5.6 Circulator

Module:5 Microwave Passive components

Course: BECE305L – Antenna and Microwave Engineering

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CHENNAI

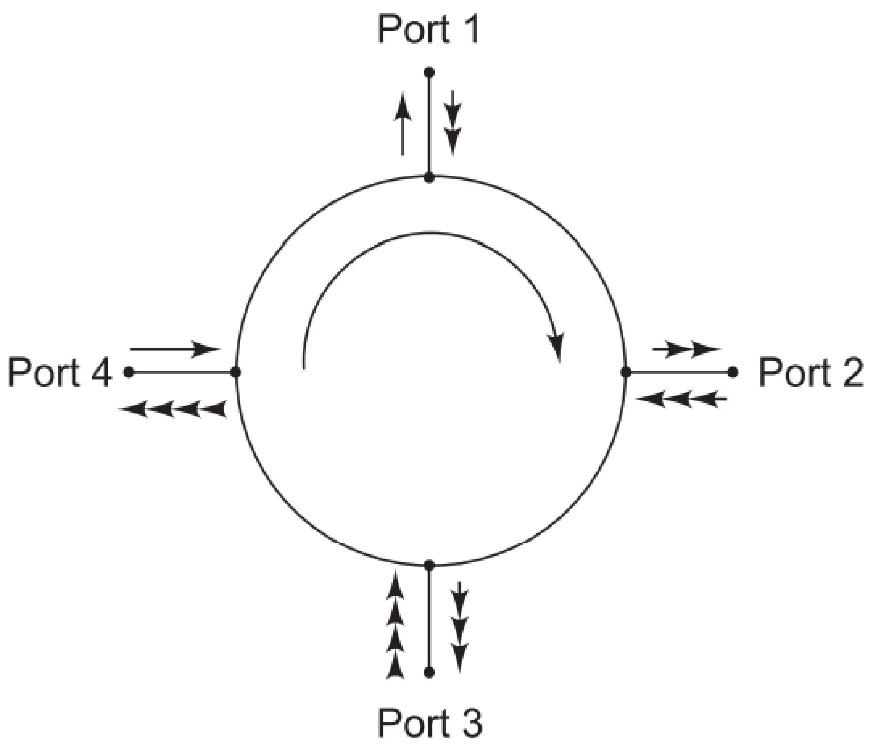
Module:5 Microwave Passive components 6 hours

- Microwave Networks - ABCD, ‘S’ parameter and its properties. E-Plane Tee, H-Plane Tee, Magic Tee and Multi-hole directional coupler. Principle of Faraday rotation, isolator, circulator and phase shifter.

- Source of the contents: Pozar

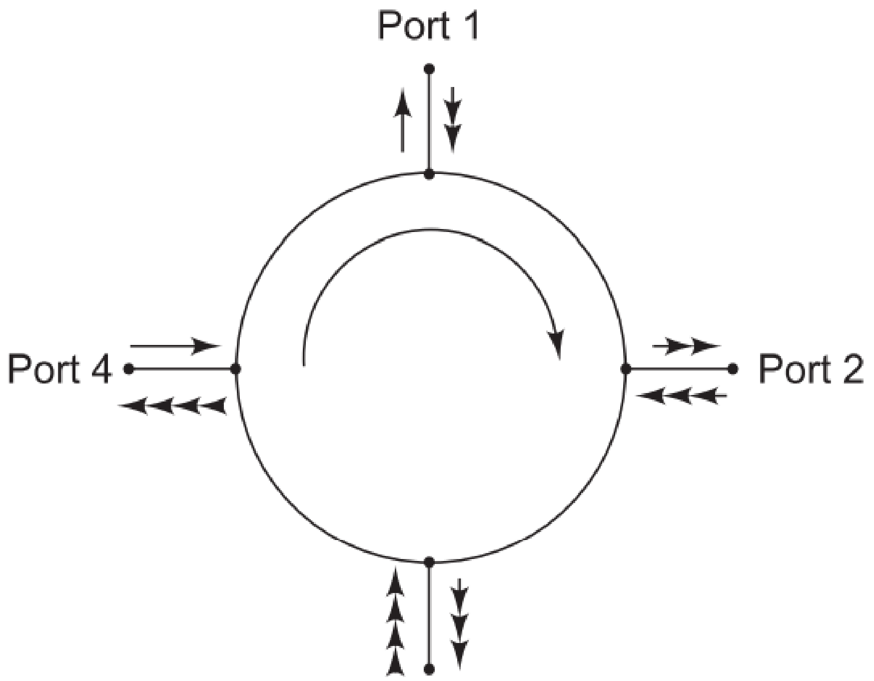
6. Circulators

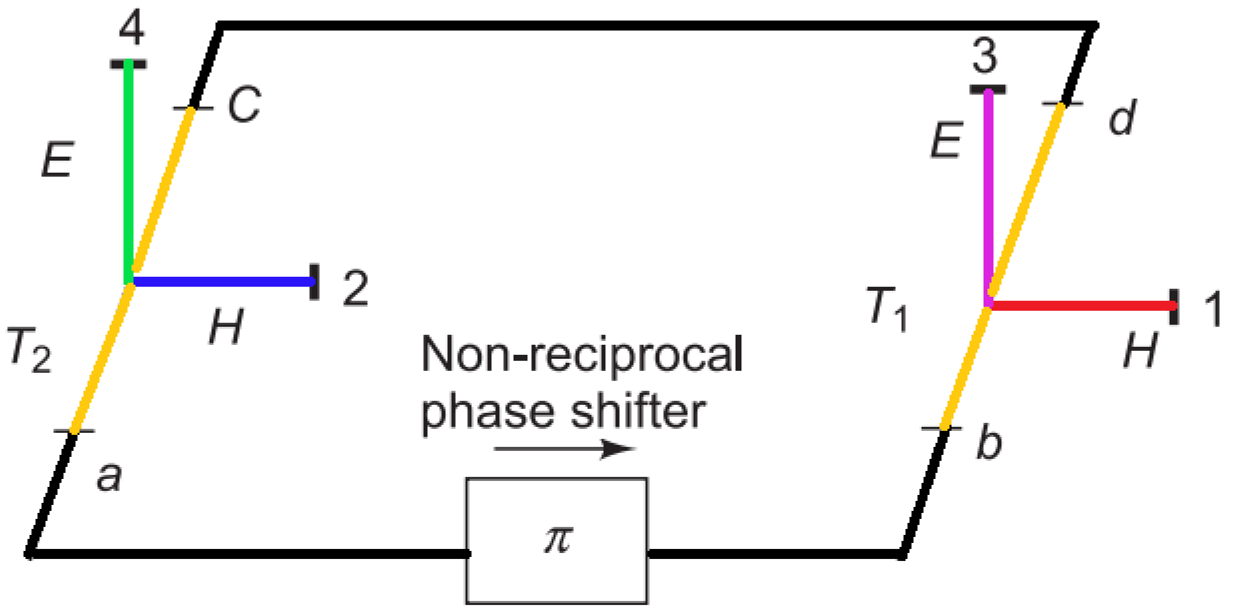
- Ferromagnetic materials (ferrite: Mg+Mn, Ni+Zn alloys) when placed in dc magntic field, electromagnetic wave propagation becomes non-reciprocal.
- This property is used for construction of circulators and isolators.
- Circulator: Multiport junction
  wave can travel from one port to the next immediate port in one direction only.
- Commonly used circulators
  Three port or
  Four port

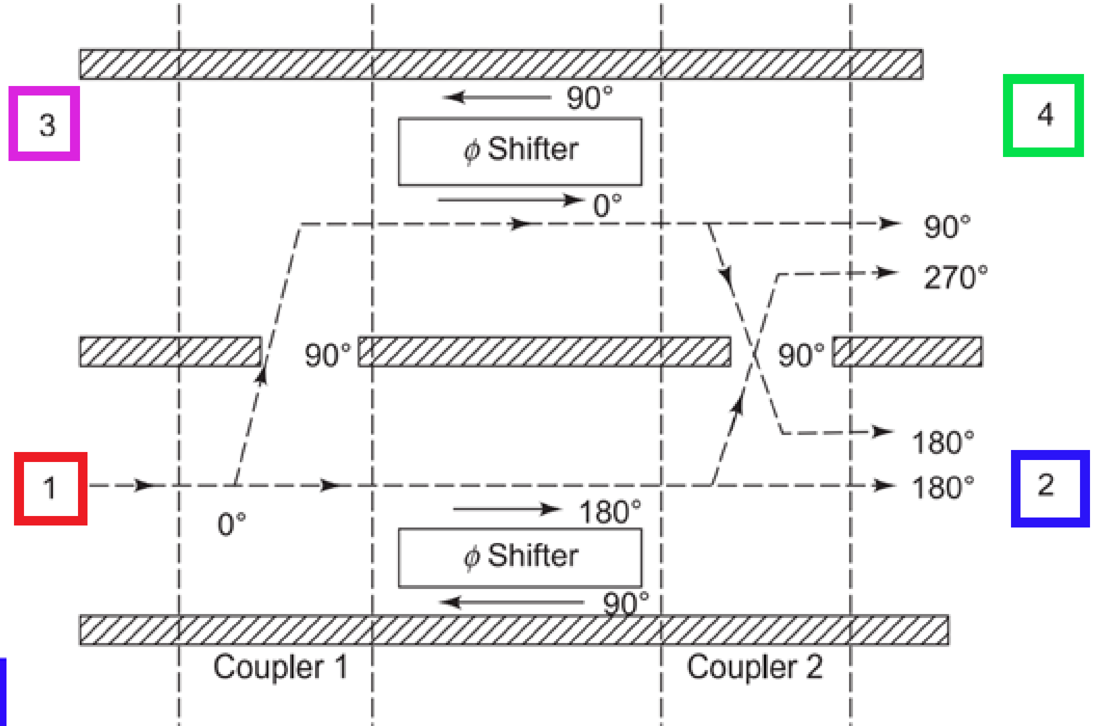


6.1 Four port Circulator

- Four port circulator – can be constructed
  1) from two magic Ts and
     a non reciprocal 180° phase shifter or
  2) a combination of two 3dB side hole
     directional couplers with
     two non-reciprocal phase shifters







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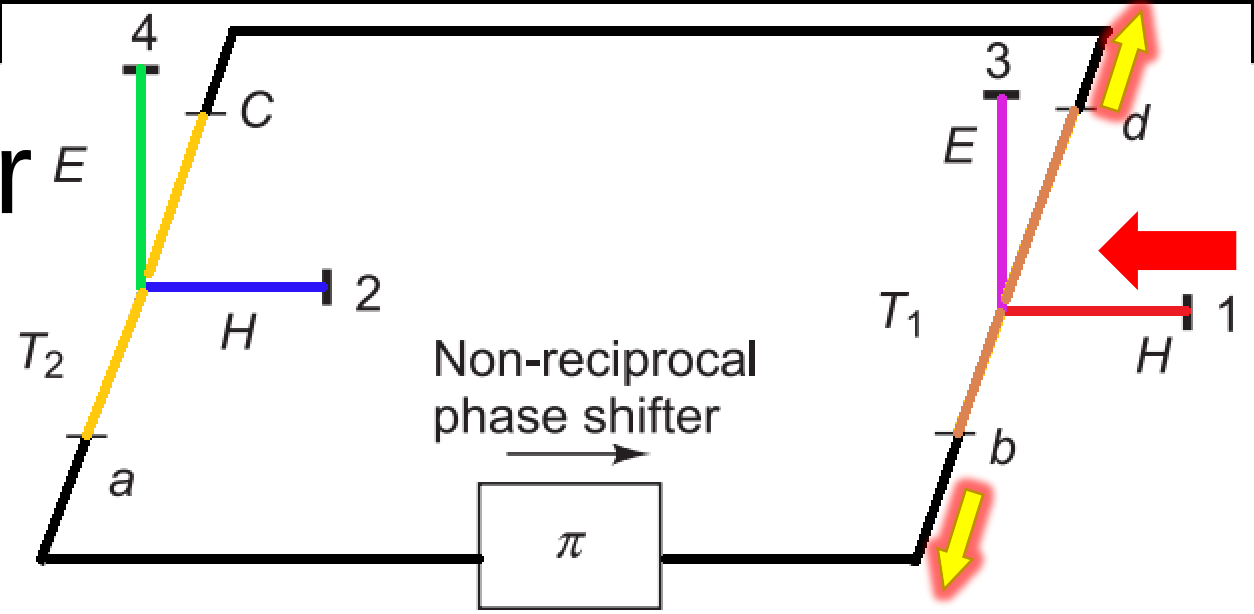

- Configuration 1:
- **Input signal at port 1** is split into two in phase and equal amplitude waves in collinear arms b and d of magic tee T1.

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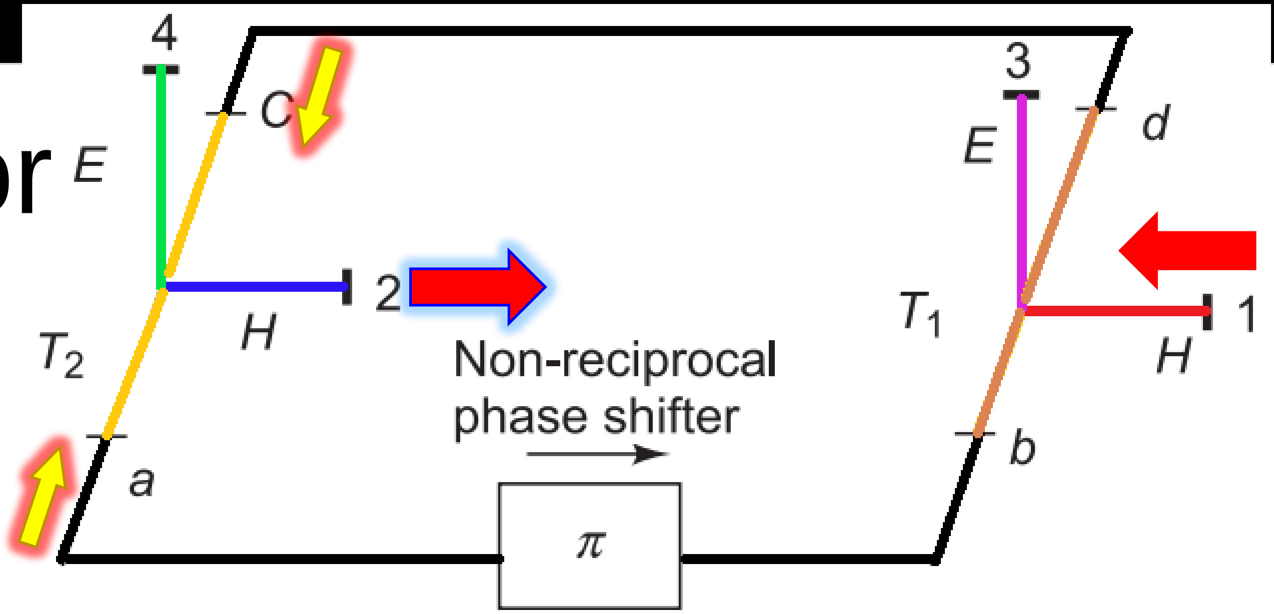

- Configuration 1:

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  They enter in phase at ports a and c of magic tee T2, and are added at **port 2**.

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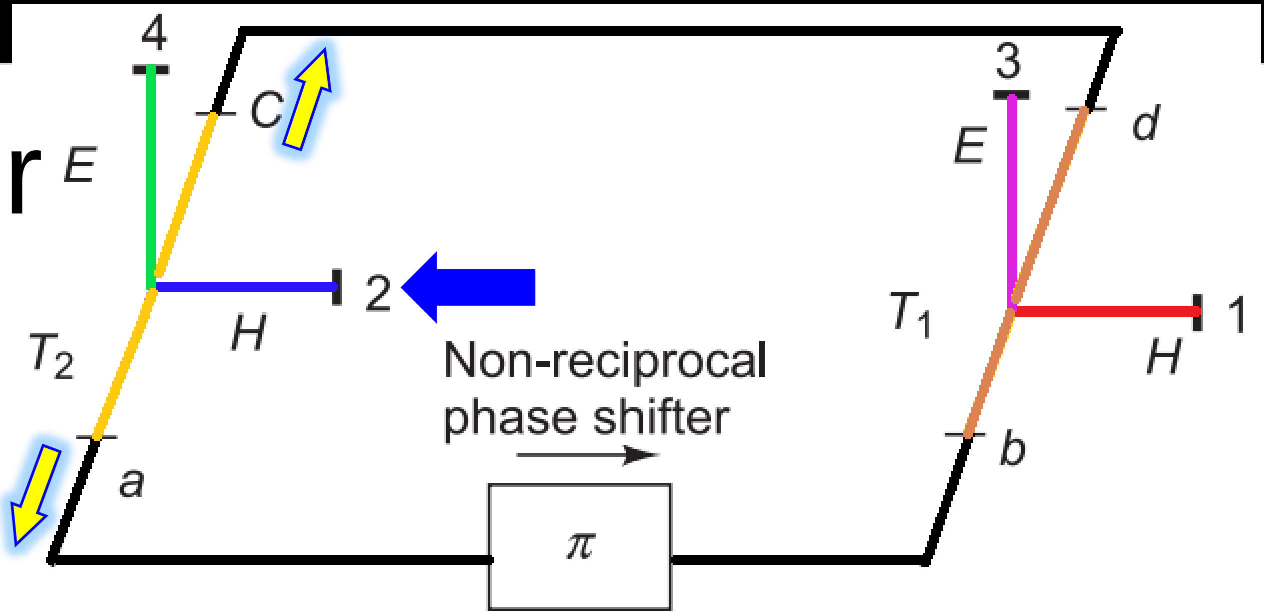

- Configuration 1:
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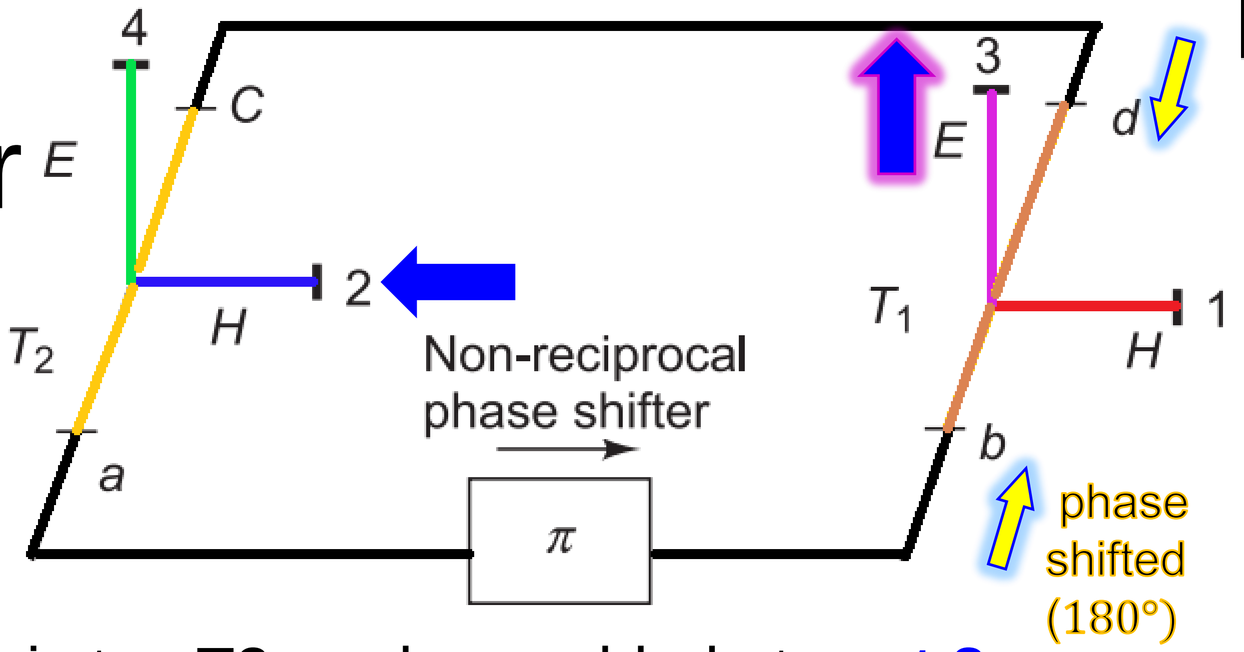

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  They enter out of phase at ports b and d of magic tee T1, and appear at **port 3**.

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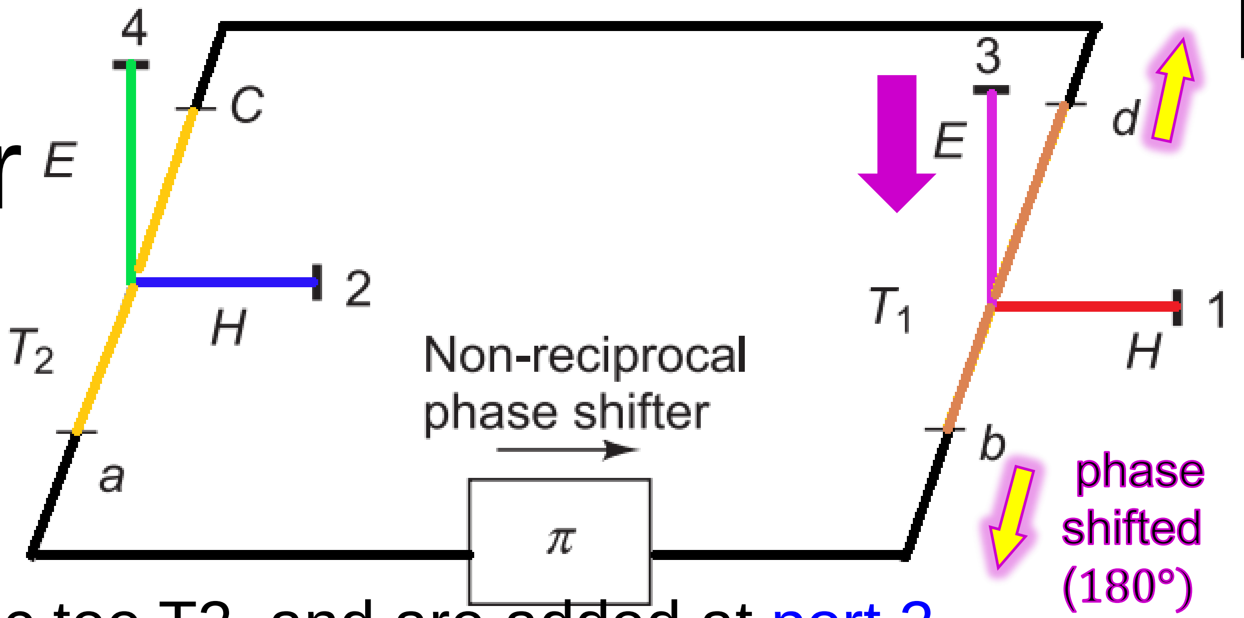

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- **Input signal at port 3** is split into two out of phase and equal amplitude waves in collinear arms b and d of magic tee T1 and

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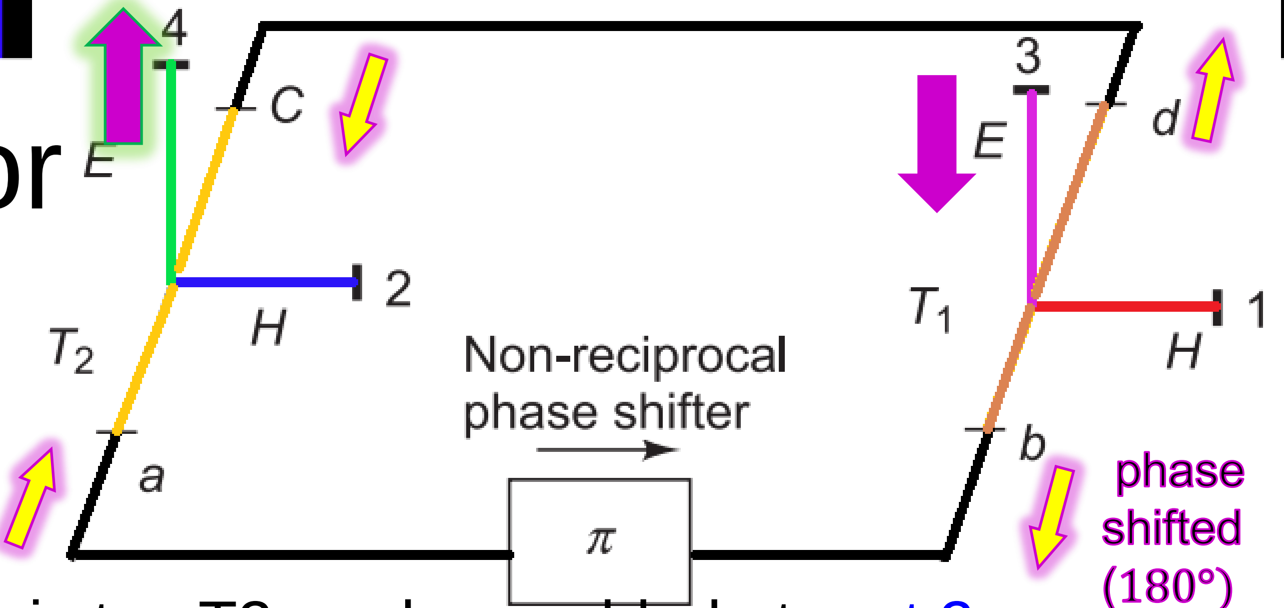

- Configuration 1:
  Input signal at port 1 is split into two in phase and equal amplitude waves in collinear arms b and d of magic tee T1.

  total phase shifted (180°)

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  They enter in phase at ports a and c of magic tee T2, and are added at port 2.
- **Input signal at port 2** is split into two in phase and equal amplitude waves in collinear arms a and c of magic tee T2.
  They enter out of phase at ports b and d of magic tee T1, and appear at **port 3**.
- **Input signal at port 3** is split into two out of phase and equal amplitude waves in collinear arms b and d of magic tee T1 and appear at **Port 4** of T2

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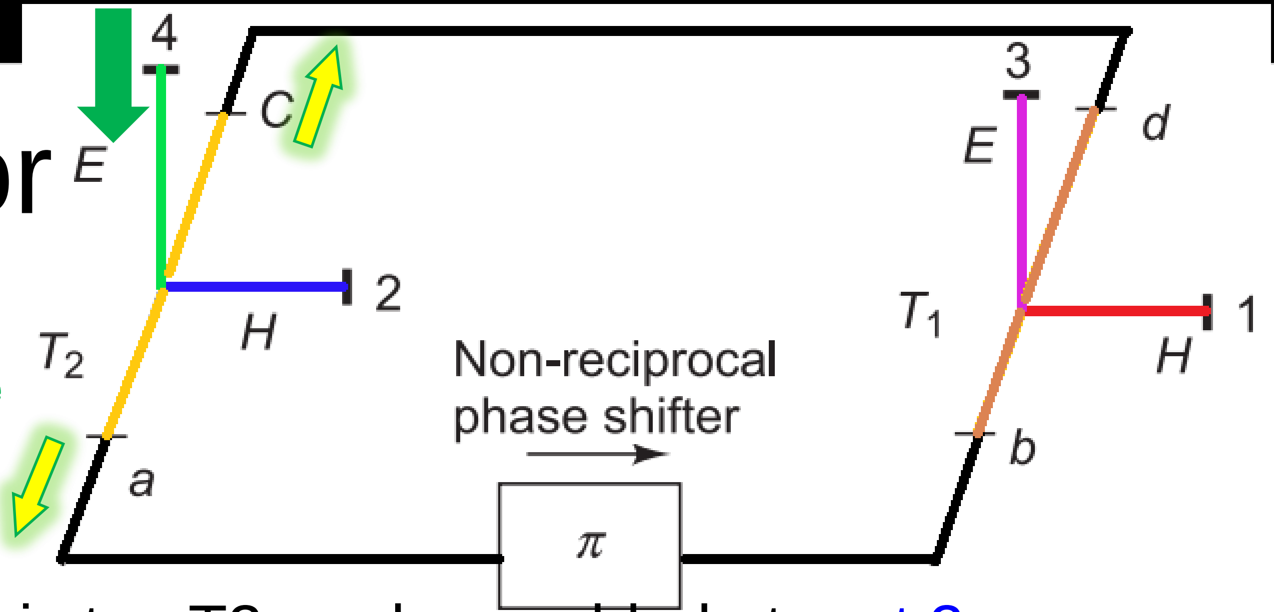

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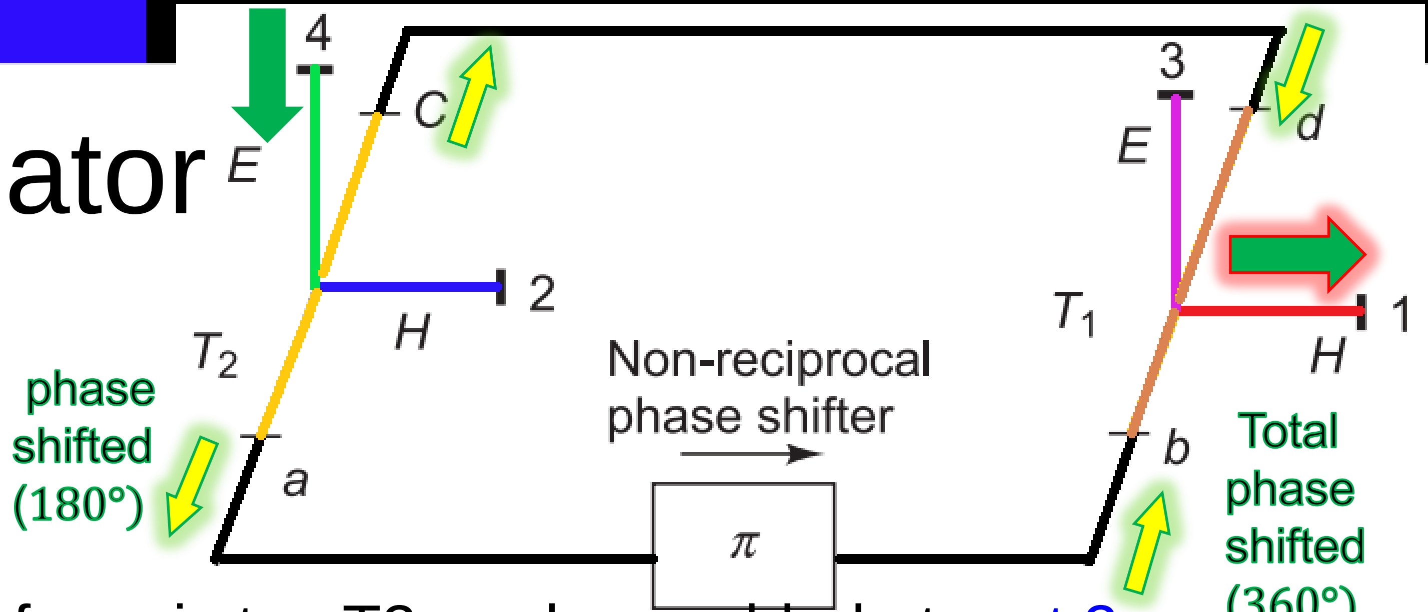

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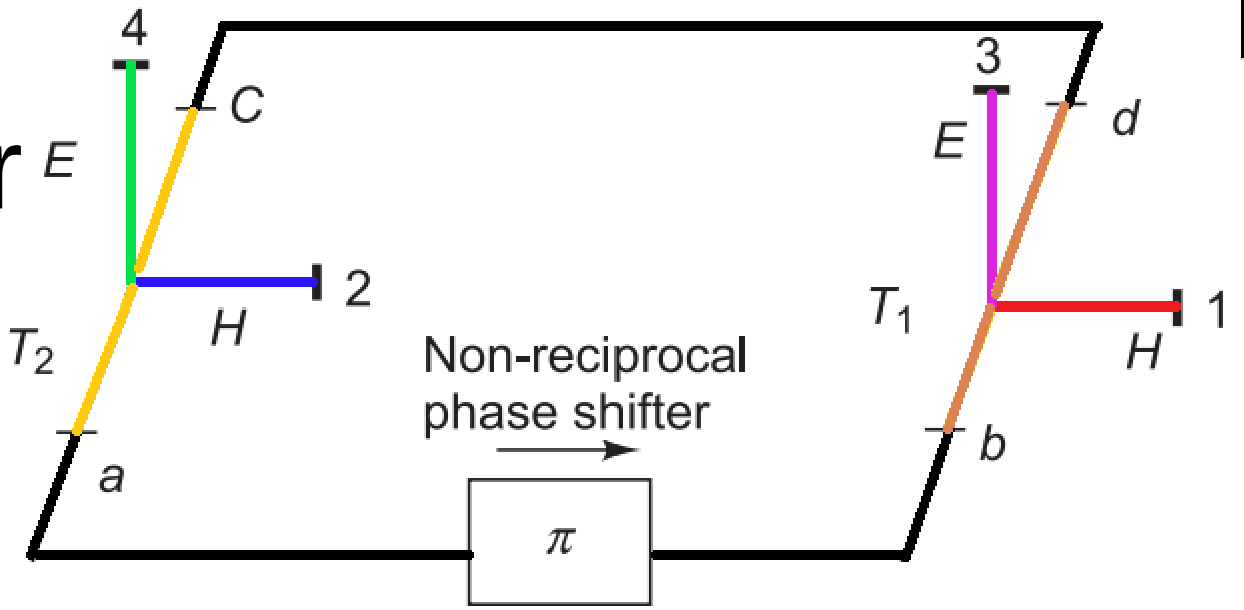

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- Input signal at port 4 is split into two out of phase and equal amplitude waves in collinear arms a and c of magic tee T2 and appear at Port 1 of T1
- **Port 1 -> port 2; port 2 -> port 3; port 3-> Port 4; Port 4-> Port 1**

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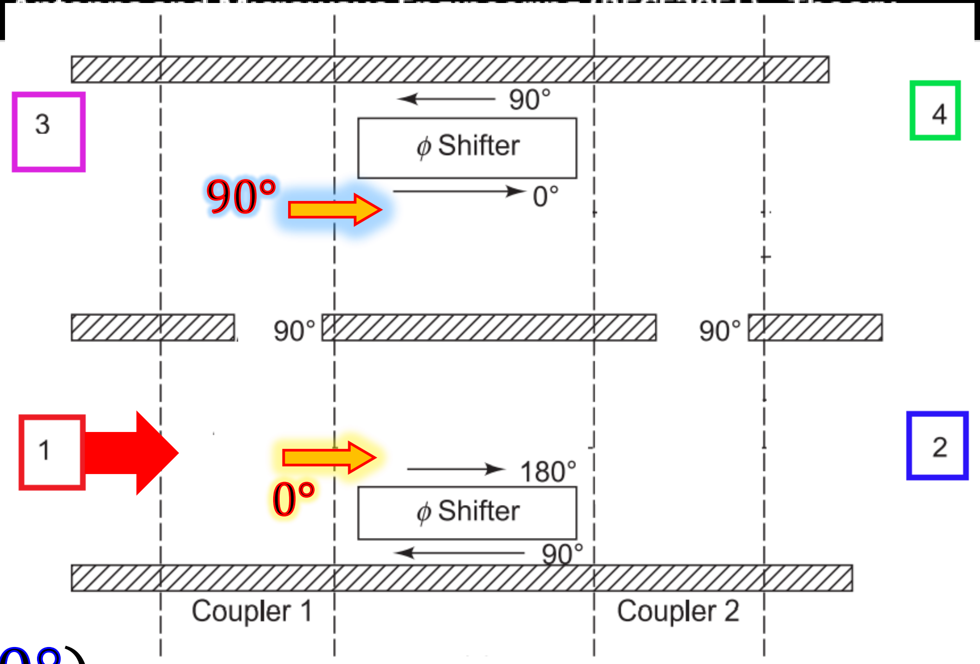

- **Configuration 2**:
- Each 3dB coupler introduces $90°$ phase shift.
- **Input signal in port 1**, splits into two at coupler 1, one with $90°$ phase shift. ($0°$, $90°$)

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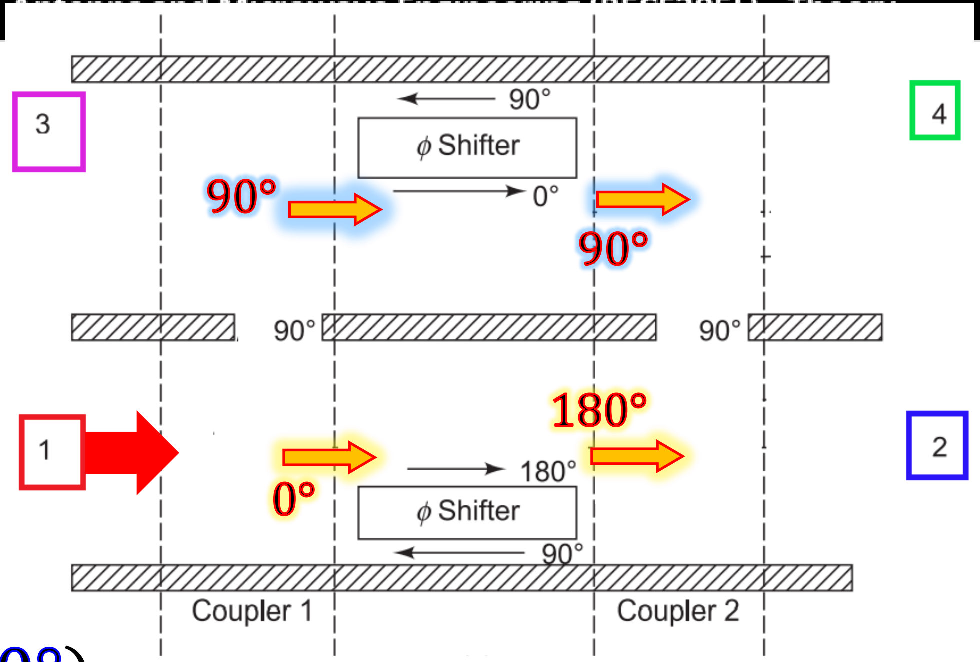

- **Configuration 2**:
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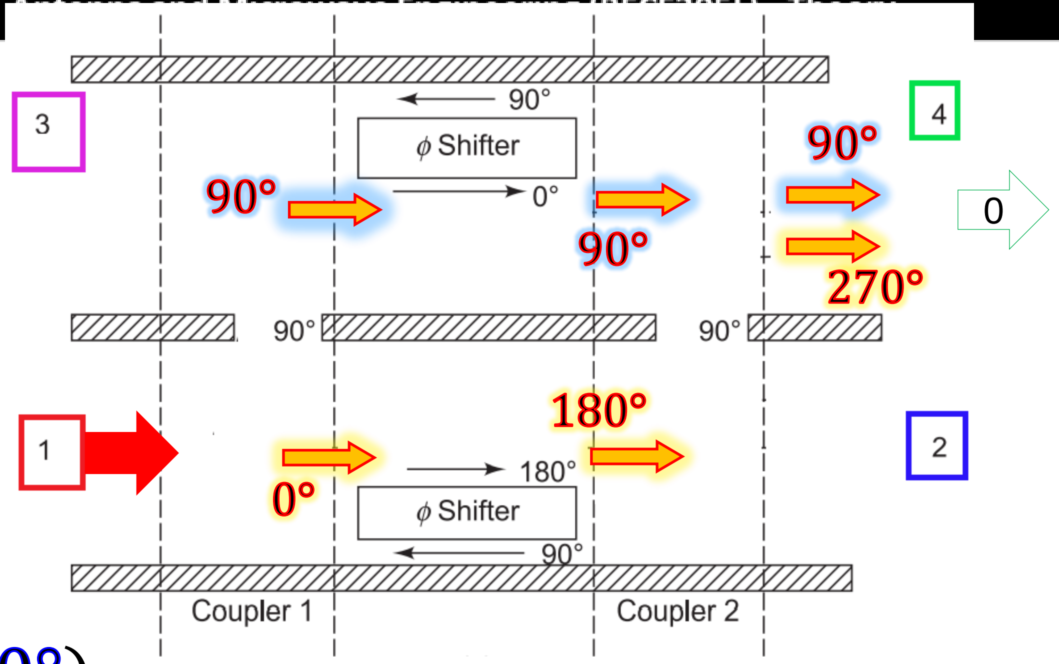

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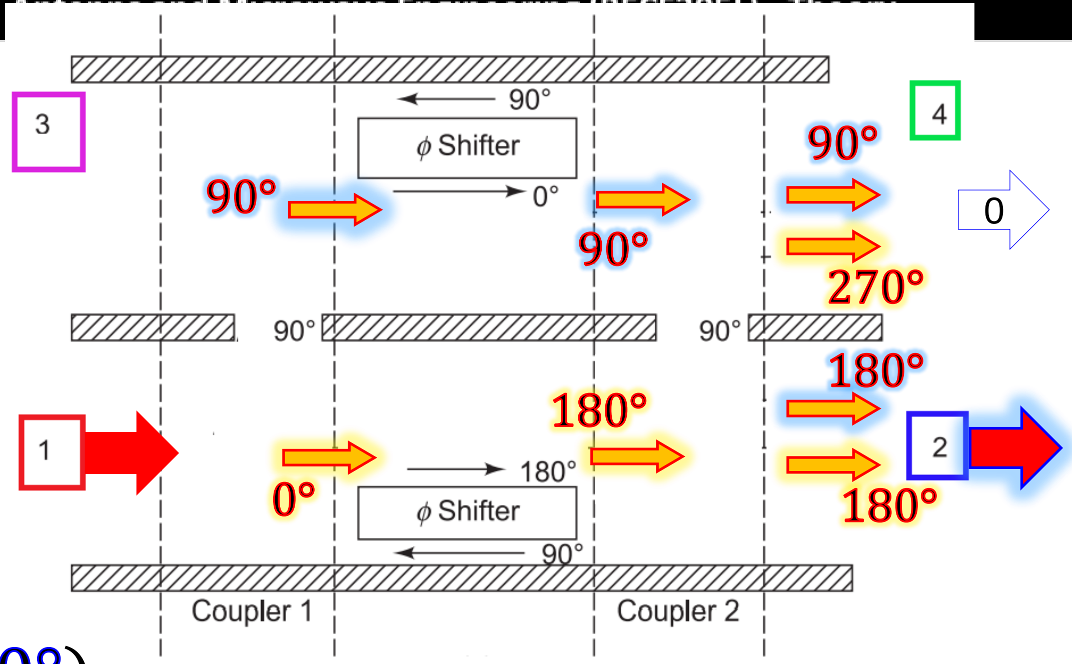

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  Summary: **port 1-> port 2**

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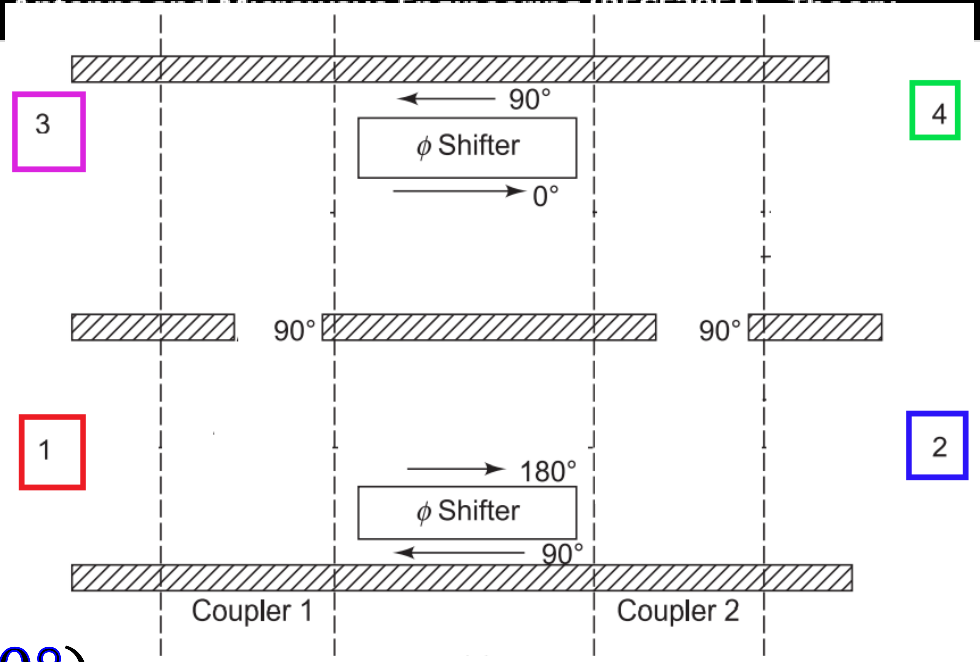

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  $\boldsymbol{Output}$ $(partly\ at\ 180°\ and\ \boldsymbol{remaining\ at\ same}\ \mathbf{180°})$ at **port 2.**
  Summary: **port 1-> port 2**
- Similarly, **port 2-> port 3;** **port 3-> port 4;** **port 4->port 1**

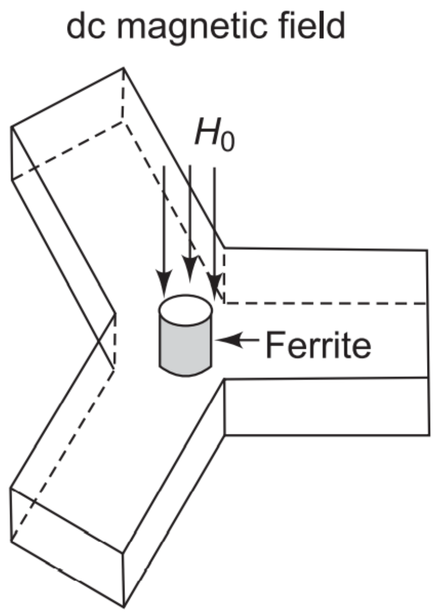
6.1 Four port Circulator

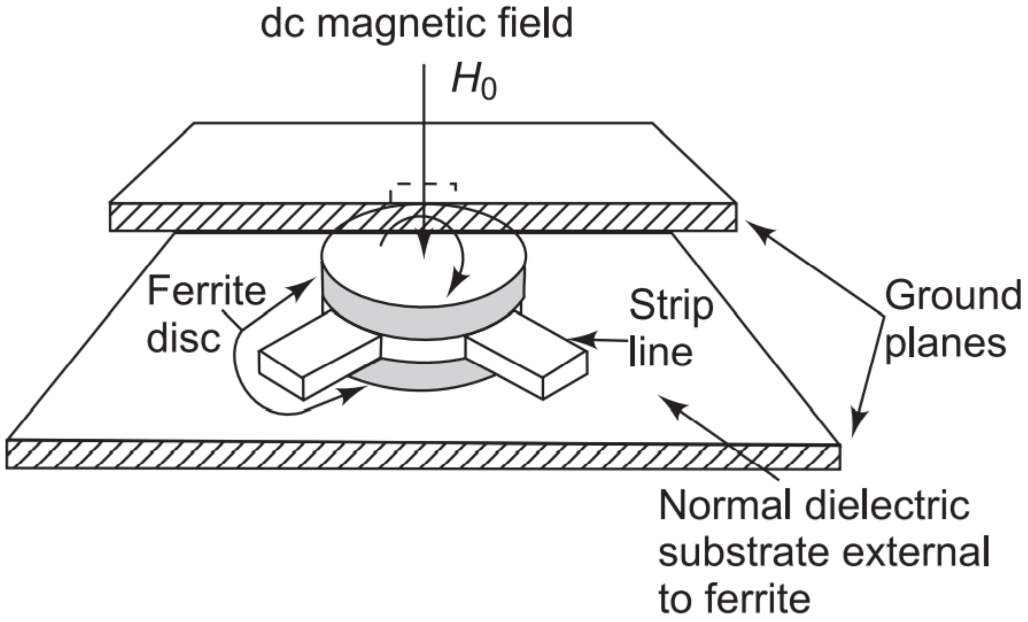
- A perfectly matched, lossless and non-reciprocal four port circulator has the S matrix:

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

6.2 Three port Circulator

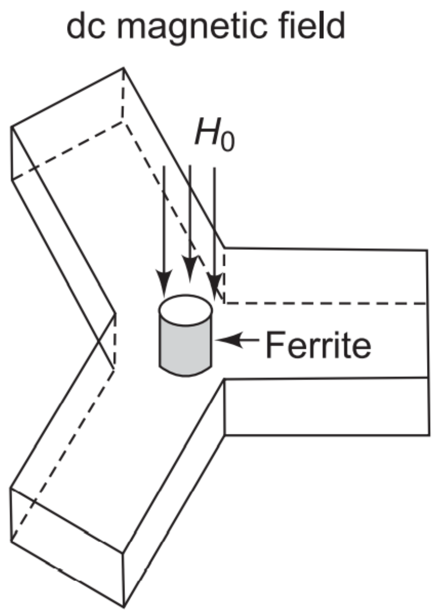
- A three port circulator is formed by a $120°$ H –plane waveguide or stripline symmetrical Y junction with a ferrite post or disc.

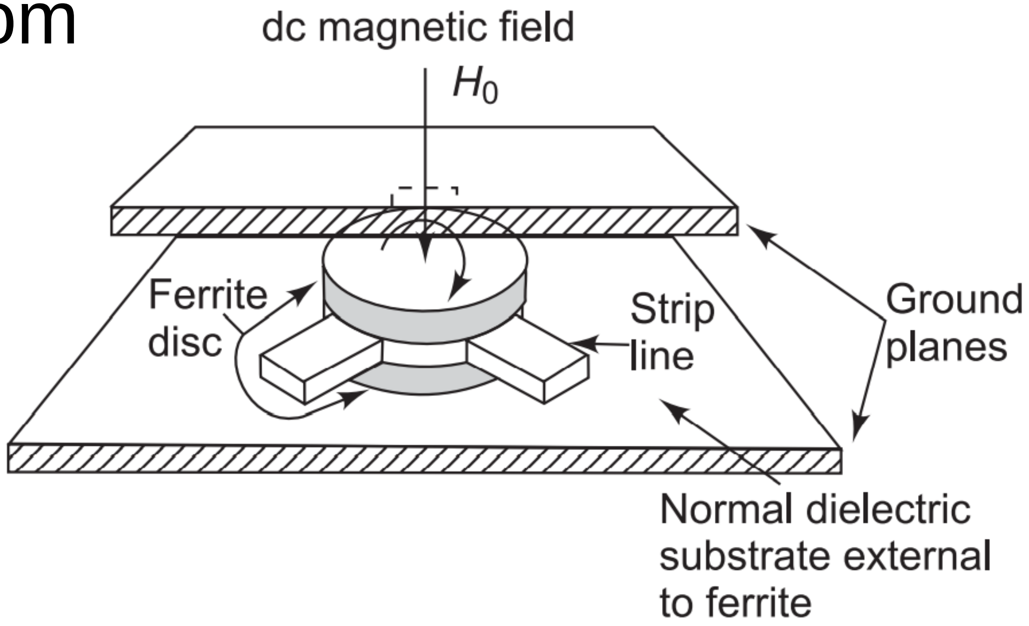




6.2 Three port Circulator

- A three port circulator is formed by a $120°$ H –plane waveguide or stripline symmetrical Y junction with a ferrite post or disc.
- A steady magnetic field $\mathbf{H_0}$ is applied along the axis of the post/disc.
- Based on the polarization of incident wave and direction of H_0, microwave signal travels from one port to immediate next one only.





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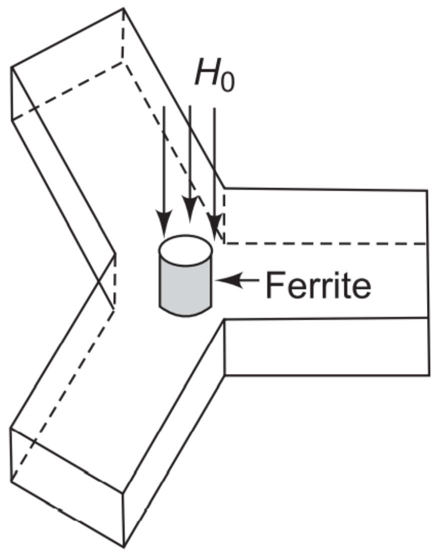
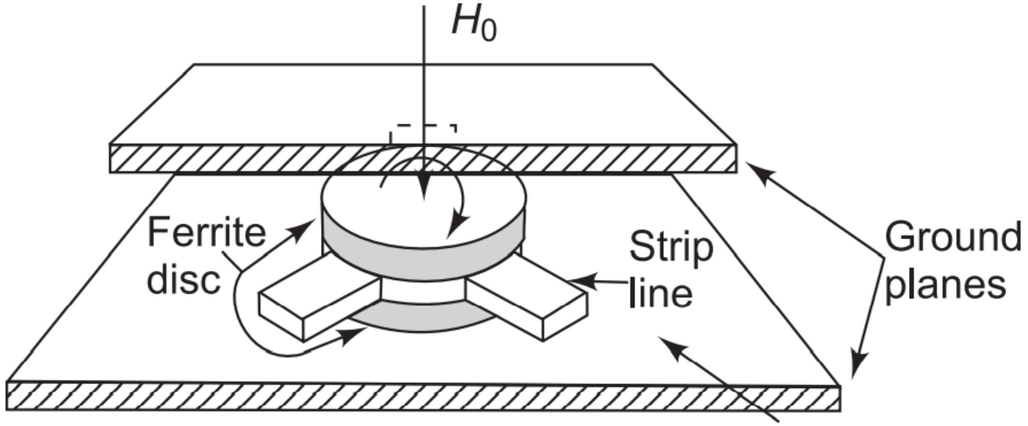
- A perfectly matched, lossless and non-reciprocal three port circulator has the S matrix:

$$[S] = \begin{bmatrix} 0 & 0 & S_{13} \\ S_{21} & 0 & 0 \\ 0 & S_{32} & 0 \end{bmatrix}$$





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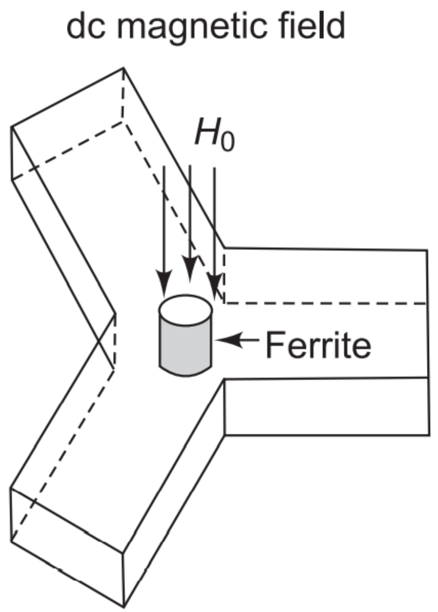
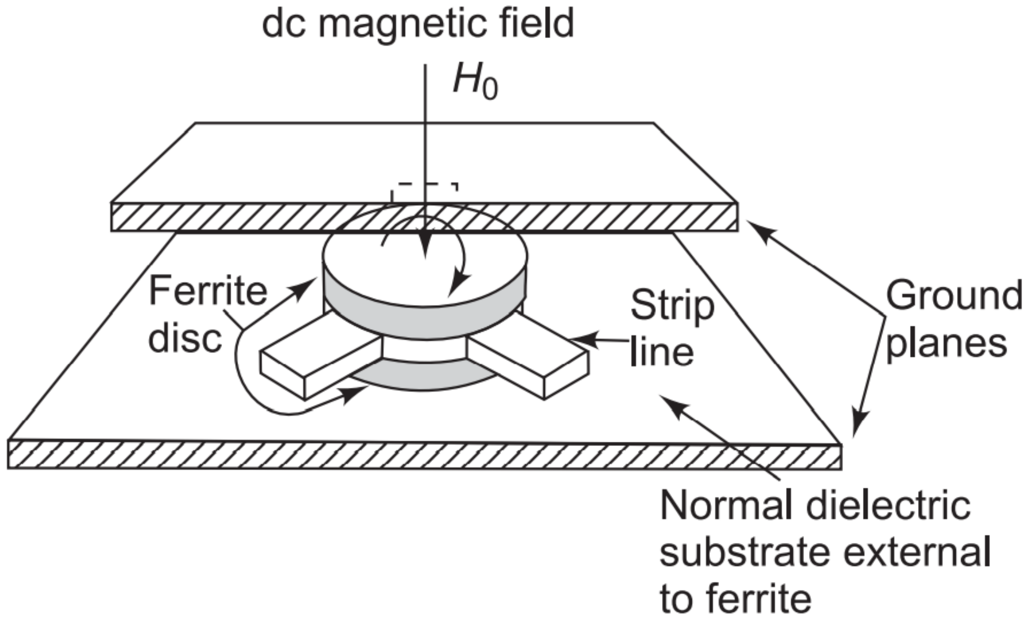
- By proper choice of terminal planes, phase angles of S_{13}, S_{21}, S_{32} are made zero and

$$S_{13} = S_{21} = S_{32} = 1$$

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





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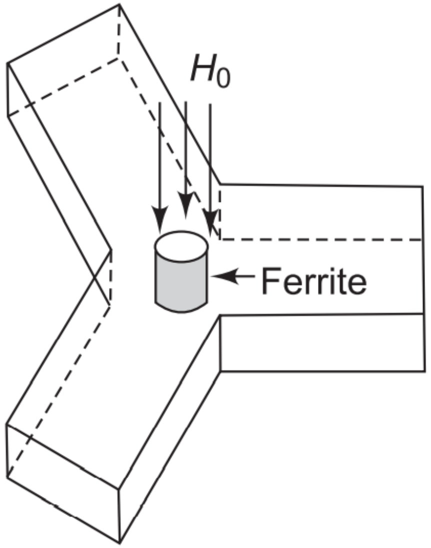
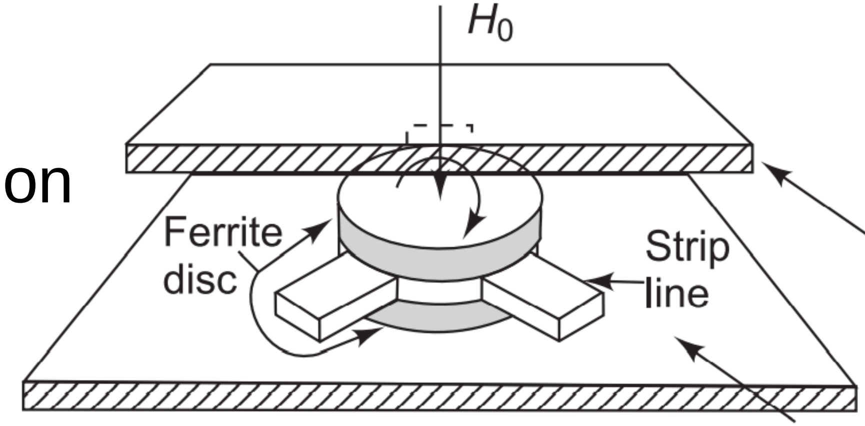
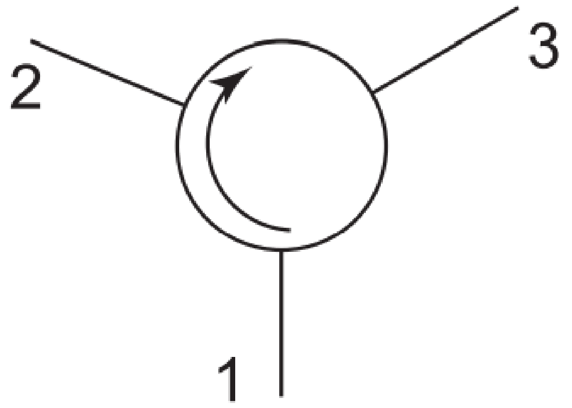
Practically, finite isolation
Insertion loss <1dB
Isolation≈30-40dB
VSWR<1.5





6.3 Problem: A three port circulator has an insertion loss of 1dB, Isolation 30dB and VSWR 1.5. Find the S matrix.



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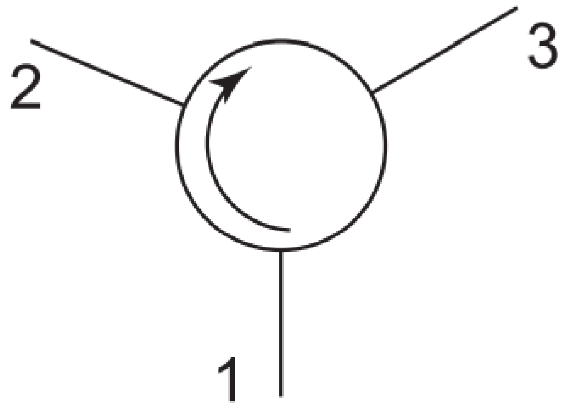
- $[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}$ S matrix of 3 port circulator



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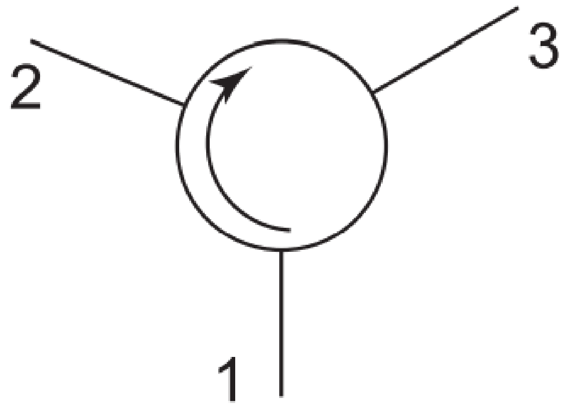
- Insertion loss=1dB=$-20\log_{10}|S_{21}|$
  $|S_{21}| = 10^{-1/20} = 0.89$



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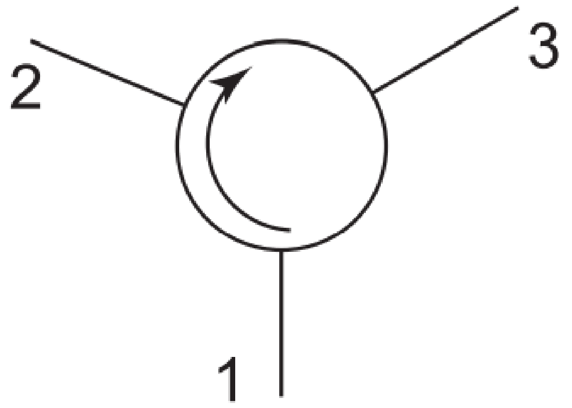

- Insertion loss=1dB=$-20\log_{10}|S_{21}|$
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Same insertion loss between ports (1,2), and (2,3) and (3,1) $|S_{21}| = |S_{32}| = |S_{13}| = 0.89$

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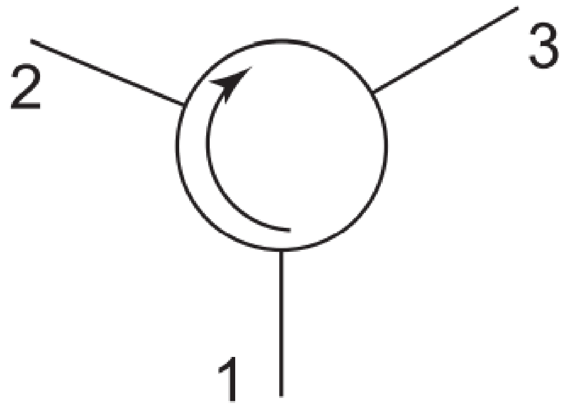

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- Isolation between ports is $30dB = -20\log_{10}|S_{31}|$
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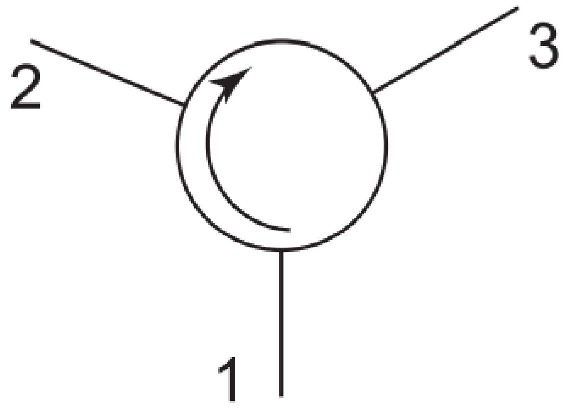

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- Isolation between ports is $30dB = -20\log_{10}|S_{31}|$
  $|S_{31}| = 10^{-30/20} = 10^{-1.5} = 0.032 = |S_{23}| = |S_{12}|$

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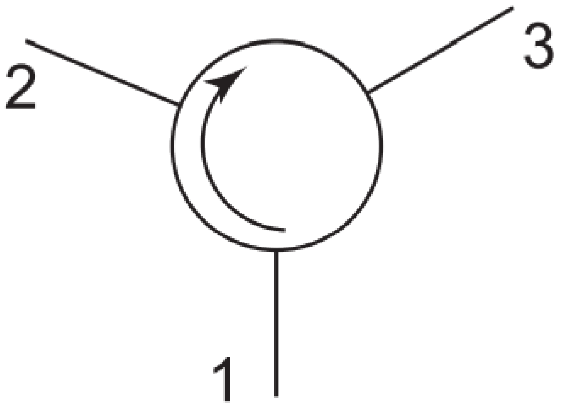

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  $|S_{31}| = 10^{-30/20} = 10^{-1.5} = 0.032 = |S_{23}| = |S_{12}|$
- $VSWR = 1.5$, reflection coefficient $|\Gamma| = \frac{S-1}{S+1} = \frac{1.5-1}{1.5+1} =$

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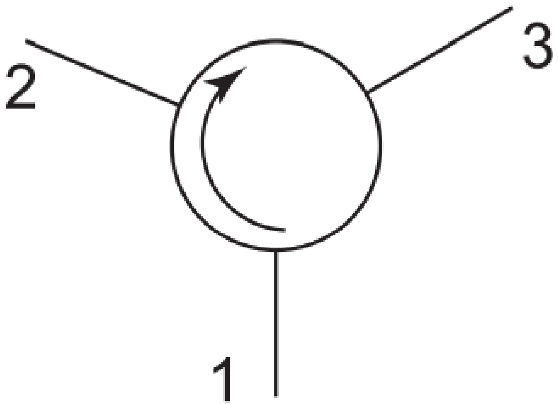

- Insertion loss=1dB=$-20\log_{10}|S_{21}|$
  $|S_{21}| = 10^{-1/20} = 0.89$

  Same insertion loss between ports (1,2), and (2,3) and (3,1) $|S_{21}| = |S_{32}| = |S_{13}| = 0.89$

- Isolation between ports is $30dB = -20\log_{10}|S_{31}|$
  $|S_{31}| = 10^{-30/20} = 10^{-1.5} = 0.032 = |S_{23}| = |S_{12}|$
- $VSWR = 1.5,$ reflection coefficient $|\Gamma| = \frac{S-1}{S+1} = \frac{1.5-1}{1.5+1} = 0.2 = |S_{11}| = |S_{22}| = |S_{33}|$

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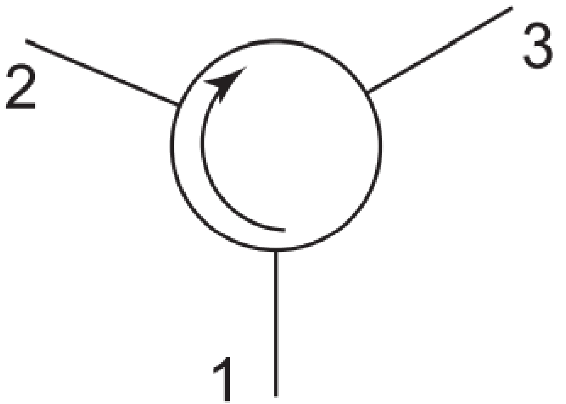

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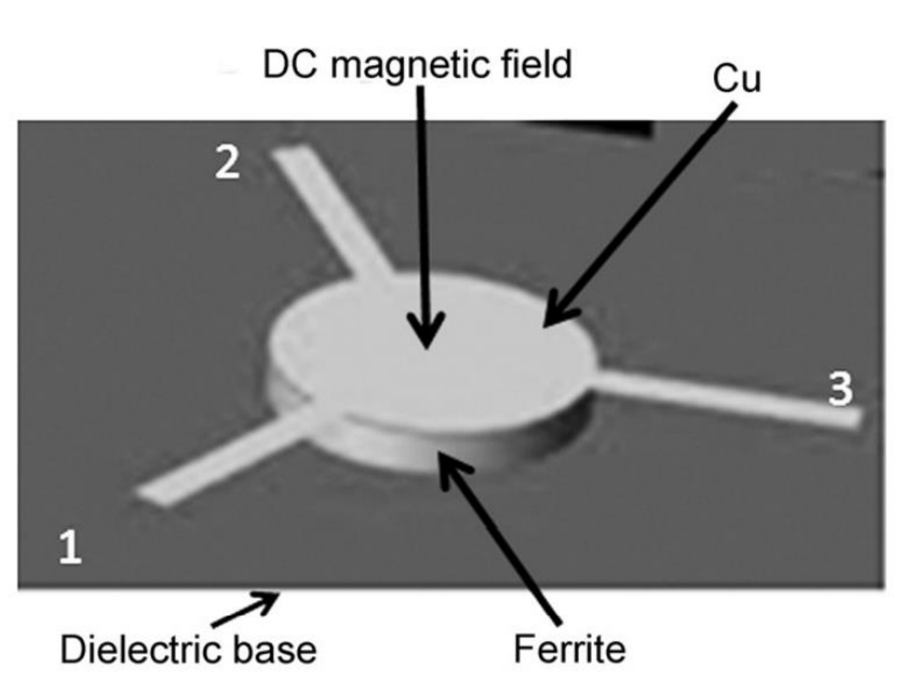
$$[S] = \begin{bmatrix} 0.2 & 0.032 & 0.89 \\ 0.89 & 0.2 & 0.032 \\ 0.032 & 0.89 & 0.2 \end{bmatrix}$$

6.4 Microstrip circulator

- Remove top ground plane in stripline
- Basic design criteria:
  Selection of radius R of ferrite disc
  Calculation of radius R of magnet cylinder for the whole ferrite substrate



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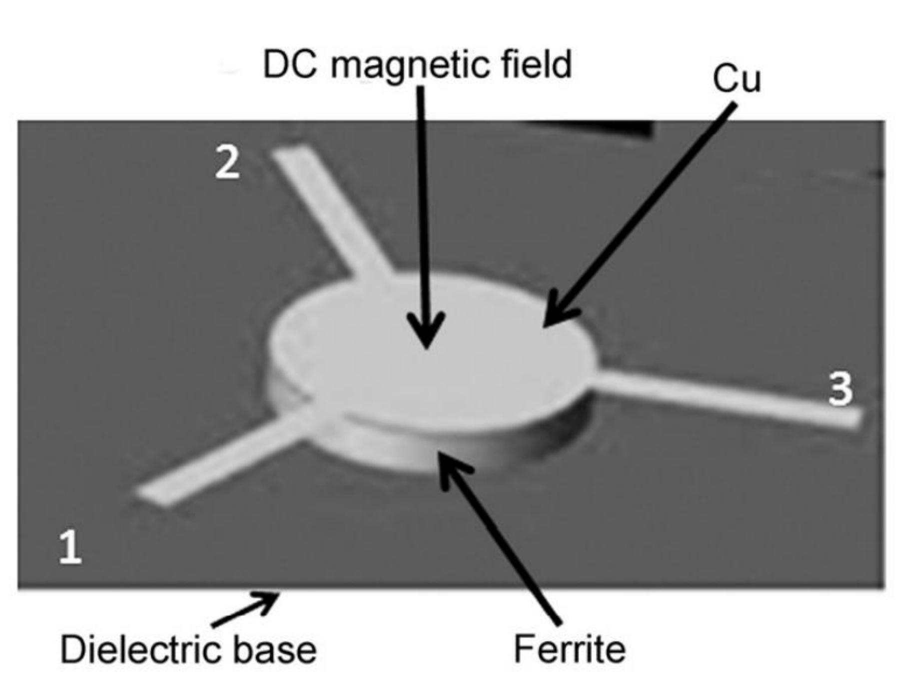

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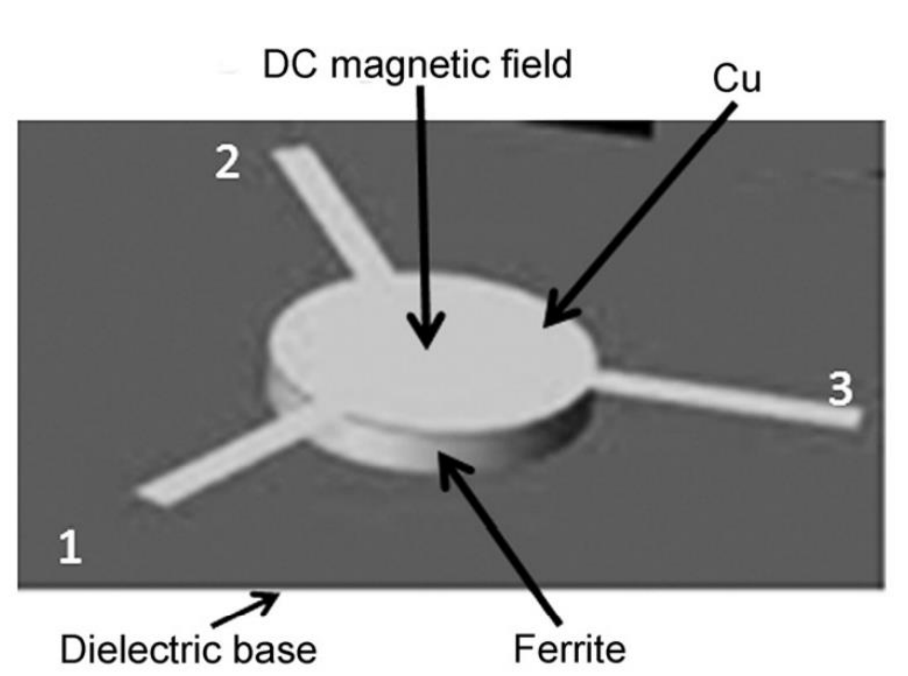

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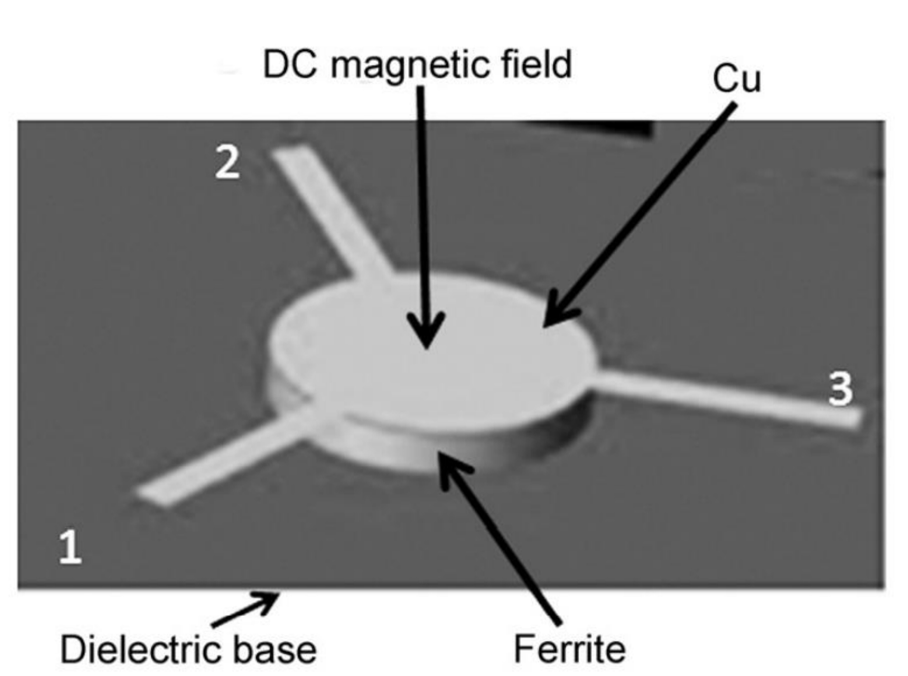

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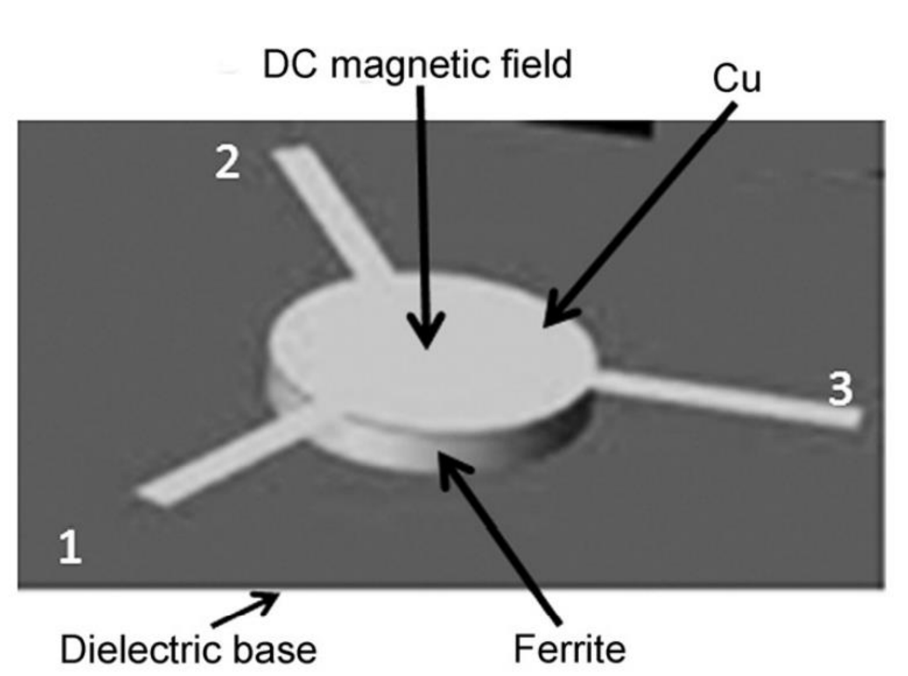

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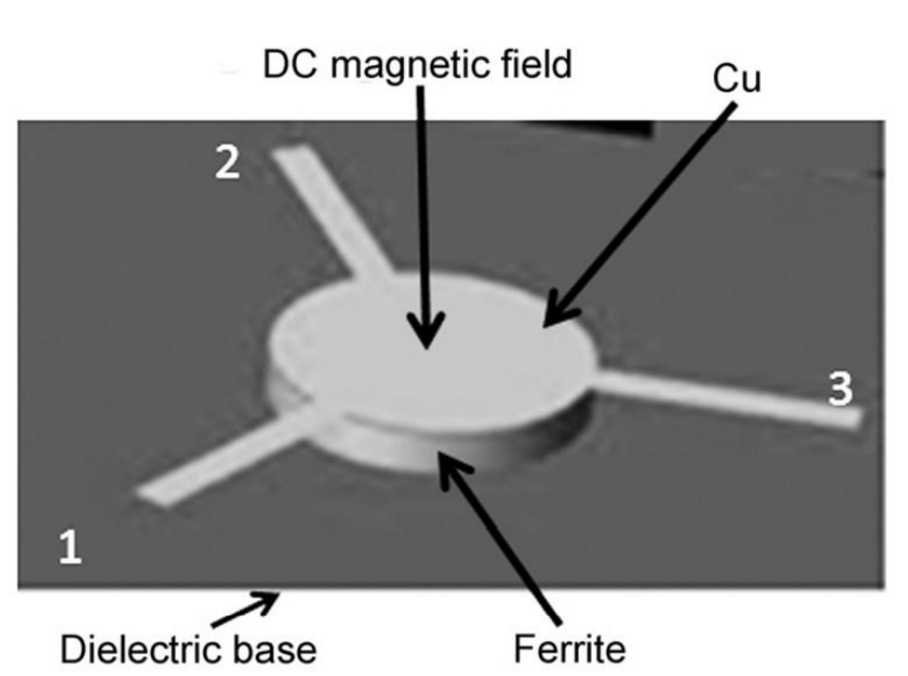

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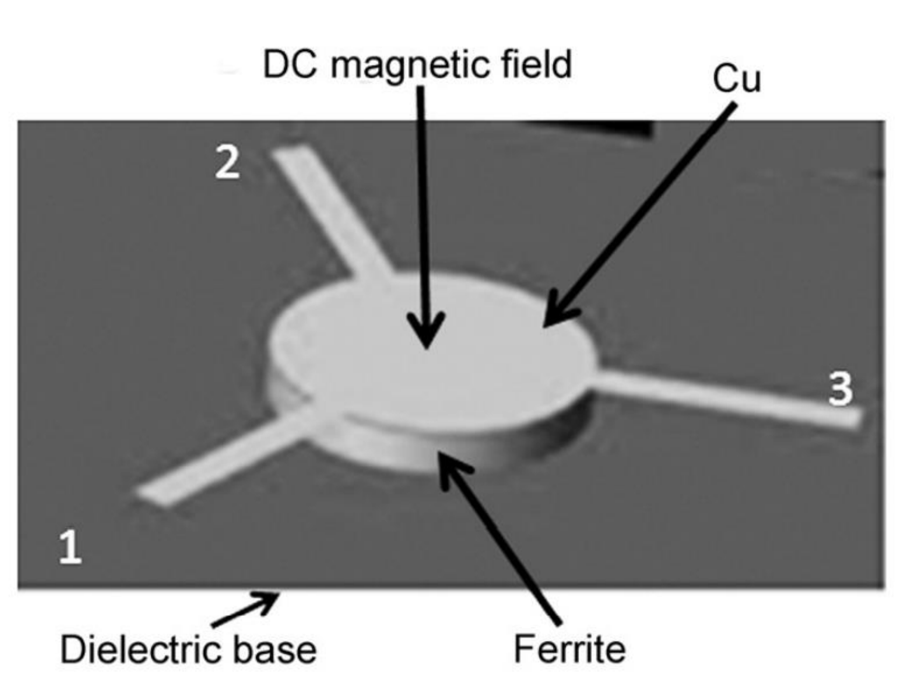

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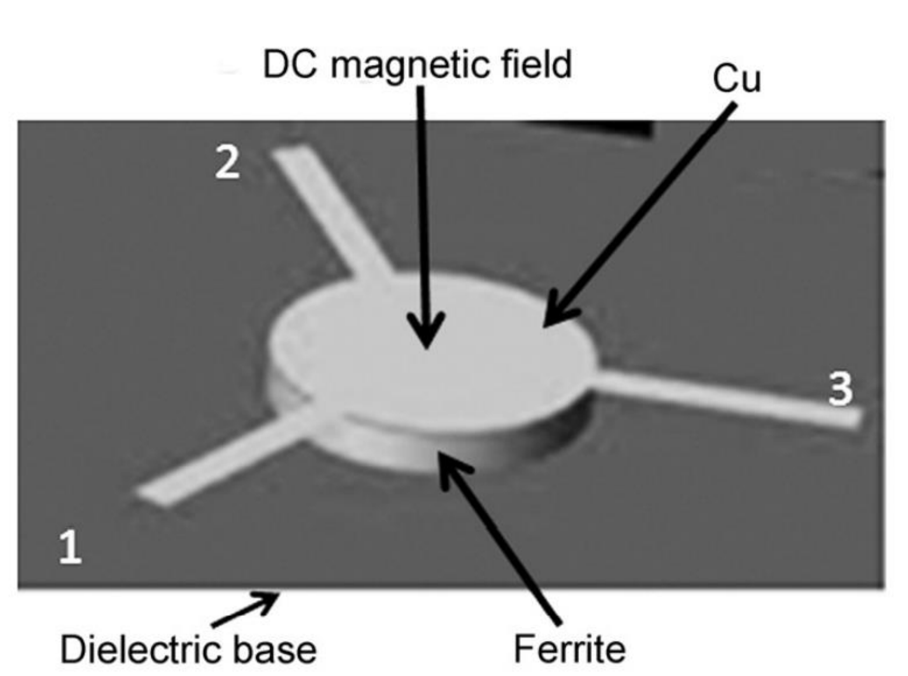

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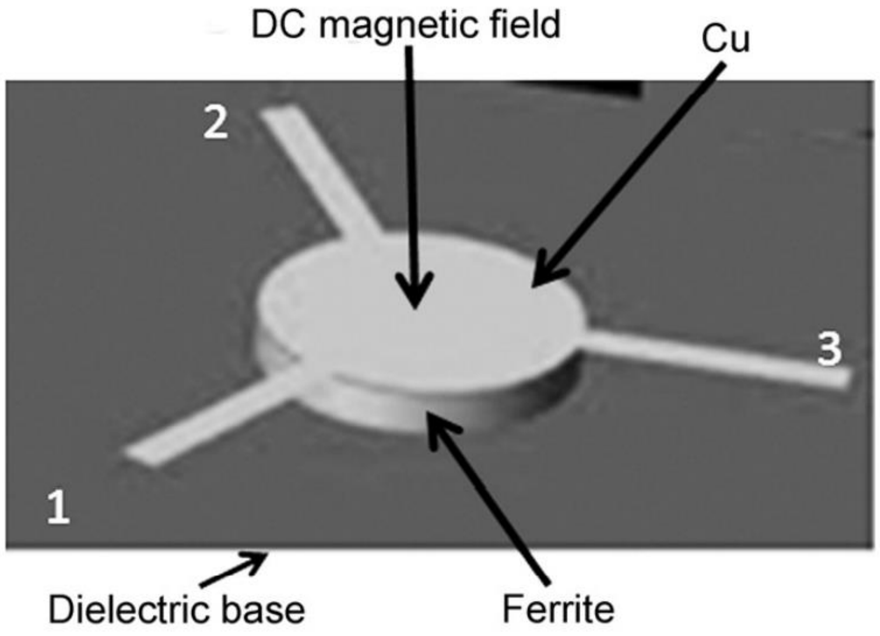

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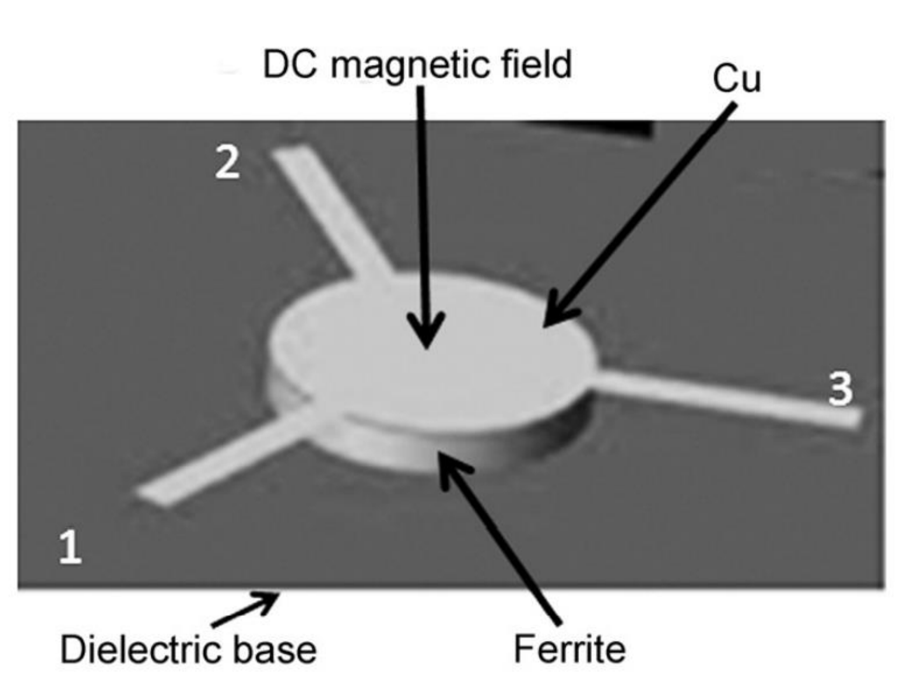
Low magnetic loss: ferrite $\dfrac{\gamma 4\pi M_s}{\omega} = \mathbf{0.6}$

6.4 Microstrip circulator

- Insertion loss between coupled ports:
  1) Copper loss of strip and ground plane
  2) Dielectric loss of input/output strips
  3) Magnetic loss of ferrite disc



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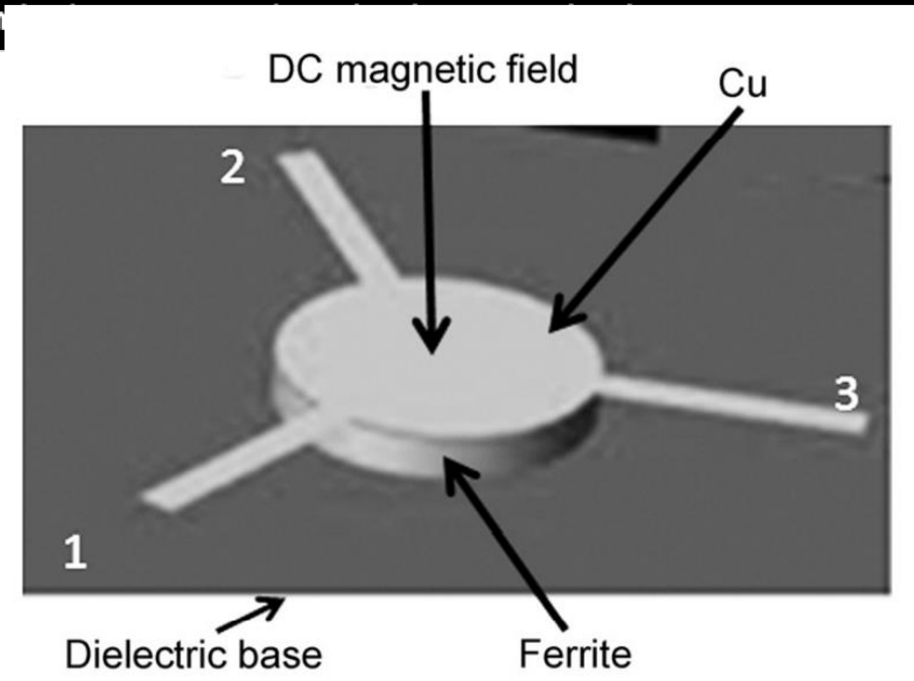

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- Isolation between ports – primarily dependent on mismatching between ports and junction.

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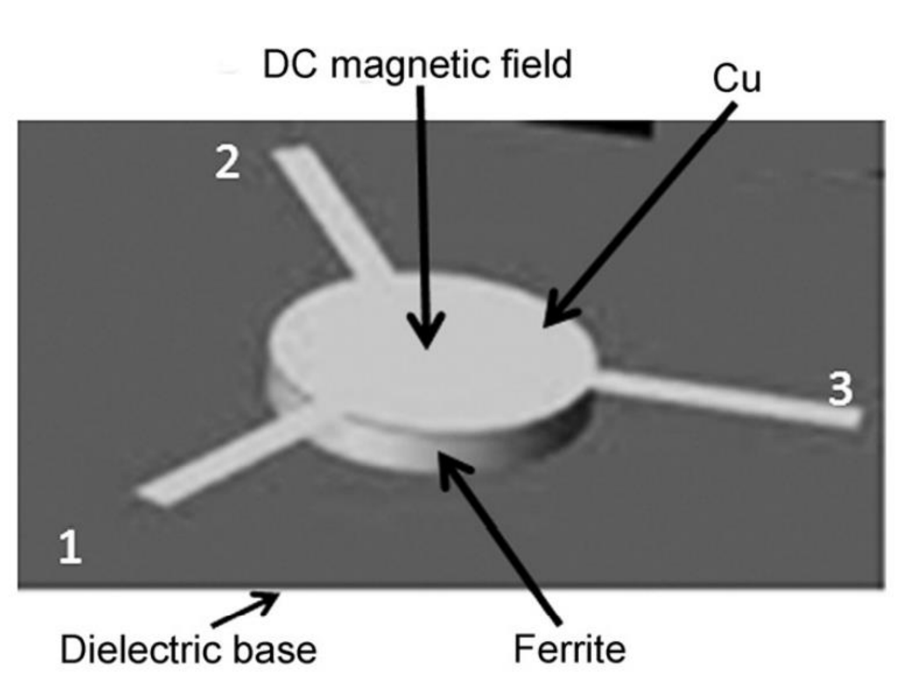

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- Tuning screws can be used for matching, this can be the parts of the mask used in photo-etching process. Magnetic disc – above or below substrate.

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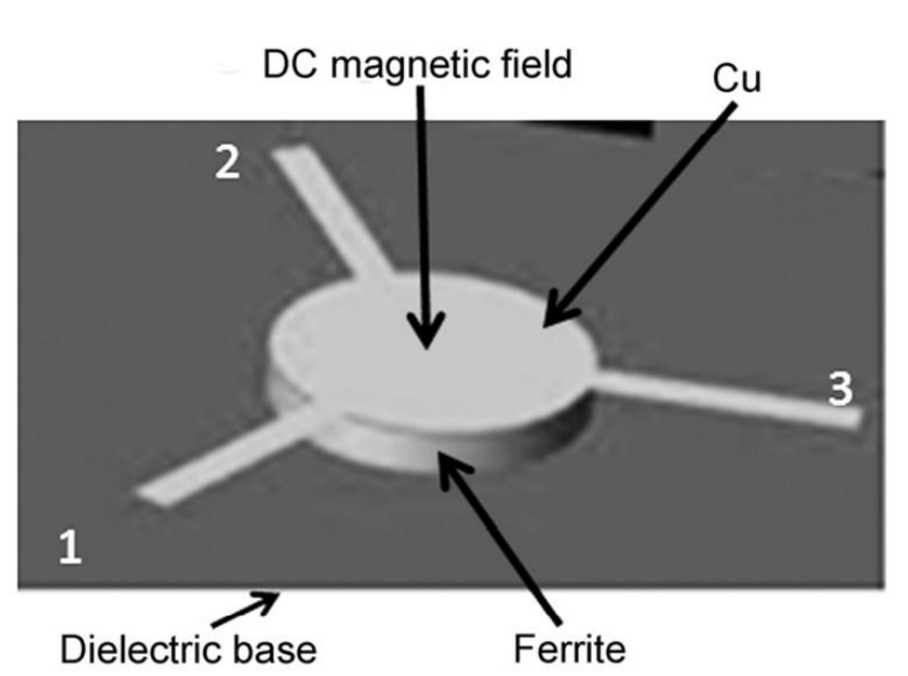

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- **YIG** (Yttrium Iron Garnet) substrate of thickness $h = 0.055$“: Isolation>20dB, VSWR<1.2, Insertion loss IL<0.8dB, Power handling of 60W over frequency range of $8.5 - 9.9GHz$

6.4 Microstrip circulator

- Power handling capability of such device can be increased by
  1) Lowering the impedance or increasing intrinsic line width.
  2) Increasing substrate thickness h
  3) Decreasing $4\pi M_S$ of the material by substituting Al ions in YIG material.