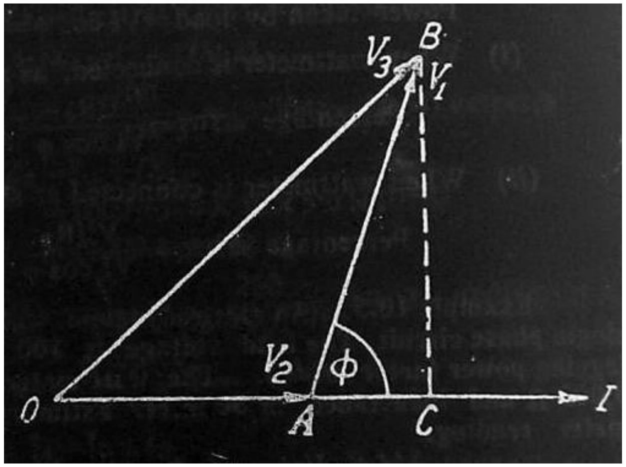
- A wattmeter is essentially an inherent combination of an ammeter and a voltmeter and, therefore , consists of two coils known as *current coil* and *pressure coil*.
- Wattmeter connection:



Wattmeter-Connections

Measurement of Power in Single Phase A.C. Circuit

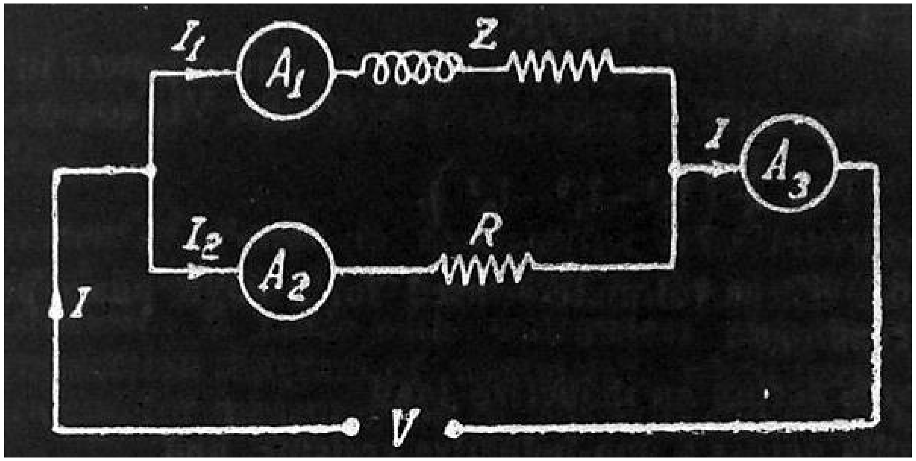


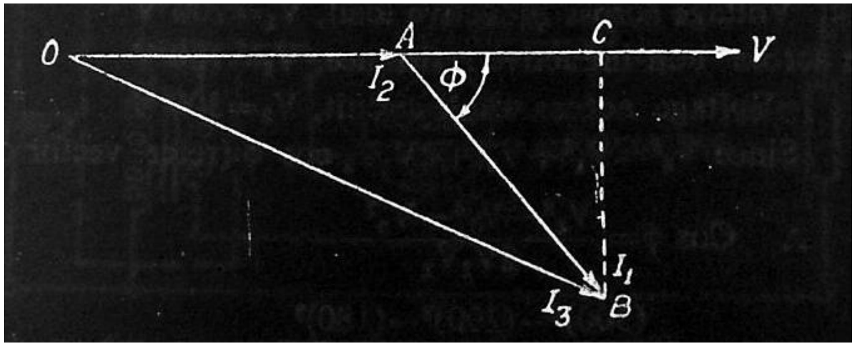


- 3-voltmeter method

$$P = \frac{V_3^2 - V_1^2 - V_2^2}{2R} \qquad \cos\varphi = \frac{V_3^2 - V_1^2 - V_2^2}{2V_1V_2}$$

- Disadvantages : (i) Even small errors in measurement of voltages may cause serious errors in the value of power, (ii) Supply voltage higher than normal voltage is required





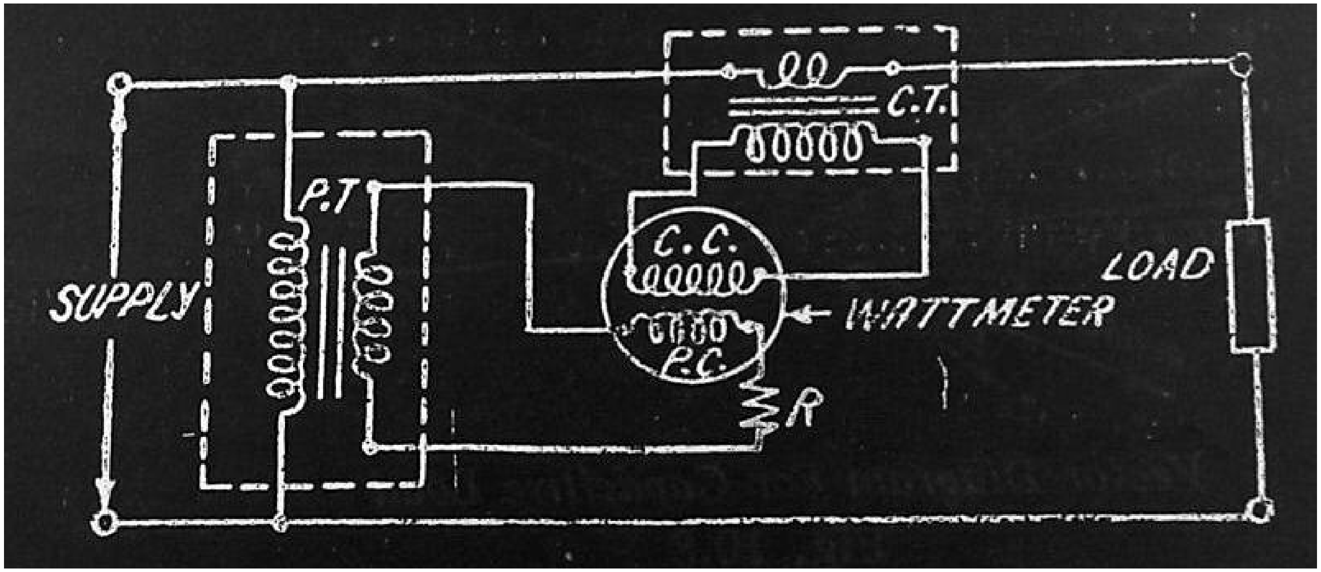
- 3-Ammeter method

$$P = \frac{R}{2}\left(I_3^2 - I_1^2 - I_2^2\right) \qquad \cos\varphi = \frac{I_3^2 - I_1^2 - I_2^2}{2I_1I_2}$$

- The disadvantages of measurement of power by 3 voltmeters are overcome in this method

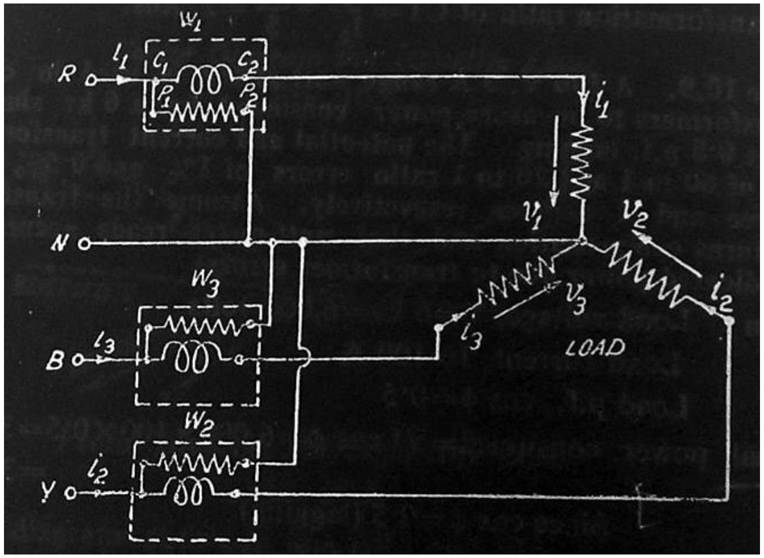
Measurement of power in conjuction with instrument transformers

- This method is used when the currents and voltages of the circuits to be measured are high
- Figure below shows a measurement of power with wattmeter in conjunction with instrument transformers in single phase A.C. circuits

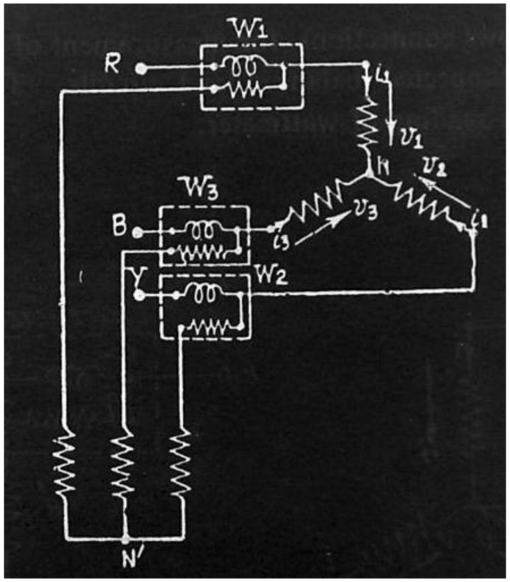


Measurement of Power in 3-Phase Circuit

- Measurement of power in 3-phase, 4-wire circuits-----------→
- $P=W_1+W_2+W_3$



- Measurement of power in 3-phase, 3-wire circuits-------------→
- $P=W_1+W_2+W_3$



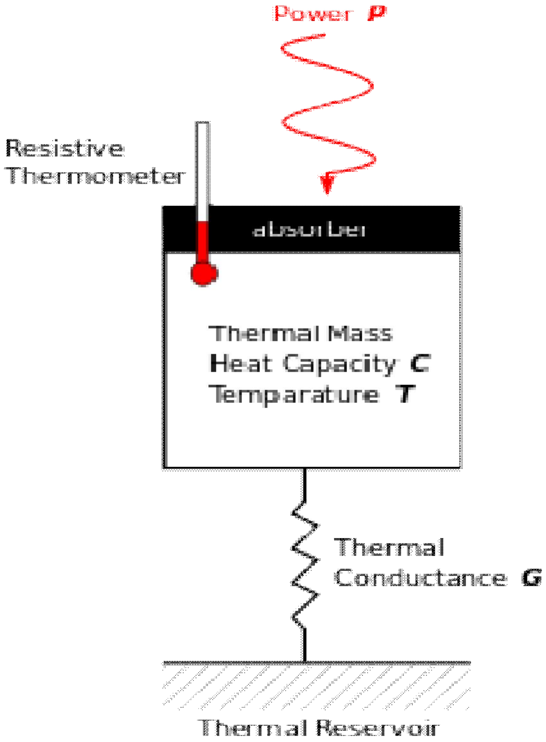
SCHOTTKY BARRIER DIODE

- A zero-biased Schottky Barrier Diode is used as a square-law detector whose output is proportional to the input power.
- The diode detectors can be used to measure power levels as low as 70dBm.

BOLOMETERS

- A Bolometer is a power sensor whose resistance changes with temperature as it absorbs microwave power.
- Are power detectors that operate on thermal principles. Since the temperature of the resistance is dependent on the signal power absorbed, the resistance must also be in proportion to the signal power.
- The two most common types of bolometer are, the barretter and the thermistor. Both are sensitive power detectors and is used to indicate microwatts of power. They are used with bridge circuits to convert resistance to power using a meter or other indicating devices.

BOLOMETER


Power P
Resistive Thermometer
absorber
Thermal Mass
Heat Capacity C
Temparature T
Thermal Conductance G
Thermal Reservoir

Power in DC circuits

- Power

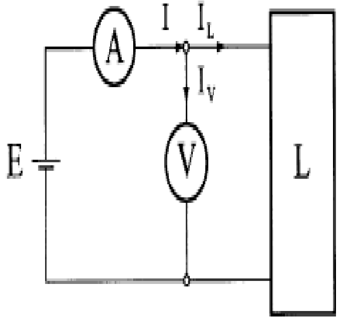
$$P = I_L V_L$$

- Can be carried out using a voltmeter and an ammeter (generally)
- Two measurement arrangements
- Wattmeters:
  - Dynamometer
  - Digital wattmeter
  - Thermal wattmeter
  - Hall-power meter

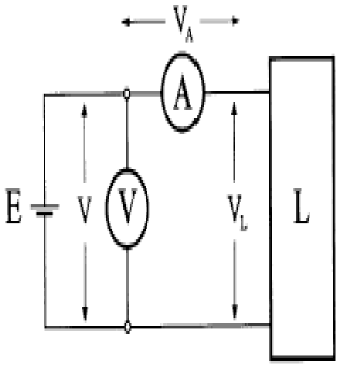
DC circuits

a) Ammeter measures current which flow into the voltmeter and load

b) Voltmeter measures voltage drop across the ammeter in addition to that dropping across the load



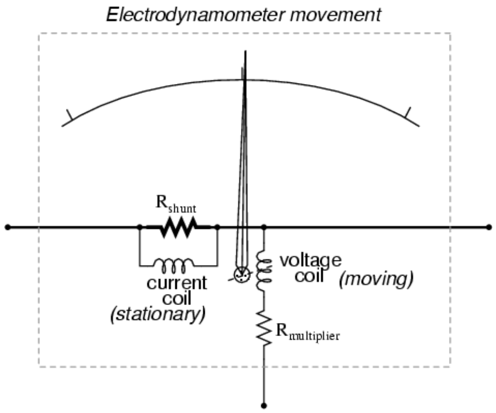
(a)



(b)

Dynamometer

- Power (direct) measurement device for DC and AC systems
- Accuracy better than 0,25 %
- Two coils: static and movable
- Torque is proportional product of current in current coil and current in voltage coil



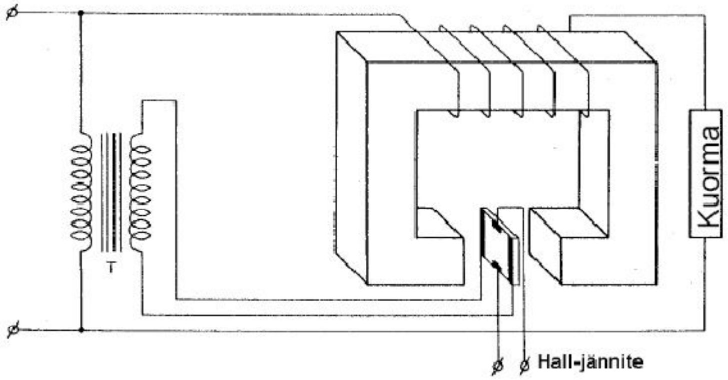
Digital wattmeter (up to 100 kHz)

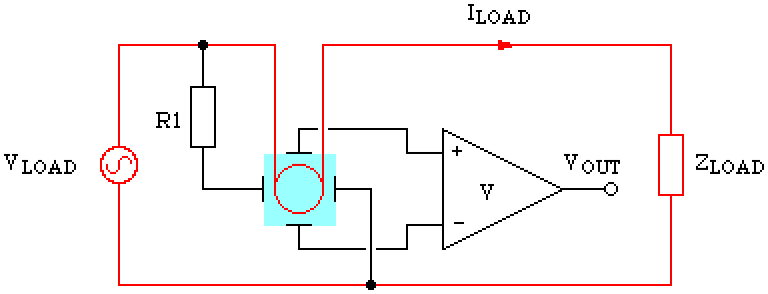
- Advantages:
  - High-resolution
  - Accuracy
- Several techniques (multiplication of signals)
- Electronic multiplier is an analog system which gives as its output a voltage proportional to the power indication required → A/D conversion

Hall-power meter

- Coil generates magnetic field which is proportional to load current
- The sensor excitation current passes through R1 and is proportional to the load voltage

  → Hall voltage is proportional to load power
- Problems: offset and linearity





Circuit 9. Schematic wattmeter based on Hall effect sensor

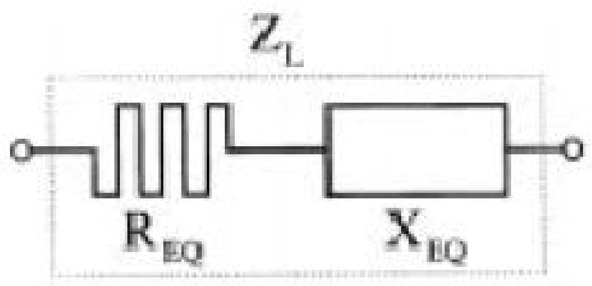
Power in AC circuits

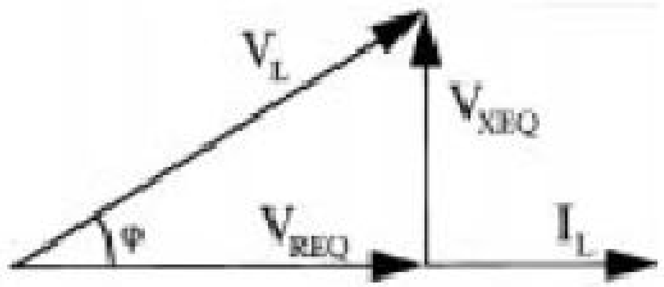
- Instantaneous power (time dependence)
- Mean power (usually the most interesting)
- Real power (active work), reactive power, apparent power
- Measures can be done same way as DC circuit (single-phase)

$$p(t) = v(t)i(t)$$

$$P = \frac{1}{T}\int_0^T p(t)dt$$

AC circuits





$$P = V_L I_L \cos\varphi$$

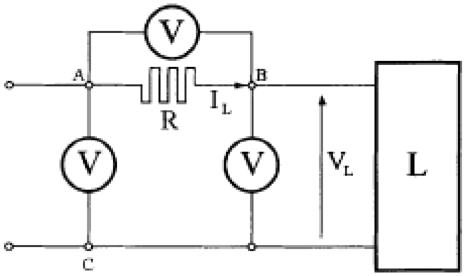
$$Q = V_L I_L \sin\varphi$$

$$S = \sqrt{P^2 + Q^2}$$

Low- and Medium-Frequency Power Measurements

- Three-Voltmeter Method
  - Single-phase arrangements
  - Power in load can be measured using a non-inductive resistor and measuring the three voltage
  - Also in DC circuits

$$P_L = \frac{V_{AC}^2 - V_{AB}^2 - V_{BC}^2}{2R}$$



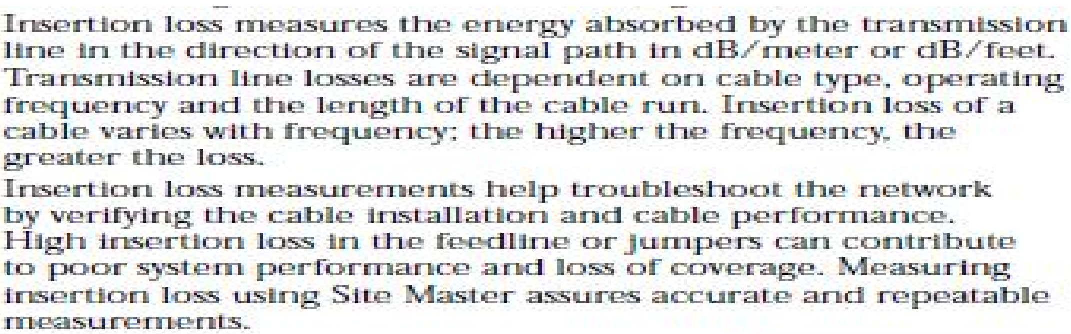
Line-Frequency Power Measurements

- Polyphase Power Measurements
  - Three-phase systems are most commonly used in industrial applications
  - Energy and power generation and distribution
  - “Real power for consumer”
  - Reactive power also important (loading)
  - Power can measured several ways
  - Power factor

Line-Frequency Power Measurements (2)

- Four (main) different cases which affects to the measurement arrangements:
  1. Symmetrical load with neutral conductor
  2. Symmetrical load without neutral conductor
  3. Unsymmetrical load with neutral conductor
  4. Unsymmetrical load without neutral conductor

Insertion Loss



Insertion loss measures the energy absorbed by the transmission line in the direction of the signal path in dB/meter or dB/feet. Transmission line losses are dependent on cable type, operating frequency and the length of the cable run. Insertion loss of a cable varies with frequency; the higher the frequency, the greater the loss.

Insertion loss measurements help troubleshoot the network by verifying the cable installation and cable performance. High insertion loss in the feedline or jumpers can contribute to poor system performance and loss of coverage. Measuring insertion loss using Site Master assures accurate and repeatable measurements.

Insertion Loss Measurement Setup

The insertion loss measurement set up for a typical transmission feed line system is shown in Figure 2. Remove the antenna and connect an enclosed precision "short" at the end of the transmission line.

If a Tower Mounted Amplifier (TMA) is in the transmission feed line system, remove the TMA and antenna and connect an enclosed short at the end of the transmission line. Insertion loss measurement for a transmission feed line system with a tower mounted amplifier is shown in Figure 3.

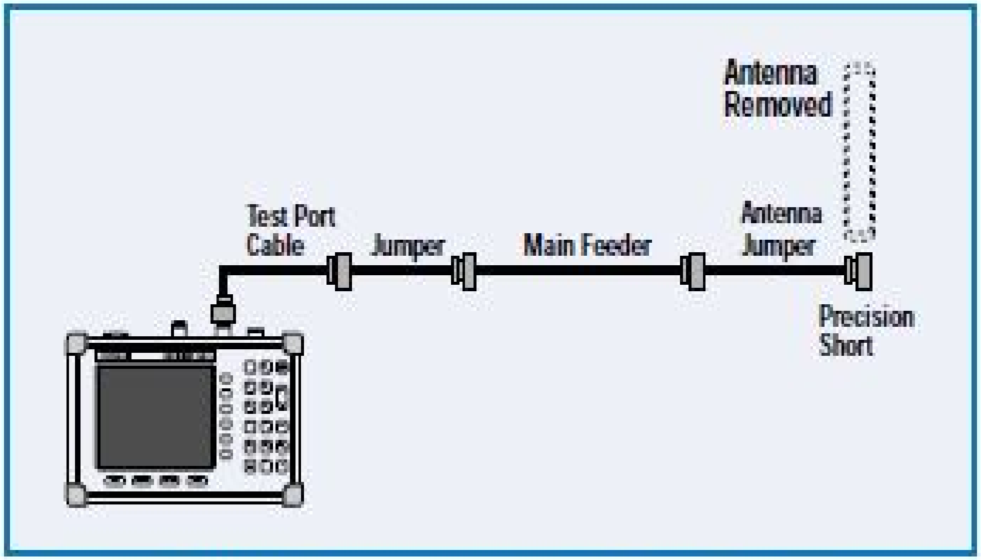
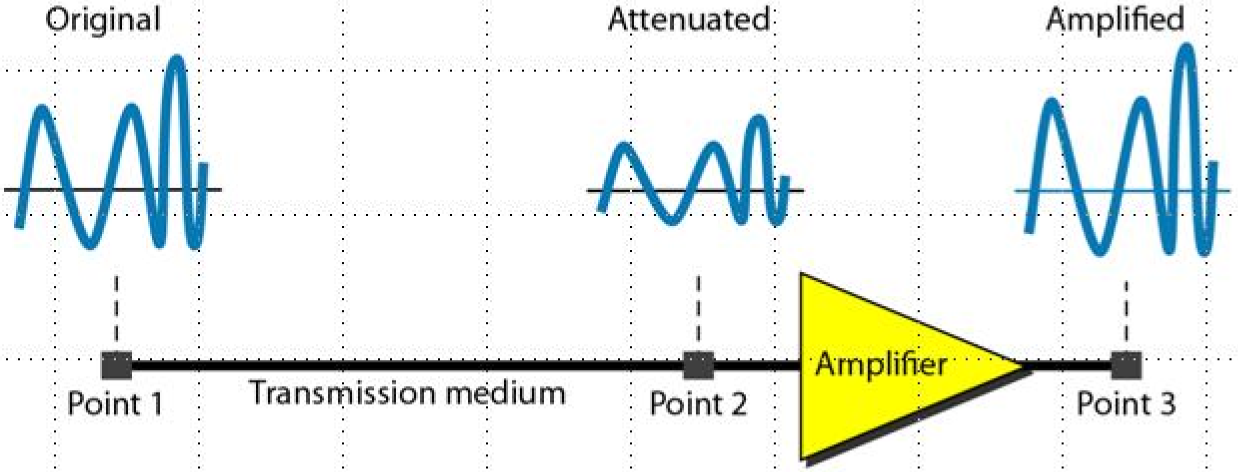


Figure 2. An insertion loss measurement setup after antenna is removed.

Attenuation Measurement

- Means loss of energy -> weaker signal
- When a signal travels through a medium it loses energy overcoming the resistance of the medium
- Amplifiers are used to compensate for this loss of energy by amplifying the signal.



Measurement of Attenuation

- To show the loss or gain of energy the unit "decibel" is used.

$$dB = 10\log_{10}P_2/P_1$$

P_1 - input signal

P_2 - output signal

VSWR Measurement

- VSWR is defined as the ratio of the maximum voltage to the minimum voltage in standing wave pattern along the length of a transmission line structure. It varies from 1 to (plus) infinity and is always positive. Unless you have a piece of slotted line-test equipment this is a hard definition to use, especially since the concept of voltage in a microwave structure has many interpretations.
- Sometimes VSWR is called SWR to avoid using the term voltage and to instead use the concept of power waves. This in turn leads to a mathematical definition of VSWR in terms of a reflection coefficient. A reflection coefficient is defined as the ratio of reflected wave to incident wave at a reference plane. This value varies from -1 (for a shorted load) to +1 (for an open load), and becomes 0 for matched impedance load. It is a complex number. This helps us because we can actually measure power.
-

VSWR Measurement

- The reflection coefficient, commonly denoted by the Greek letter gamma (Γ), can be calculated from the values of the complex load impedance and the transmission line characteristic impedance which in principle could also be a complex number.
- $\Gamma = (Z_l - Z_0)/(Z_l + Z_0)$
- The square of $|\Gamma|$ is then the power of the reflected wave, the square hinting at a historical reference to voltage waves.
- Now we can define VSWR (SWR) as a scalar value:
- VSWR= $(1 + |\Gamma|)/(1 - |\Gamma|)$ or in terms of s-parameters: VSWR= $(1 + |S_{11}|)/(1 - |S_{11}|)$
- This is fine but what has it to do with common usage in ads and specifications. Generally, VSWR is sometimes used as a stand-in for a figure of merit for impedance matching. Sometimes this simplification of a scalar quantity and it's restricted definition can lead to confusion in the matter of a source to load match. Most of the time there is no problem but, technically, VSWR derives from the ratio using the load impedance and the characteristic impedance of the transmission line in which the standing waves reside and not specifically to a source to load match. I prefer to think of VSWR as a figure of merit and to use the reflection coefficient whenever I am trying to solve problems.
- By the way, if you think you have never experienced a standing wave personally, it's very unlikely. Standing waves in a microwave oven are the reason that food is cooked unevenly (the turntable is a partial solution to that problem). The wavelength of the 2.45 GHz signal is about 12 centimeters, or about five inches. Nulls in the radiation (and heating) will be separated at a distance similar to wavelength.

FREQUENCY MEASUREMENT

- The frequency meter used has a cavity which is coupled to the waveguide by a small coupling hole which is used to absorb only a tiny fraction of energy passing along the waveguide.

- Adjusting the micrometer of the Frequency Meter will vary the plunger into the cavity. This will alters the cavity size and hence the resonance frequency.

- The readings on the micrometer scales are calibrated against frequency. As the plunger enters the caviy, its sized is reduced and the frequency increases.

- The wavemeter is adjusted for maximum or minimum power meter readings depending on whether the cavity is a transmission or absorption type device. With the transmission-type device, the power meter will be adjusted for a maximum. It only allows frequency close to resonance to be transmitted through them. Other frequencies are reflected down the waveguide. The wavemeter acts as a short circuit for all other frequencies.

- For the absorption-type wavemeter, the power meter will be adjusted for a minimum. Its absorp power from the line around resonant frequency and act as a short to other frequencies.

- The absorbing material used is to absorb any unwanted signal that will cause disturbance to the system.

VSWR (VOLTAGE STANDING WAVE RATIO) MEASUREMENT

- Used to determine the degree of mismatch between the source and load when the value VSWR ≠ 1.
- Can be measured by using a slotted line. **Direct Method Measurement** is used for VSWR values upto about 10. Its value can be read directly using a standing wave detector .
- The measurement consists simply of adjusting attenuator to give an adequate reading, making sure that the frequency is correct and then using the dc voltmeter to measure the detector output at a maximum on the slotted section and then at the nearest minimum.

The ratio of the voltage maximum to the minimum gives the VSWR i.e

$$\mathbf{VSWR = V_{max} / V_{min}}$$

$$\mathbf{ISWR = I_{max} / I_{min}}$$

$$\mathbf{= k (V_{max})^2 / k (V_{min})^2}$$

$$\mathbf{= (V_{max} / V_{min})^2}$$

$$\mathbf{= VSWR^2}$$

$$\boxed{\mathbf{VSWR = \sqrt{(I_{max} / I_{min})} = \sqrt{ISWR}}}$$

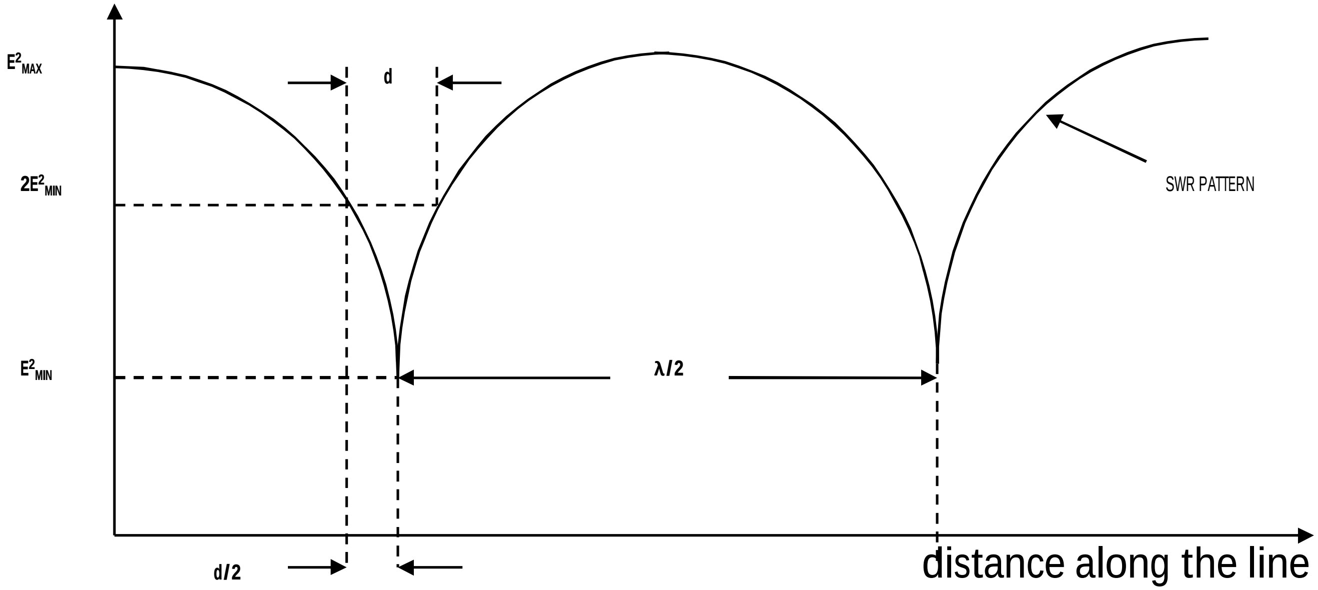
- Methods used depends on the value of VSWR whether it is high or low. If the load is not exactly matched to the line, standing wave pattern is produced.

- Reflections can be measured in terms of voltage, current or power. Measurement using voltage is preffered because it is simplicity.

- When reflection occured, the incident and the reflected waves will reinforce each other in some places, and in others they will tend to cancel each other out.

DOUBLE MINIMUM METHOD MEASUREMENT (VSWR > 10)

- ‘Double Minimum’ method is usually employed for VSWR values greater than about 10.



- The detector output (proportional to field strength squared) is plotted against position. The probe is moved aling the line to find the minimum value of signal.

- It is then moved either side to determine 2 positions at which twice as much detector signal is obtained. The distance d between these two positions then gives the VSWR according to the formula :

$$\mathbf{S = \surd\ 1 + 1/Sin^2(\pi d/\lambda)}$$

POWER MEASUREMENT

- Power is defined as the quantity of energy dissipated or stored per unit time.
- Methods of measurement of power depend on the frequency of operation, levels of power and whether the power is continuous or pulsed.
- The range of microwave power is divided into three categories :-

  i. Low power (< 10mW @ 0dBm)

  ii. Medium power (from 10 mW - 10 W @ 0 – 40 dBm)

  iii. High power (> 10 W @ 40 dBm)
- The microwave power meter consists of a power sensor, which converts the microwave power to heat energy.
- The sensors used for power measurements are the Schottky barrier diode, bolometer and the thermocouple.

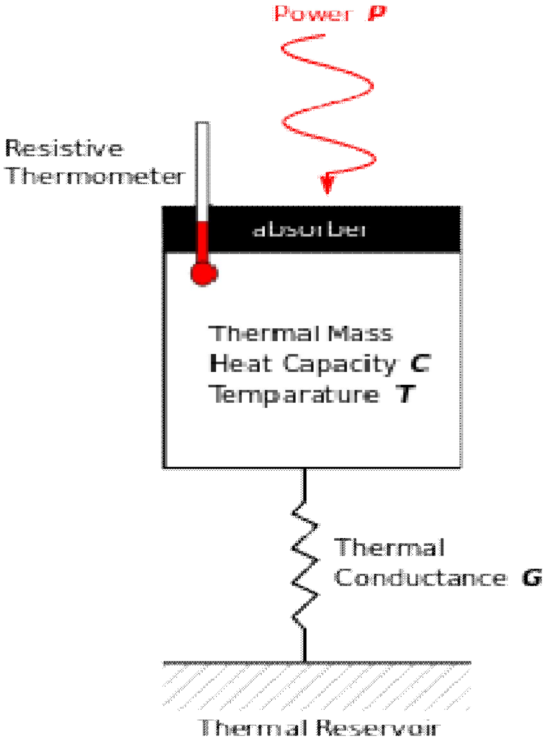
SCHOTTKY BARRIER DIODE

- A zero-biased Schottky Barrier Diode is used as a square-law detector whose output is proportional to the input power.
- The diode detectors can be used to measure power levels as low as 70dBm.

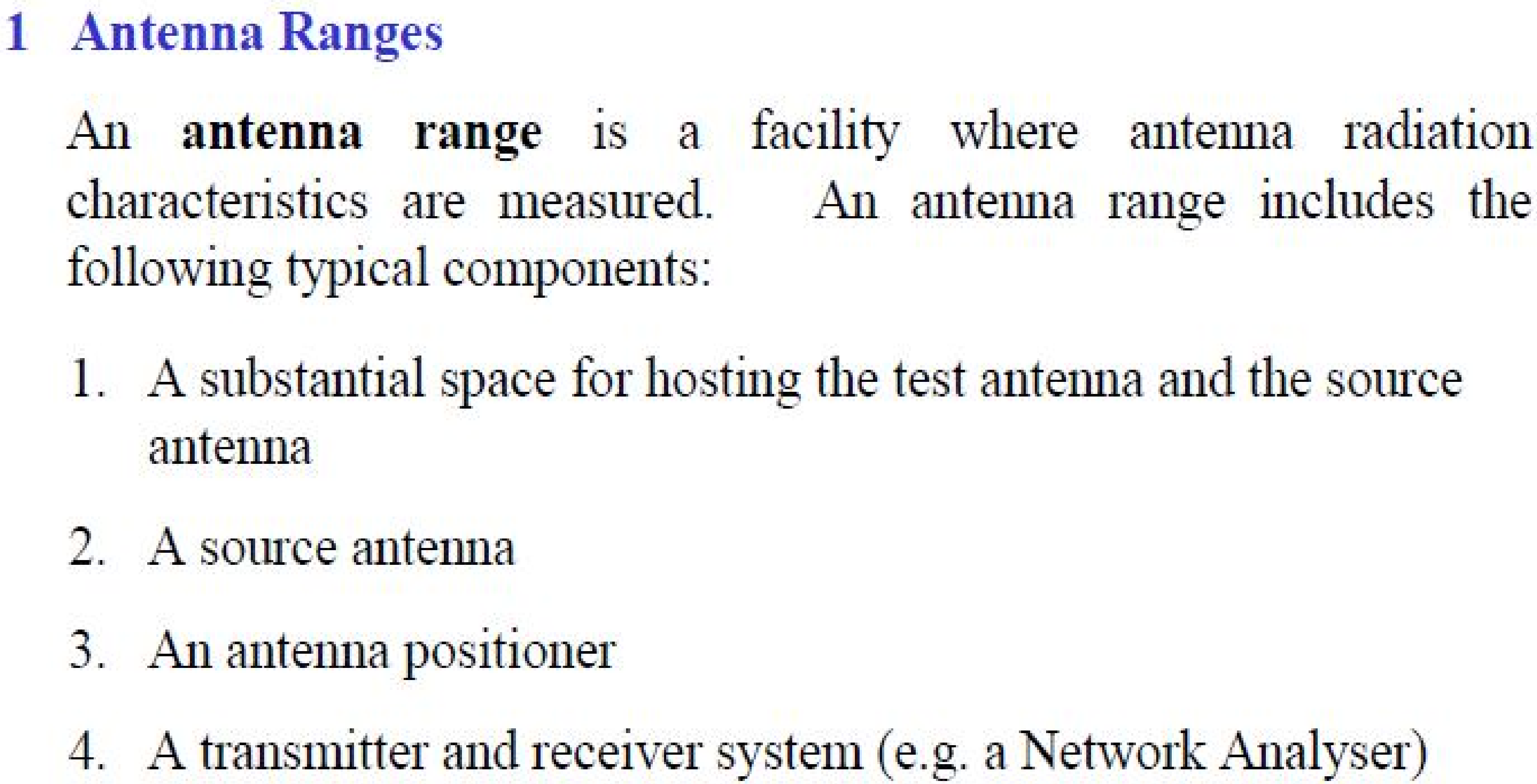
BOLOMETERS

- A Bolometer is a power sensor whose resistance changes with temperature as it absorbs microwave power.
- Are power detectors that operate on thermal principles. Since the temperature of the resistance is dependent on the signal power absorbed, the resistance must also be in proportion to the signal power.
- The two most common types of bolometer are, the barretter and the thermistor. Both are sensitive power detectors and is used to indicate microwatts of power. They are used with bridge circuits to convert resistance to power using a meter or other indicating devices.

BOLOMETER


Power P
Resistive Thermometer
absorber
Thermal Mass
Heat Capacity C
Temparature T
Thermal Conductance G
Thermal Reservoir

Antenna Measurement

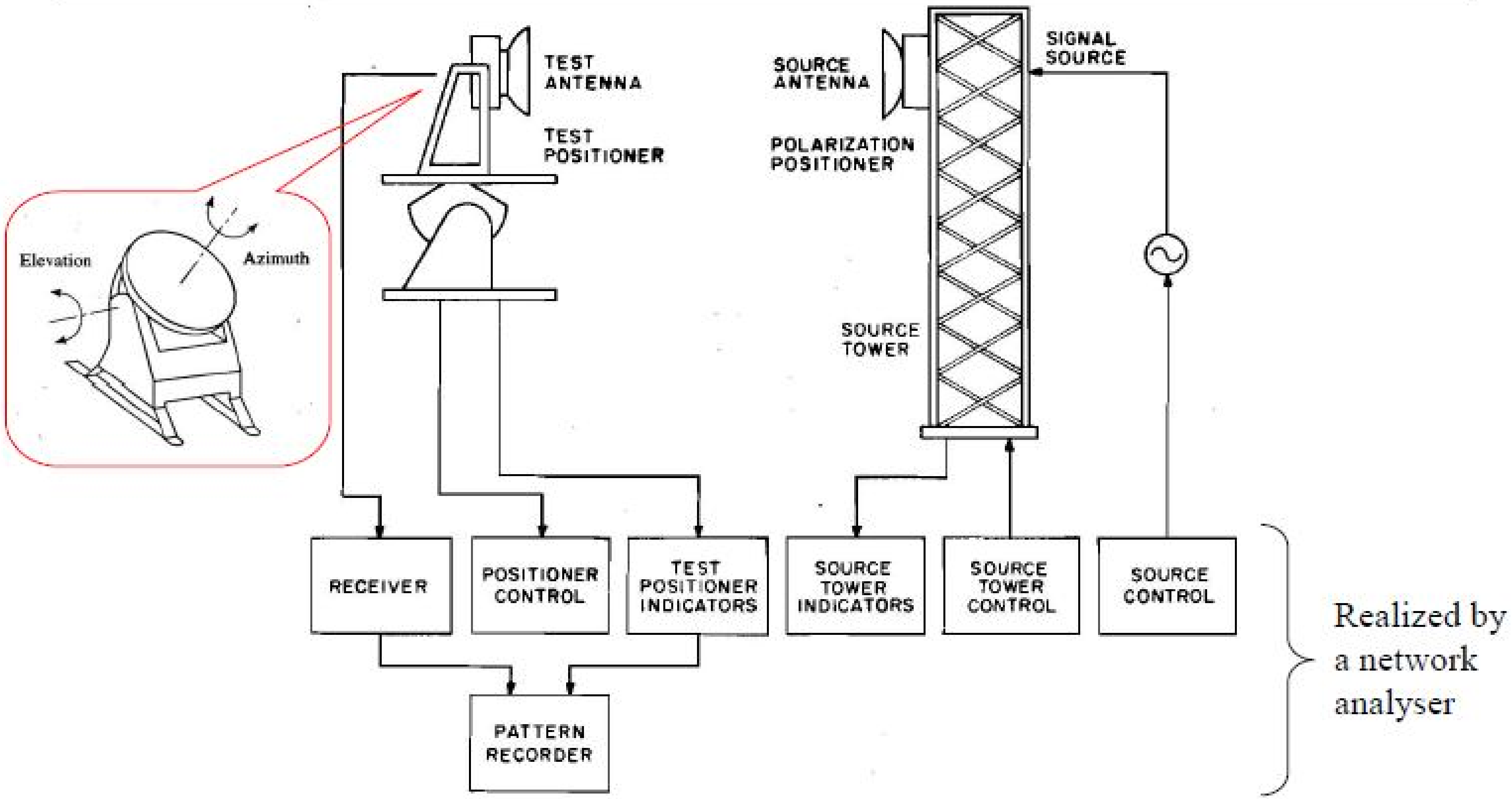


1 Antenna Ranges

An **antenna range** is a facility where antenna radiation characteristics are measured. An antenna range includes the following typical components:

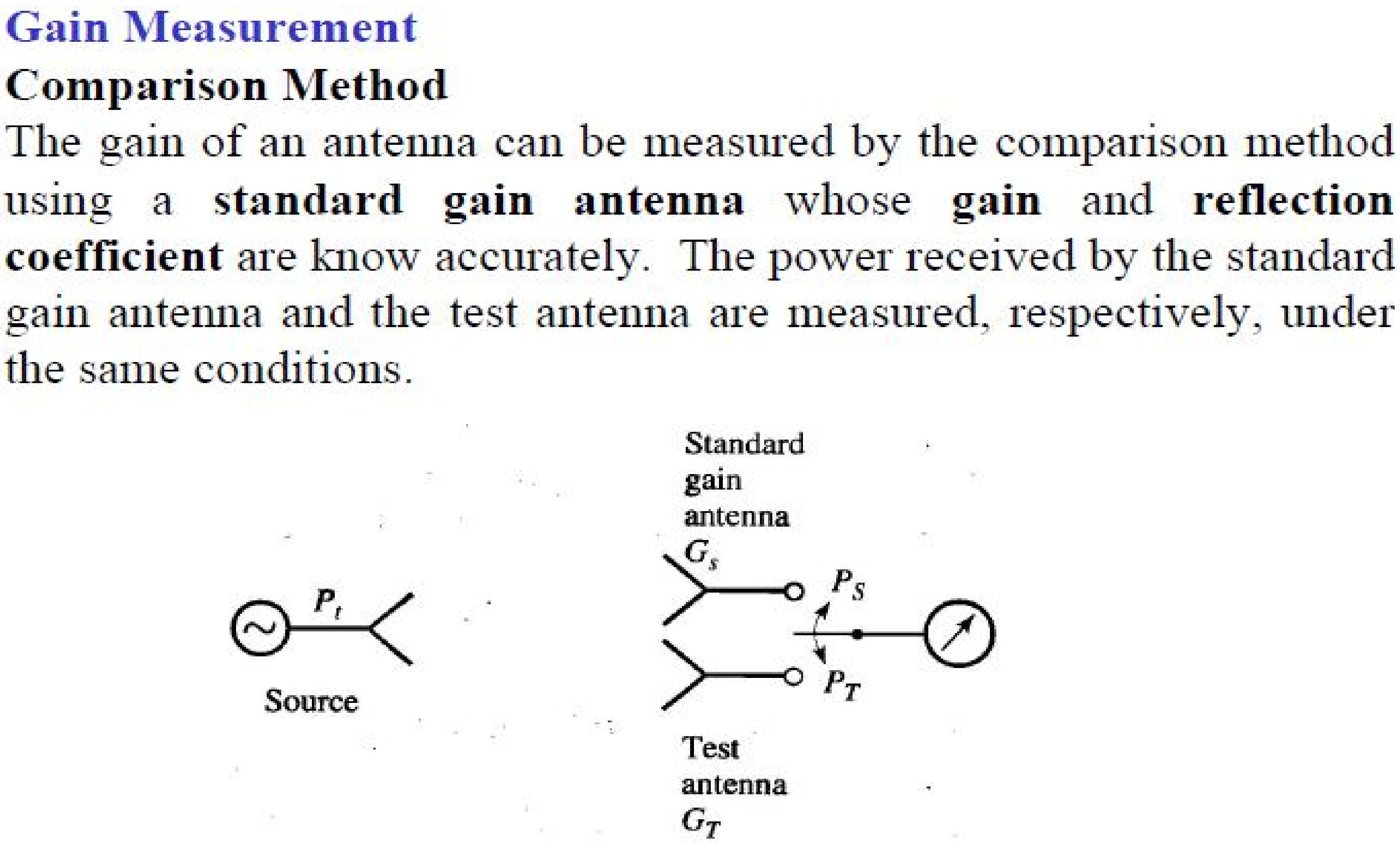
1. A substantial space for hosting the test antenna and the source antenna
2. A source antenna
3. An antenna positioner
4. A transmitter and receiver system (e.g. a Network Analyser)

Antenna Measurement



Block diagram of a typical antenna-measurement system

Gain Measurement

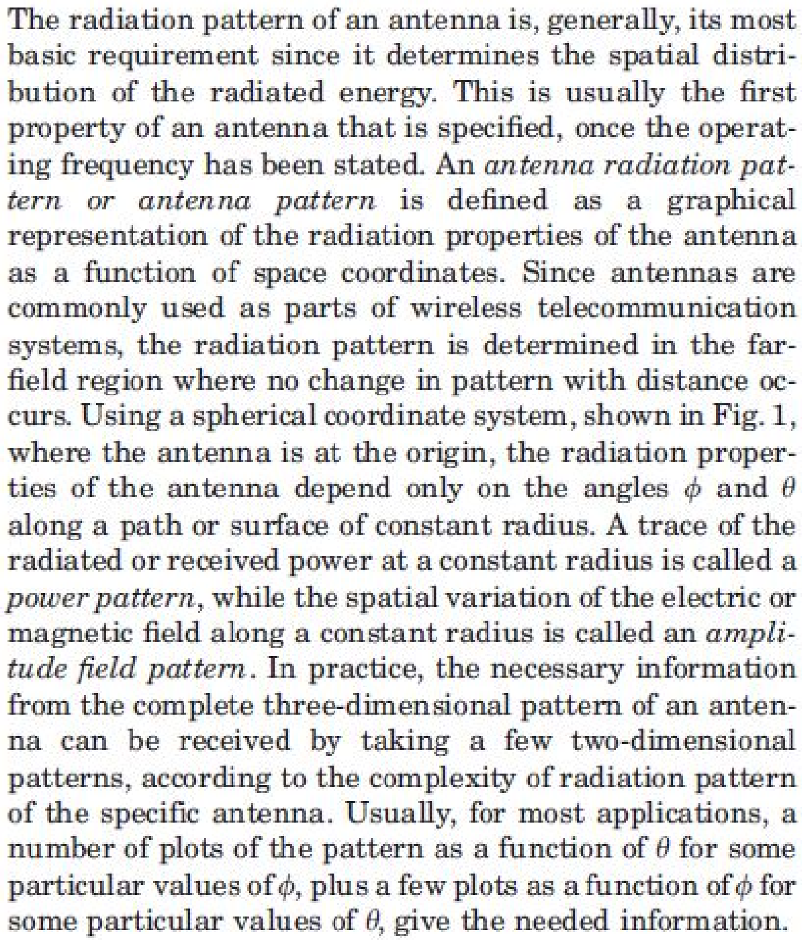


Gain Measurement

Comparison Method

The gain of an antenna can be measured by the comparison method using a **standard gain antenna** whose **gain** and **reflection coefficient** are know accurately. The power received by the standard gain antenna and the test antenna are measured, respectively, under the same conditions.

Radiation Pattern



The radiation pattern of an antenna is, generally, its most basic requirement since it determines the spatial distribution of the radiated energy. This is usually the first property of an antenna that is specified, once the operating frequency has been stated. An *antenna radiation pattern or antenna pattern* is defined as a graphical representation of the radiation properties of the antenna as a function of space coordinates. Since antennas are commonly used as parts of wireless telecommunication systems, the radiation pattern is determined in the far-field region where no change in pattern with distance occurs. Using a spherical coordinate system, shown in Fig. 1, where the antenna is at the origin, the radiation properties of the antenna depend only on the angles ϕ and θ along a path or surface of constant radius. A trace of the radiated or received power at a constant radius is called a *power pattern*, while the spatial variation of the electric or magnetic field along a constant radius is called an *amplitude field pattern*. In practice, the necessary information from the complete three-dimensional pattern of an antenna can be received by taking a few two-dimensional patterns, according to the complexity of radiation pattern of the specific antenna. Usually, for most applications, a number of plots of the pattern as a function of θ for some particular values of ϕ, plus a few plots as a function of ϕ for some particular values of θ, give the needed information.

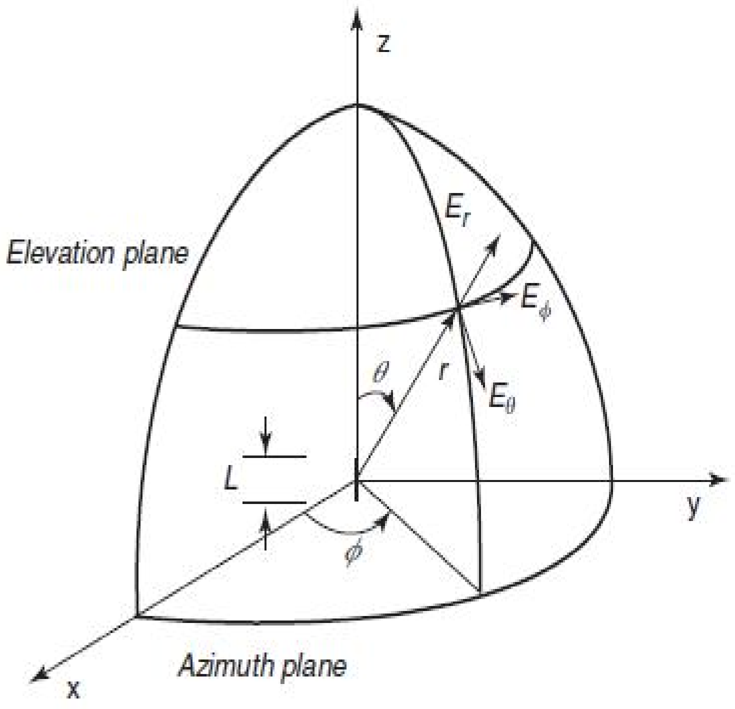


Figure 1. Spherical coordinate system for antenna analysis purposes. A very short dipole is shown with its no-zero field component directions.