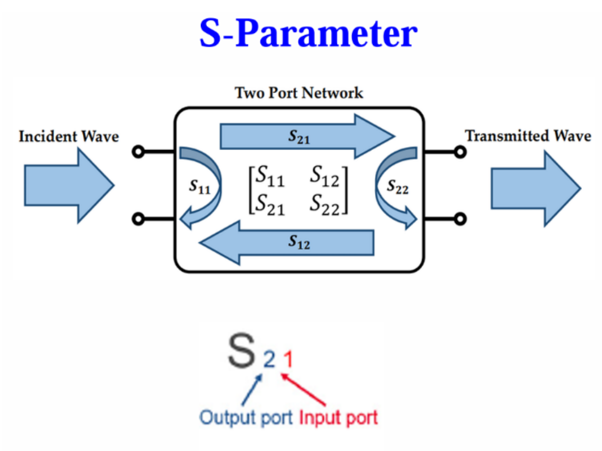
UNIT 2 – Microwave Communication

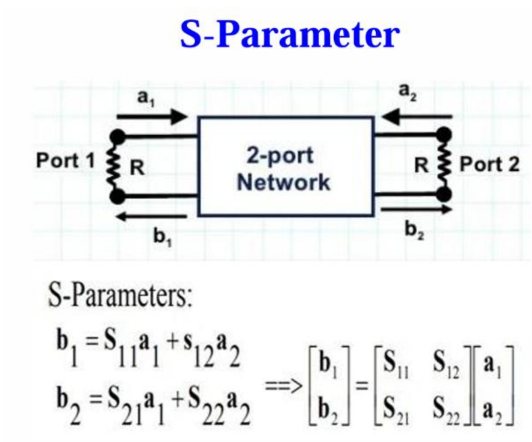
1. S-Parameter Set

- S-parameters describe how incident, reflected, and transmitted signals interact at each port.

- Key terms:
  - S_{11}: Input reflection coefficient (how much is reflected back at port 1).
  - S_{22}: Output reflection coefficient (reflection at port 2).
  - S_{21}: Forward transmission (how much signal from port 1 reaches port 2).
  - S_{12}: Reverse transmission (how much signal from port 2 reaches port 1).

- The bottom section explains notation:
  - S_{21} (blue arrow) means signal output at port 2 due to an input at port 1.





$$S_{11} = \frac{b_1}{a_1}\bigg|_{a_2=0} = \underline{\text{Input reflection coefficient } \Gamma\text{in}} \text{ for case of } Z_L=Z_0$$

$$S_{21} = \frac{b_2}{a_1}\bigg|_{a_2=0} = \underline{\text{Forward transmission (insertion) gain}} \text{ for case of } Z_L=Z_0$$

$$S_{12} = \frac{b_1}{a_2}\bigg|_{a_1=0} = \underline{\text{Reverse transmission (insertion) gain}} \text{ for case of } Z_s=Z_0$$

$$S_{22} = \frac{b_2}{a_2}\bigg|_{a_1=0} = \underline{\text{Output reflection coefficient } \Gamma\text{out}} \text{ for case of } Z_s=Z_0$$

$$(S_{11}) \quad (one-port)$$

$$\begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \quad (two-port)$$

$$\begin{pmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{pmatrix} \quad (three-port)$$

2. Direction Coupler

- A Directional coupler is a device that samples a small amount of Microwave power for measurement purposes. The power measurements include incident power, reflected power, VSWR values, etc.

Functions:

□ Power Monitoring & Signal Sampling

- Extracts a small amount of power from a high-power signal for measurement without disturbing the main signal.
- Used in VSWR (Voltage Standing Wave Ratio) meters to check transmission line efficiency.

□ Signal Isolation

- Provides isolation between ports to prevent signal reflections and interference.
- Reduces leakage and unwanted feedback in RF circuits.

□ Power Splitting & Distribution

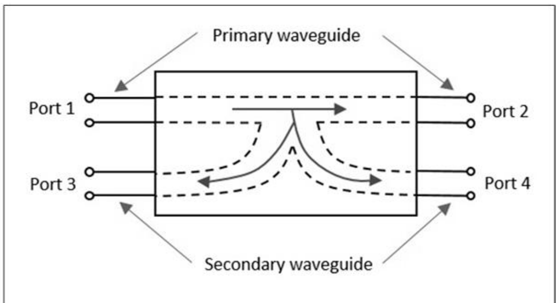
- Helps distribute power to multiple outputs while maintaining impedance matching.
- Used in antenna arrays and radar systems for even power distribution.

 Directional Signal Flow

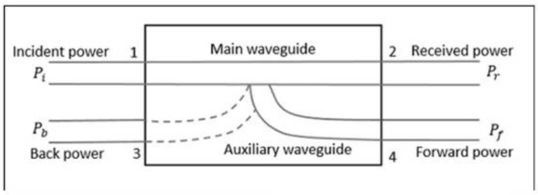
- Allows signals to flow in a particular direction while minimizing signal flow in the opposite direction.
- Used in transmit/receive (T/R) modules to separate transmitted and received signals.

 Impedance Matching & Load Protection

- Detects reflected power due to impedance mismatches in transmission lines.
- Prevents damage to power amplifiers and antennas by diverting excess power.



Directional Coupler



$$C = 10\,log_{10}\frac{P_i}{P_f}dB \qquad D = 10\,log_{10}\frac{P_f}{P_b}dB$$

$$I = 10\,log_{10}\frac{P_i}{P_b}dB$$

Isolation in dB = Coupling factor + Directivity

Has four ports:

- Port 1: Input signal enters.
- Port 2: Main output (transmitted signal).
- Port 3: Coupled output (sampled signal from the input).
- Port 4: Isolated port (ideally no signal).
- Primary and secondary waveguides allow controlled power coupling.

- Dashed lines indicate signal paths, showing how a portion of the signal is coupled into the secondary waveguide.

- P_i : Incident power (input power).
- P_r : Received power at the output port.
- P_f : Forward coupled power.
- P_b : Backward coupled power.

Mathematical Parameters:

- **Coupling Factor (C):** Measures how much power is transferred to the coupled port.

$$C = 10 \log_{10} \left(\frac{P_i}{P_f} \right) \text{ dB}$$

- **Directivity (D):** Ratio of forward to backward coupled power.

$$D = 10 \log_{10} \left(\frac{P_f}{P_b} \right) \text{ dB}$$

- **Isolation (I):** Measures how well the input is isolated from the coupled port.

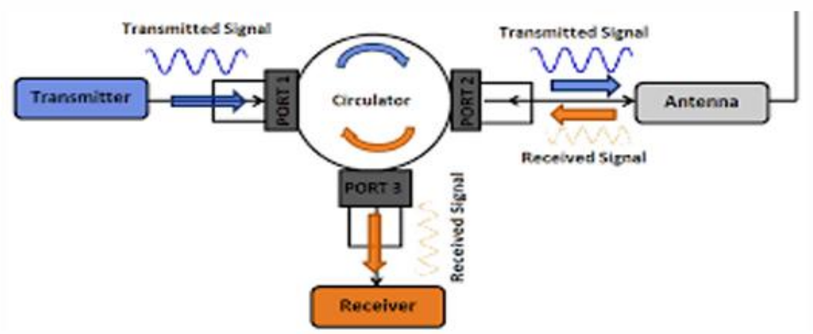
$$I = 10 \log_{10} \left(\frac{P_i}{P_b} \right) \text{ dB}$$

Formula for Isolation:

$$\text{Isolation (dB)} = \text{Coupling Factor} + \text{Directivity}$$

3. **E-PLANE** – PPT page: 100 to 104
4. **H-PLANE** – PPT page: 105 to 109
5. **Magic Tee** – PPT page: 110 to 115

6. Microwave Circulators



This diagram illustrates the working of an RF circulator, a three-port non-reciprocal device used to control signal flow in RF and microwave communication systems.

1. Components in the Diagram:

- Transmitter: Generates the transmitted signal.
- Antenna: Radiates the transmitted signal and receives incoming signals.
- Circulator: A three-port device that directs signals in a clockwise manner (Port 1 → Port 2 → Port 3).
- Receiver: Captures and processes the received signal.

2. Working of the Circulator:

1. Transmission Process:
    - The transmitter sends an RF signal to Port 1 of the circulator.
    - The circulator directs this signal to Port 2, which is connected to the antenna.
    - The antenna radiates the signal into free space.
2. Reception Process:
    - The antenna receives incoming signals from the environment.
    - This signal enters Port 2 of the circulator.
    - The circulator directs the received signal to Port 3, which is connected to the receiver.

3. Purpose of the Circulator:

- Ensures unidirectional signal flow (prevents interference between transmitted and received signals).
- Isolates the transmitter from the receiver to avoid self-interference.
- Prevents power loss and reflections, improving system efficiency.

4. Applications:

- Radar Systems: Separates transmitted and received signals.
- Antenna Duplexing: Used in base stations and satellite communication.
- Microwave Communication: Used in RF front-end circuits.

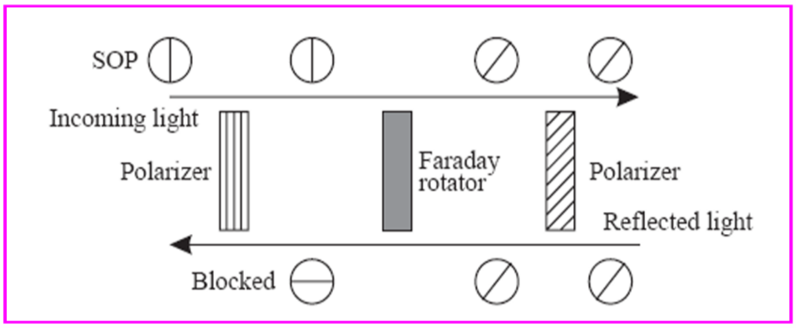
Conclusion:

The circulator allows a single antenna to handle both transmission and reception by directing signals in a controlled manner, ensuring efficient and interference-free communication.

7. Microwave Isolators

- Only allows transmission in one direction through it.
- To protect klystron tube and microwave supply from returning reflected light.

Polarization Dependent Isolator



This diagram represents a Polarization Dependent Isolator (PDI), an optical device that allows light to pass in one direction while blocking it in the reverse direction. It is commonly used in fibre optic communication systems to prevent back reflections and interference.

1. Components in the Diagram:

- Incoming Light: Light entering the isolator with a specific State of Polarization (SOP).

- Polarizer (Input Side): Filters incoming light, allowing only a specific polarization state to pass.
- Faraday Rotator: Rotates the polarization of light by 45° in a non-reciprocal manner.
- Polarizer (Output Side): Aligns with the rotated polarization to allow forward transmission.
- Reflected Light: Light that tries to travel in the reverse direction.
- Blocked Light: The reverse traveling light is blocked due to polarization misalignment.

2. Working Principle:

- Forward Direction (Allowed Transmission):
  - The incoming light passes through the first polarizer, which ensures a specific polarization.
  - The Faraday rotator rotates the polarization by 45°, allowing it to pass through the second polarizer.
  - The light exits without loss, ensuring efficient transmission.
- Reverse Direction (Blocked Light):
  - Any reflected light entering from the output side undergoes another 45° rotation in the same direction by the Faraday rotator.
  - This causes a misalignment with the first polarizer, blocking the light from passing through.
  - As a result, the reflected light is absorbed or deflected, preventing interference.

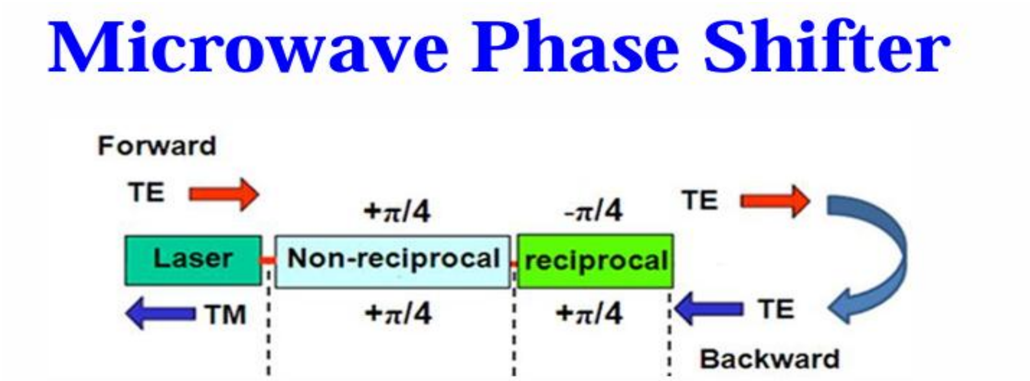
3. Purpose of the Isolator:

- Prevents back reflections in fiber optic communication.
- Protects laser sources from feedback, ensuring stable operation.
- Enhances system efficiency by reducing noise and signal distortion.

Conclusion:

A Polarization Dependent Isolator (PDI) is a crucial optical component that ensures unidirectional light transmission, preventing feedback interference and protecting sensitive optical devices.

8. Microwave Phase Shifters



A Microwave Phase Shifter is a device that changes the phase of an electromagnetic wave without altering its amplitude. It is widely used in radar systems, phased array antennas, and communication systems to control signal direction and beam steering.

1. Working Principle:

- The top part of the diagram illustrates how phase shifting occurs in a microwave phase shifter.
- The non-reciprocal section introduces a different phase shift ($+\pi/4$) for transverse electric (TE) and transverse magnetic (TM) waves, ensuring different phase responses.
- The reciprocal section further modifies the phase shift, ensuring that forward and backward waves experience different phase changes.
- Forward wave (TE mode): Undergoes phase shifts of $+\pi/4$ and $-\pi/4$, maintaining its mode.

- Backward wave (TM mode): Undergoes phase shifts of +π/4 and +π/4, converting to TE mode.

2. Structure:

The bottom part illustrates the physical construction of a microwave phase shifter:

- Input transition: Initial wave enters.
- Fixed quarter wave plate (45°): Partially alters polarization.
- Rotatable half-wave plate: Introduces the main phase shift.
- Another fixed quarter wave plate: Completes phase modification.
- Output transition: Delivers the phase-shifted wave.

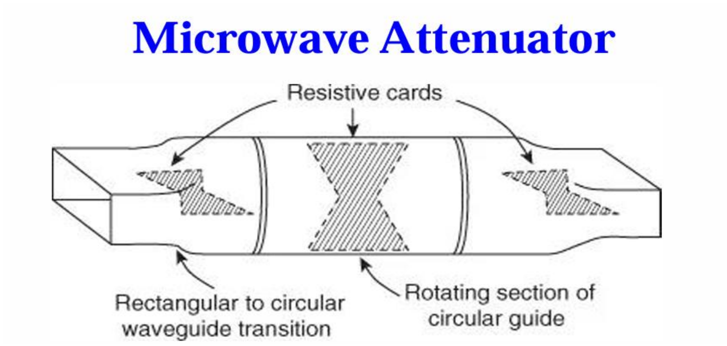
3. Applications:

- Phased Array Antennas: Controls beam direction dynamically.
- Radar Systems: Enhances target detection.
- Satellite Communications: Adjusts signal paths for better connectivity.

Conclusion:

The Microwave Phase Shifter modifies the phase of a wave using a combination of reciprocal and non-reciprocal components. It plays a critical role in beamforming, signal processing, and advanced communication systems.

9. Microwave Attenuator



A Microwave Attenuator is a device used to reduce the power of a microwave signal without distorting its waveform. It is essential for controlling signal strength in microwave circuits, preventing damage to sensitive components, and ensuring stable system performance.

1. Working Principle:

- The top part of the diagram shows the structure of a microwave attenuator with key components:
    - Resistive Cards: These absorb part of the microwave energy, reducing the signal strength.
    - Rectangular to Circular Waveguide Transition: Converts the rectangular waveguide mode into a circular mode for better attenuation control.
    - Rotating Section of Circular Guide: Allows adjustment of attenuation by changing the alignment of resistive elements relative to the wave propagation direction.
    - Input transition: Where the microwave signal enters.
    - Fixed and Rotatable Sections: The rotatable section adjusts attenuation by varying how much energy is absorbed.
    - Output transition: The attenuated signal exits with reduced amplitude.

2. Attenuation Control:

- The attenuation level is determined by the angle of the rotatable section (θm) in the circular waveguide.
- The output signal strength follows $E \cos^2(\theta m)$, meaning attenuation can be adjusted dynamically.

3. Applications:

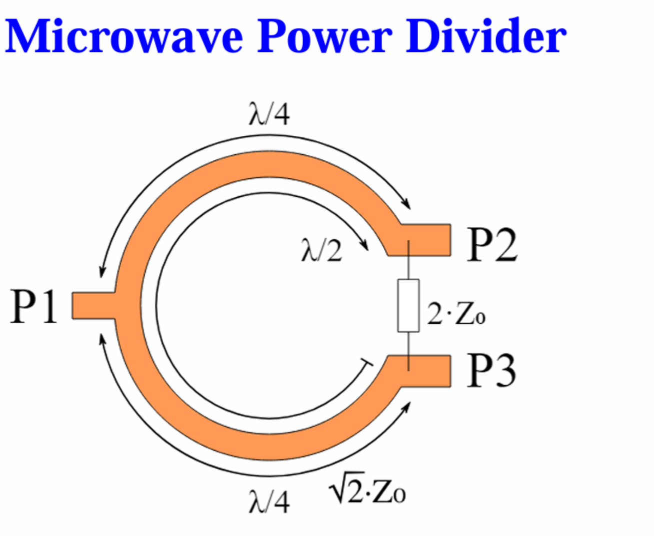
- Microwave Testing & Calibration: Controls signal power in test environments.
- Radar Systems: Adjusts signal levels to prevent receiver saturation.

- Satellite Communications: Maintains stable power levels in transmission links.
- Phased Array Antennas: Fine-tunes signal strength for optimal performance.

Conclusion:

The Microwave Attenuator provides controlled signal attenuation using resistive elements and a rotating circular waveguide section. It is crucial for power regulation, testing, and preventing system overloads in high-frequency microwave applications.

10. Microwave Power divider



A Microwave Power Divider is a passive device used in RF and microwave circuits to split an input signal into two or more output signals with specific phase and amplitude characteristics.

1. Working Principle:

- Input Port (P1): The microwave signal is fed into this port.
- Output Ports (P2, P3): The signal is divided into two equal or specified power levels.
- Quarter-Wavelength Sections (λ/4): These ensure impedance matching for minimal signal reflection.

- Half-Wavelength Section ($\lambda/2$): Helps in phase balancing.
- Impedance Matching:
    - The impedance at different sections follows $\sqrt{2} \cdot Z_o$ and $2 \cdot Z_o$ to ensure power is split efficiently.

2. Key Features:

- Equal or Unequal Power Division: Depending on design, it can split power equally or in a specified ratio.
- Impedance Matching: The transmission lines ensure minimal loss.
- Isolation Between Ports: The resistor ($2 \cdot Z_o$) helps reduce signal leakage between P2 and P3.

3. Applications:

- Antenna Feed Networks: Distributes power to multiple antenna elements.
- Microwave Communication Systems: Used in signal distribution and phased array systems.
- Radar Systems: Splits power among different radar components.
- RF Test Equipment: Ensures accurate power division for signal measurement.

Conclusion:

This Microwave Power Divider efficiently splits an input signal into two outputs while maintaining impedance matching and isolation. It is widely used in RF, radar, and communication systems to distribute signals effectively.