5.4 E-Plane Tee, H-Plane Tee, Magic Tee

Module:5 Microwave Passive components

Course: BECE305L – Antenna and Microwave Engineering

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VIT®

Vellore Institute of Technology

(Deemed to be University under section 3 of UGC Act, 1956)

CHENNAI

Module:5 Microwave Passive components
6 hours

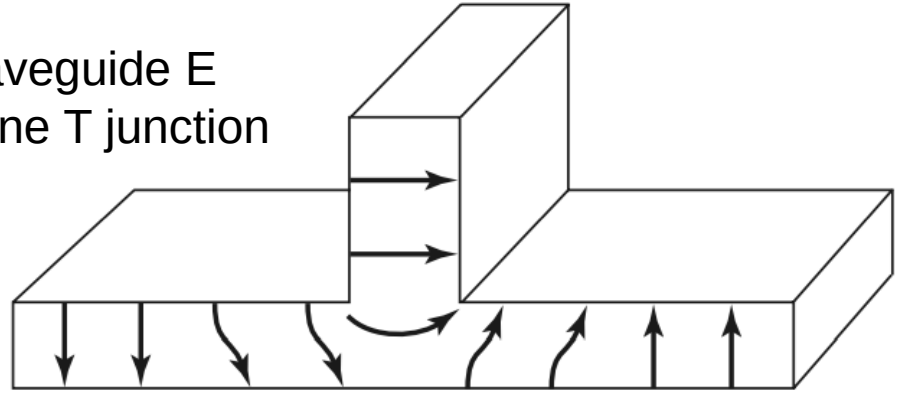
- Microwave Networks - ABCD, ‘S’ parameter and its properties. E-Plane Tee, H-Plane Tee, Magic Tee and Multi-hole directional coupler. Principle of Faraday rotation, isolator, circulator and phase shifter.

- Source of the contents: Pozar

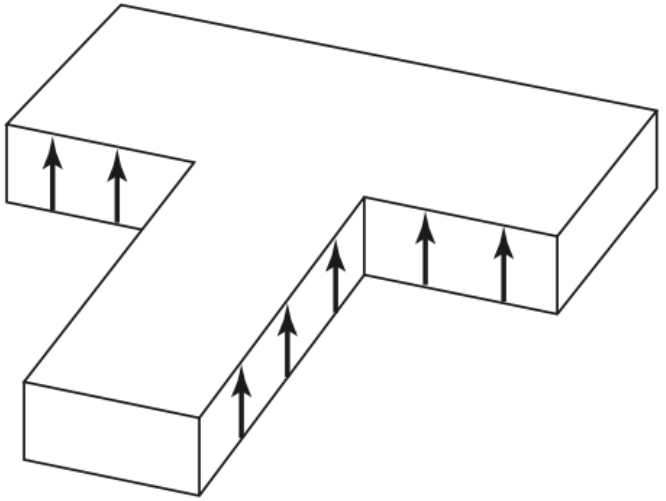
4.1 T-junction power divider

- A simple three-port network that can be used for power division or power combining,
- Can be implemented in virtually any type of transmission line medium.
- In the absence of transmission line loss, **lossless junctions**.

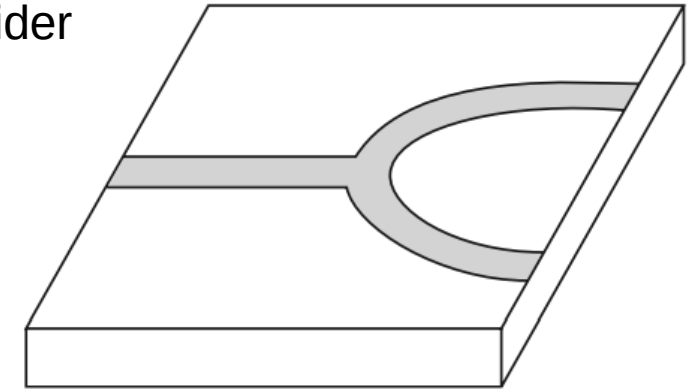
Waveguide E plane T junction



Waveguide H plane T junction



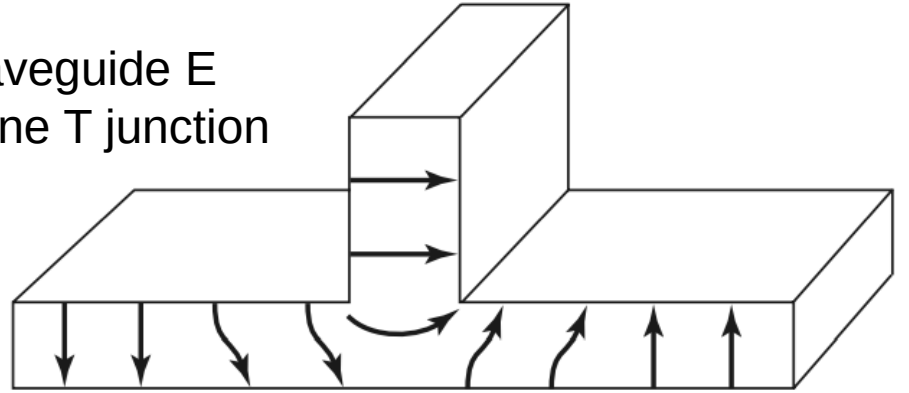
Microstrip T junction divider



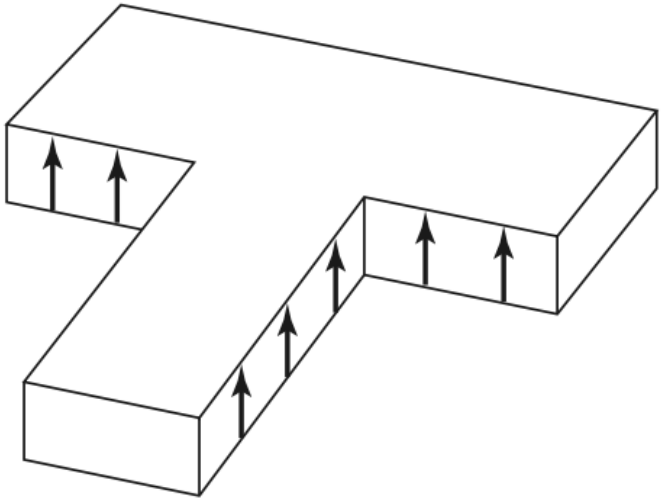
4.1 T-junction power divider

- A simple three-port network that can be used for power division or power combining,
- Can be implemented in virtually any type of transmission line medium.
- In the absence of transmission line loss, lossless junctions.
- Thus, **such junctions cannot be matched simultaneously at all ports**.
- But the **resistive power divider, which can be matched at all ports** but is **not lossless**. (Power dissipated in resistors)

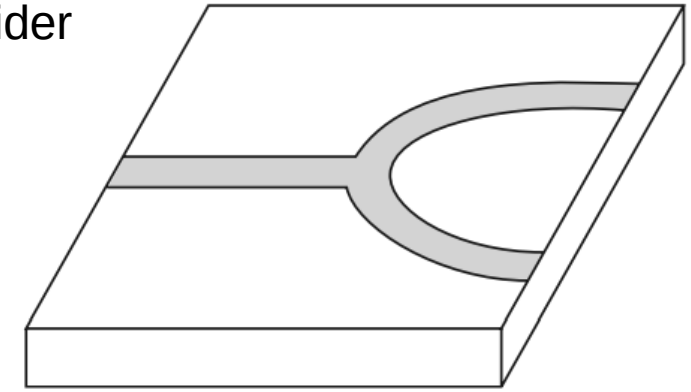
Waveguide E plane T junction



Waveguide H plane T junction

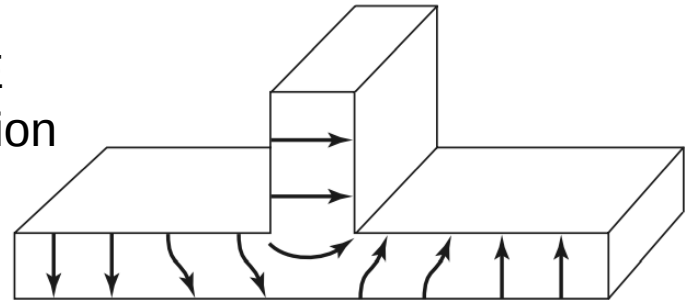


Microstrip T junction divider

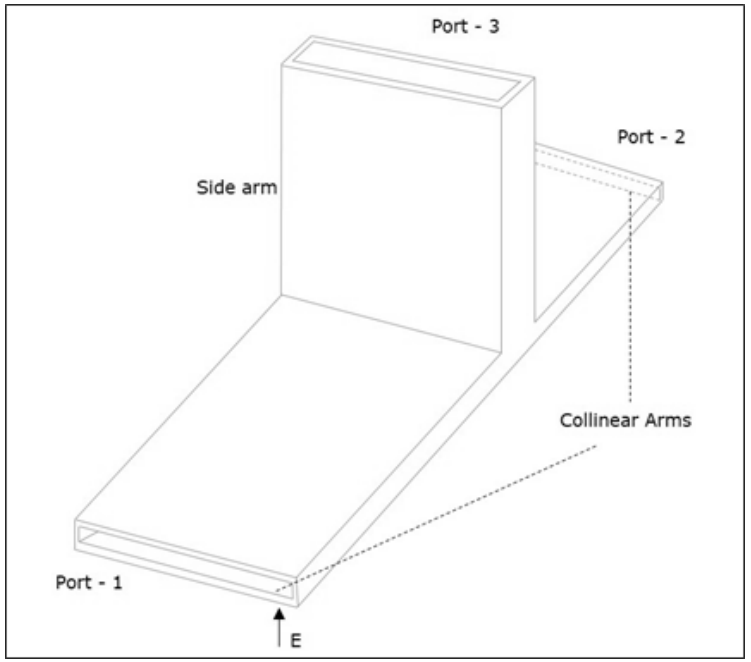


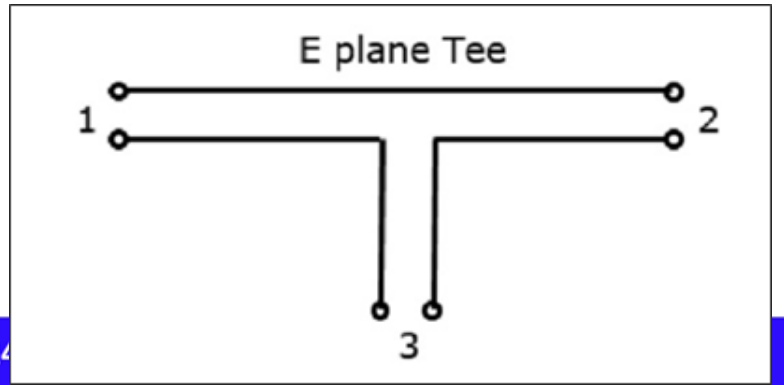
4.2 S-matrix analysis of E-Plane Tee

Waveguide E plane T junction



- Attaching simple waveguide (**port 3 – side arm: E-arm**) to the broader dimension of rectangular waveguide (**Ports 1 and 2 are collinear arms**).
- **Side arm is parallel** to **E field** of collinear arms.
- **Voltage or Series junction**.





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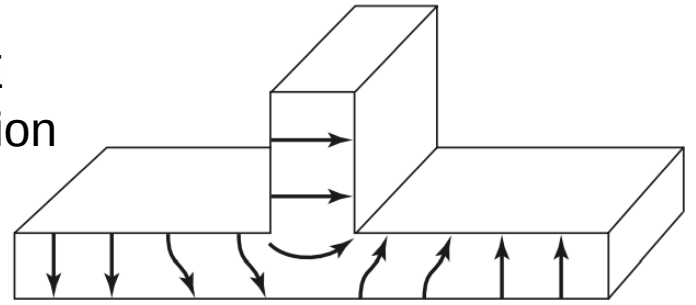
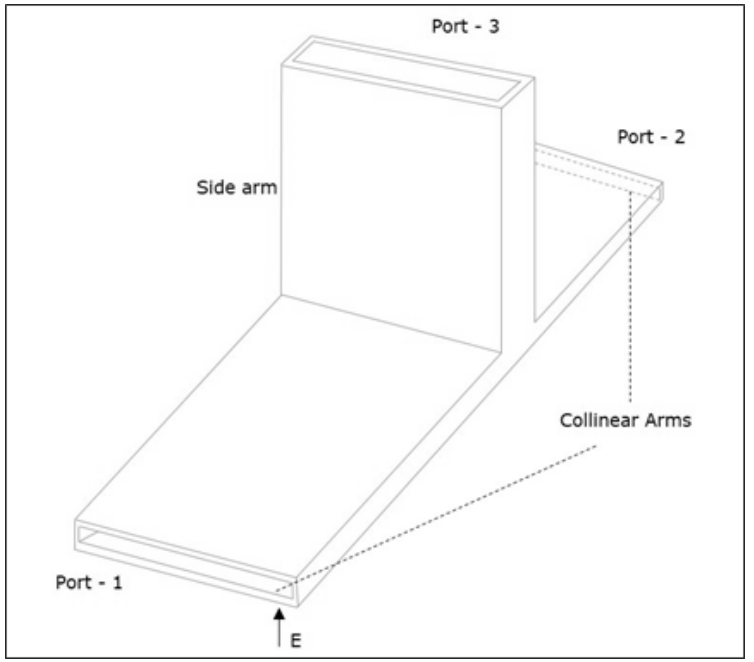
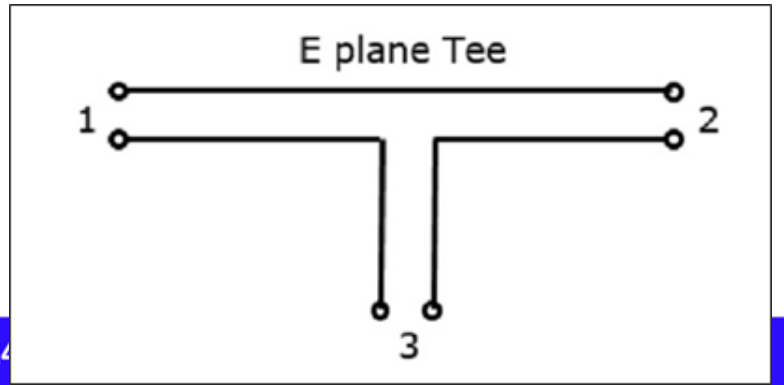
Waveguide E plane T junction



- Attaching simple waveguide (**port 3 – side arm: E-arm**) to the broader dimension of rectangular waveguide (Ports 1 and 2 are collinear arms).
- Side arm is parallel to E field of collinear arms.
- Voltage or Series junction.
- **Ports 1 and 2 are 180° out of phase** with each other.
- Connection made by side arm to bidirectional waveguide to form parallel port.

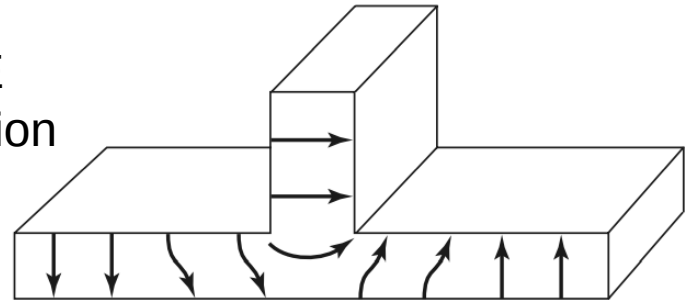


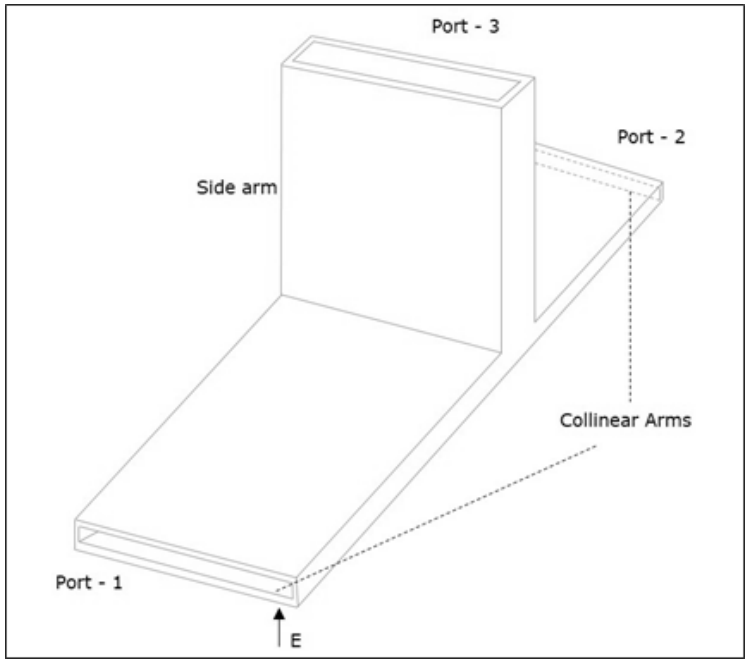


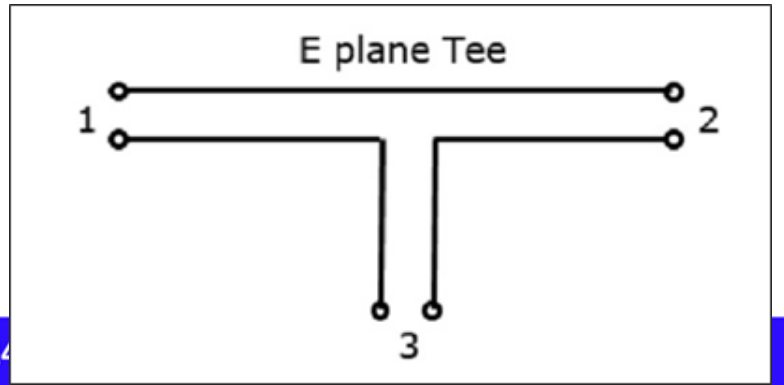
4.3 Properties of E plane Tee

- S matrix $[S]_{3\times3}$ matrix
- with $S_{13} = -S_{23}$ (180° out of phase in collinear arms.

Waveguide E plane T junction







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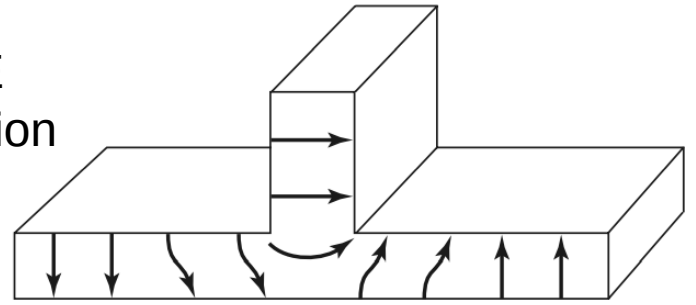
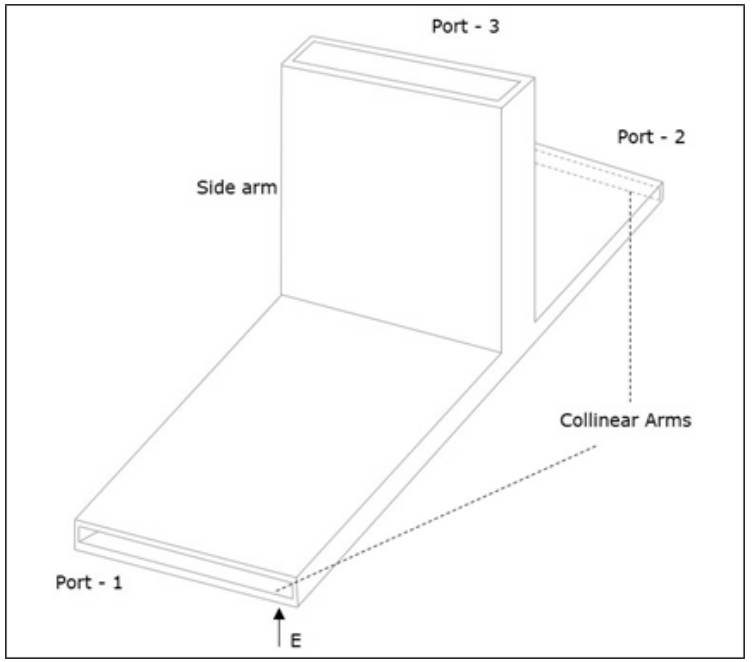
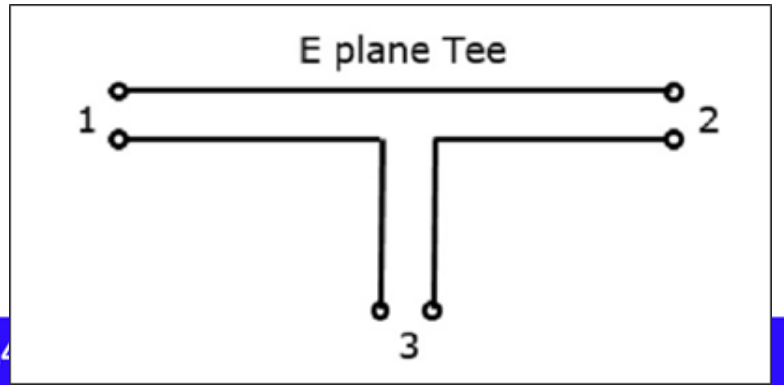


- S matrix $[S]_{3\times3}$ matrix
- with $S_{13} = -S_{23}$ (180° out of phase in collinear arms.
- At **port 3 – perfectly matched**, $S_{33} = 0$
- Symmetric property $S_{ij} = S_{ji}$

$$S_{12} = S_{21}\ ; \quad S_{23} = S_{32} \quad ; \quad S_{13} = S_{31}$$





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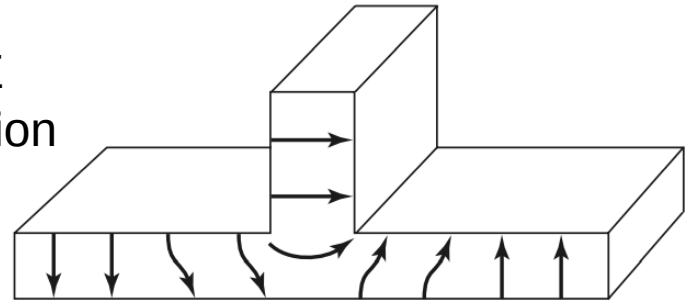

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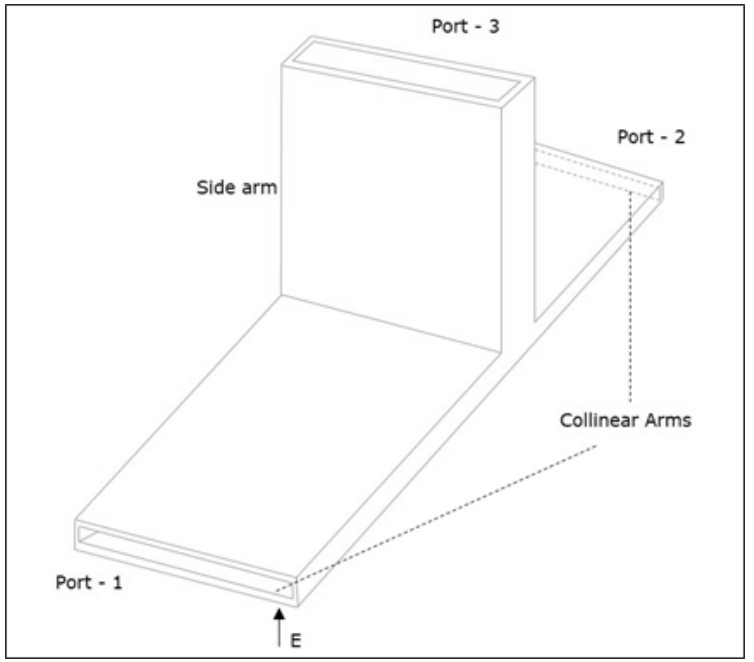
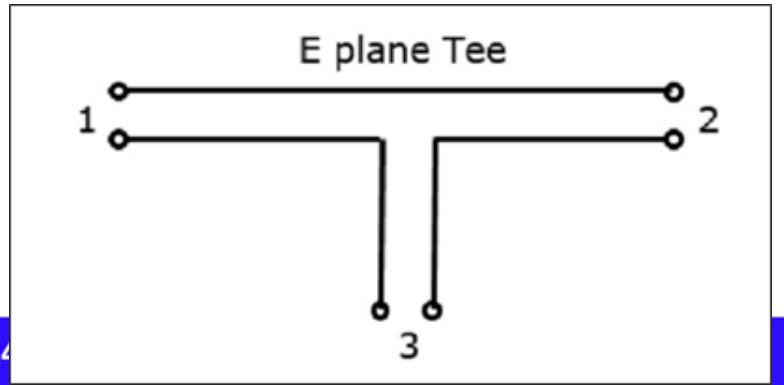
$$S_{12} = S_{21}\ ;\quad S_{23} = S_{32}\quad ;\quad S_{13} = S_{31}$$

- $$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & -S_{13} \\ S_{13} & -S_{13} & 0 \end{bmatrix}$$





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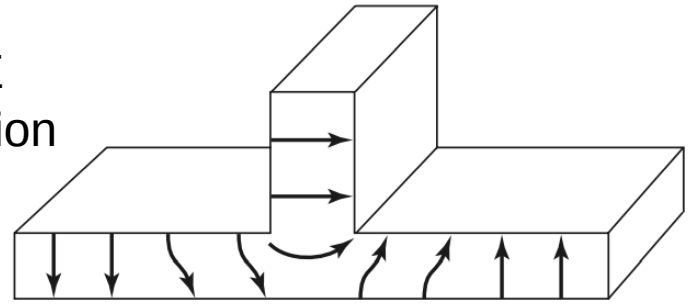
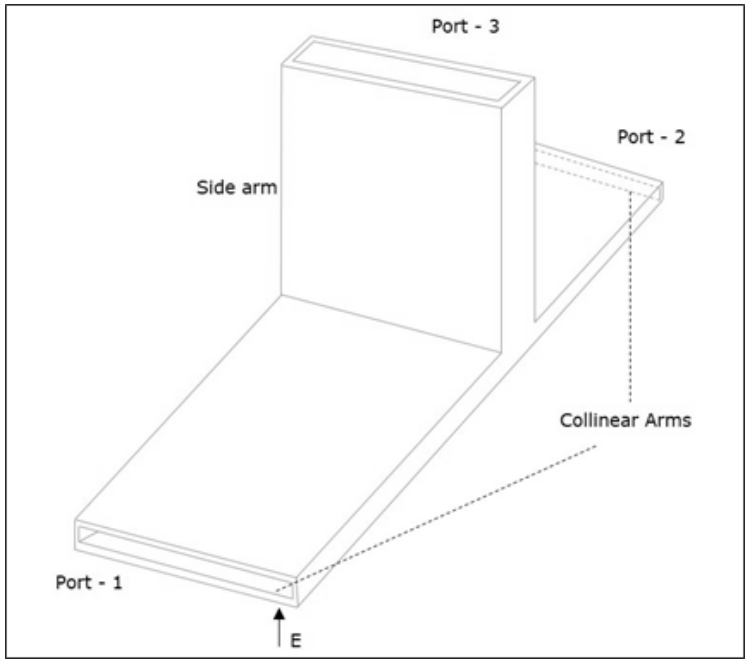
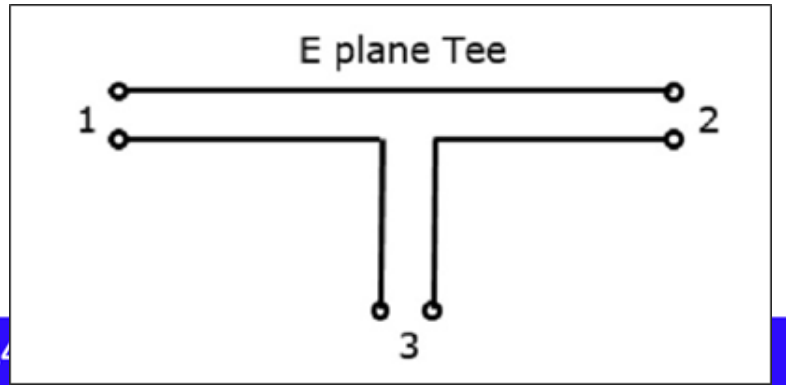
- $[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & -S_{13} \\ S_{13} & -S_{13} & 0 \end{bmatrix}$
- With unitary property $[S][S]^* = [I]$
- $\begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & -S_{13} \\ S_{13} & -S_{13} & 0 \end{bmatrix} \begin{bmatrix} S_{11}^* & S_{12}^* & S_{13}^* \\ S_{12}^* & S_{22}^* & -S_{13}^* \\ S_{13}^* & -S_{13}^* & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$

Waveguide E plane T junction







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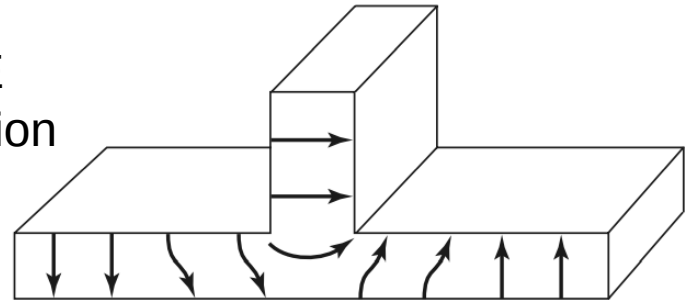
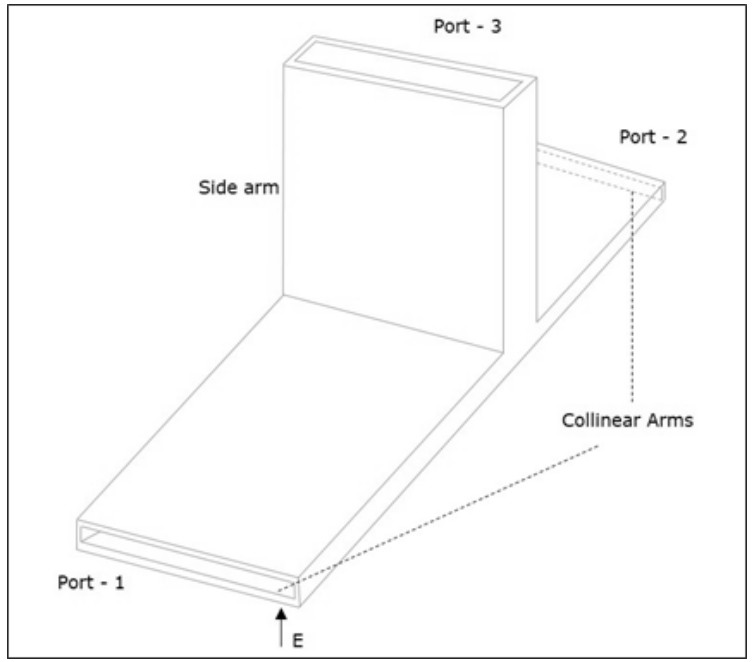
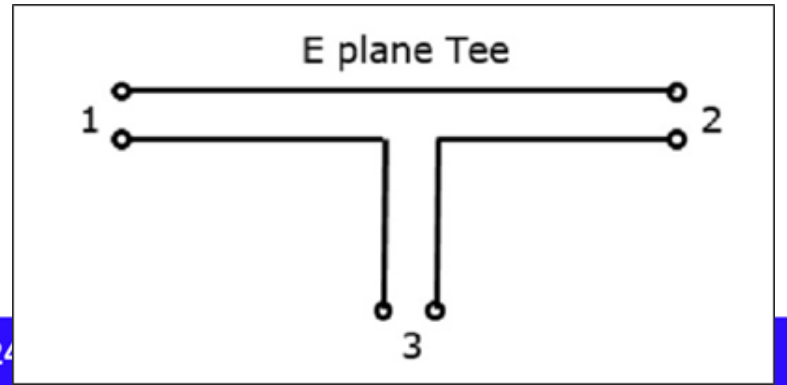
- R_1C_1: $|S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 = 1$
- R_2C_2: $|S_{12}|^2 + |S_{22}|^2 + |S_{13}|^2 = 1 \quad S_{11} = S_{22}$

Waveguide E plane T junction

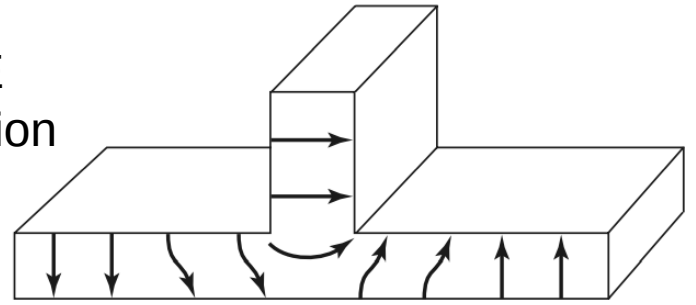






4.3 Properties of E plane Tee

Waveguide E plane T junction



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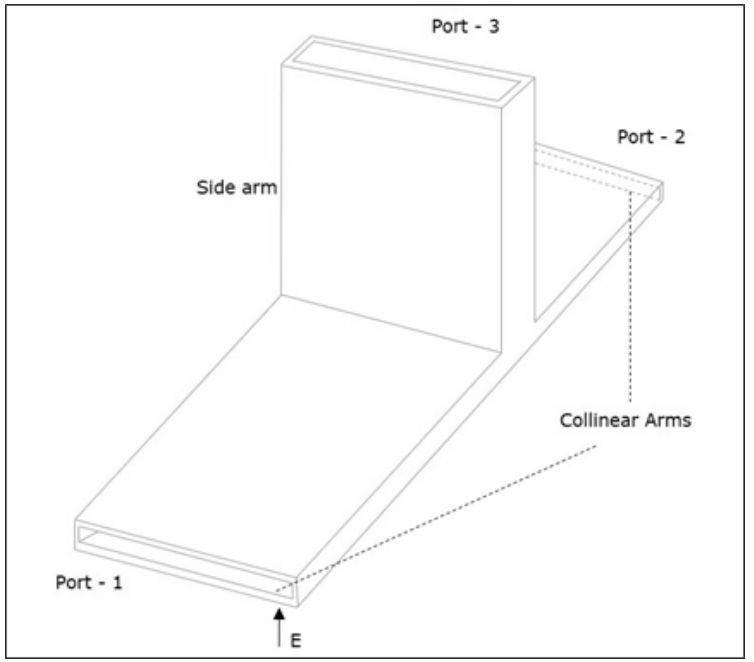
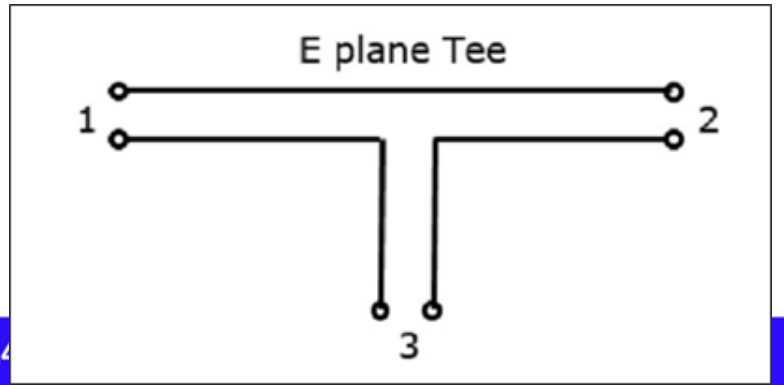
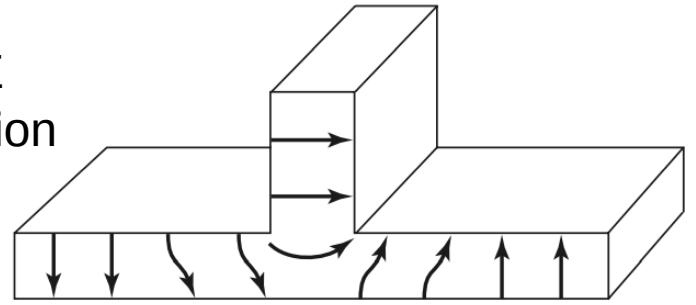
- R_3C_3: $|S_{13}|^2 + |S_{13}|^2 = 1 \quad : S_{13} = 1/\sqrt{2}$





4.3 Properties of E plane Tee

Waveguide E plane T junction



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- R_1C_1: $|S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 = 1$
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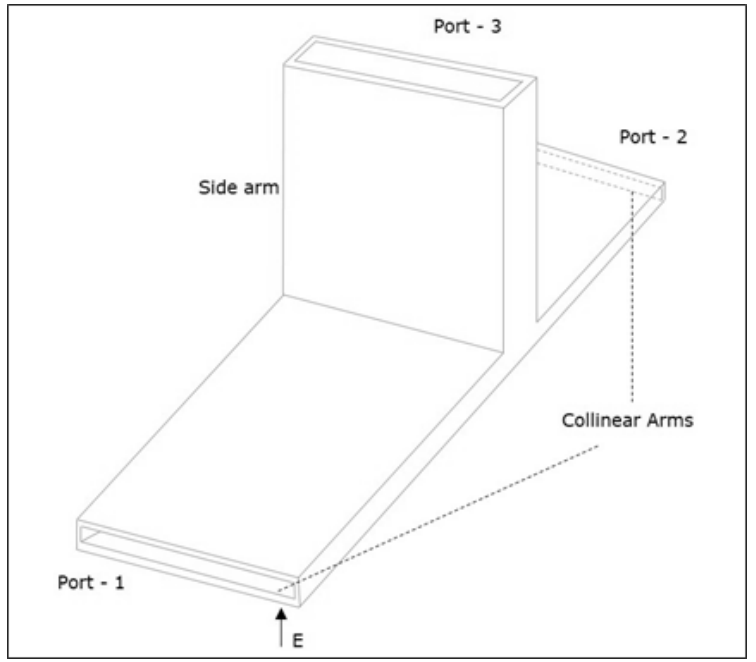
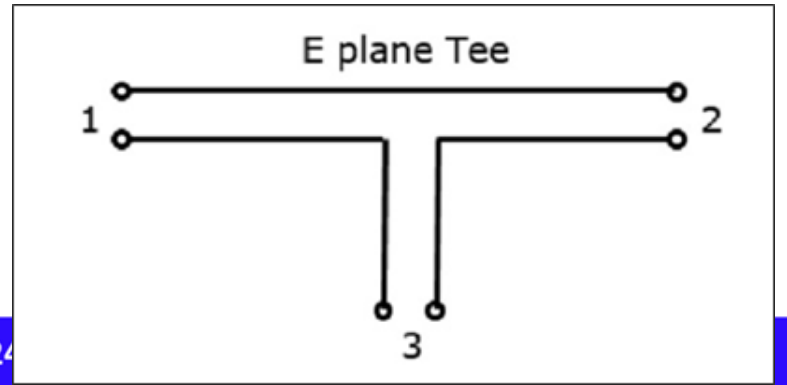
- R_3C_3: $|S_{13}|^2 + |S_{13}|^2 = 1 \quad : S_{13} = 1/\sqrt{2}$
- R_3C_1: $S_{13}(S_{11}^* - S_{12}^*) = 0 \quad : S_{11} = S_{12}$





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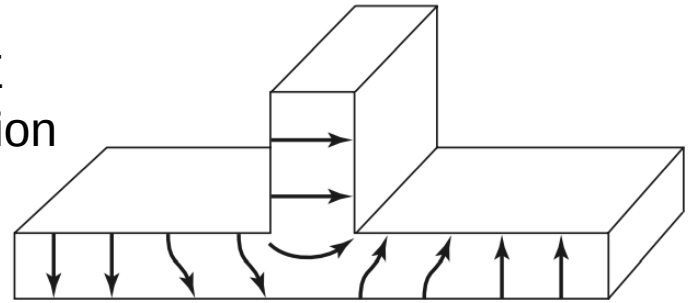
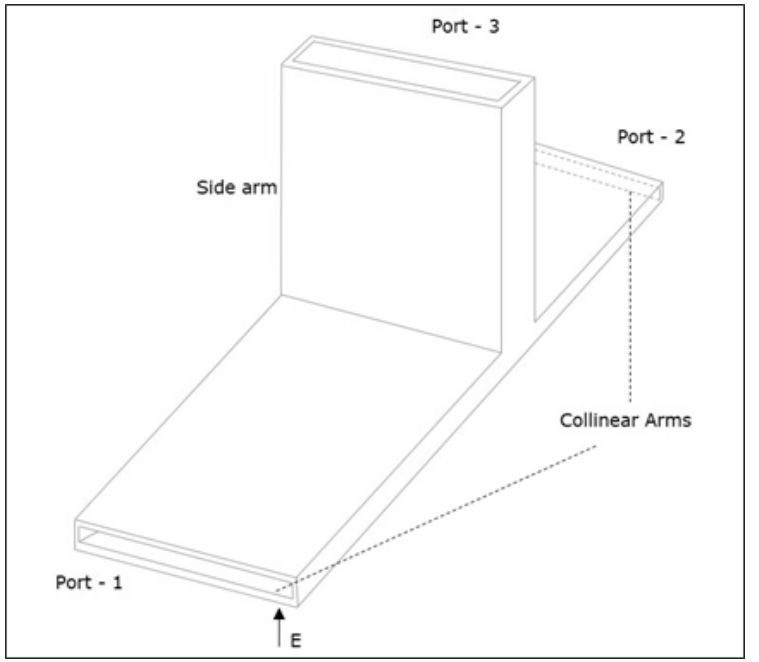
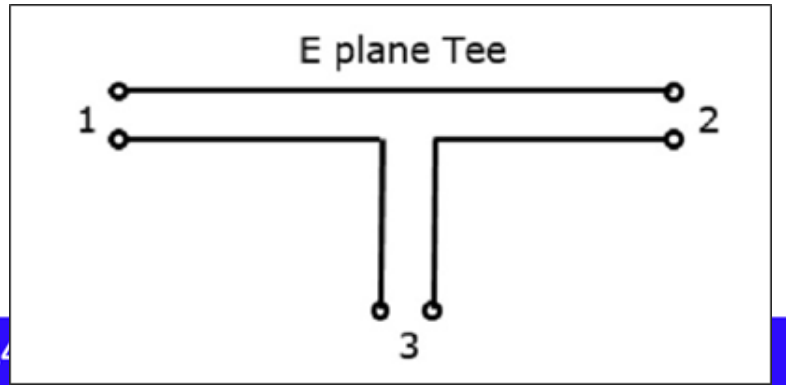
Waveguide E plane T junction



- $S_{11} = S_{12} = S_{22} \quad S_{13} = 1/\sqrt{2}$
- $R_1C_1: |S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 = 1$

$$|S_{11}|^2 + |S_{11}|^2 + 1/2 = 1 \quad : \quad S_{11} = 1/2 = S_{12} = S_{22}$$





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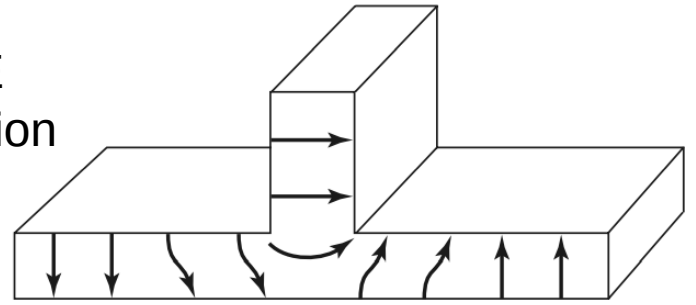

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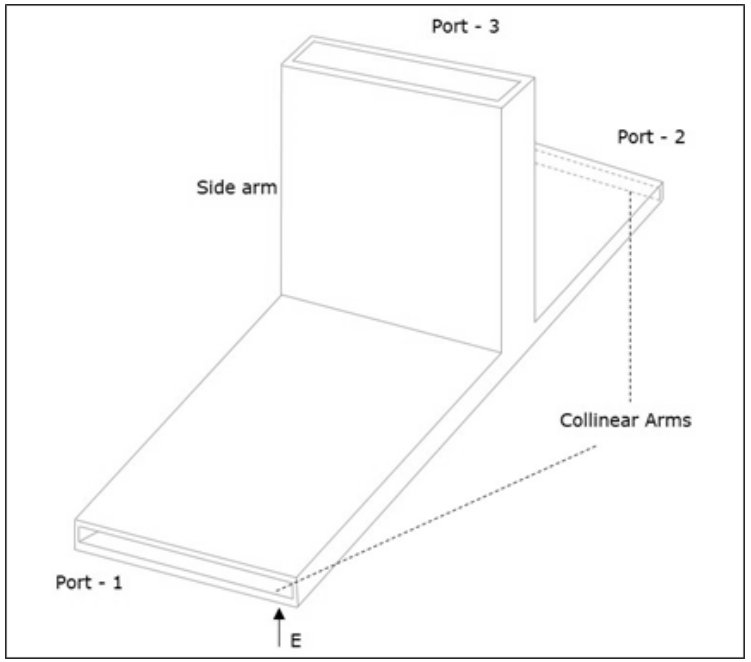
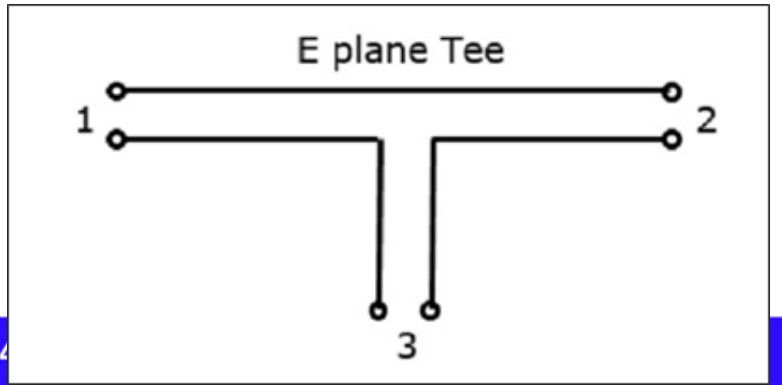
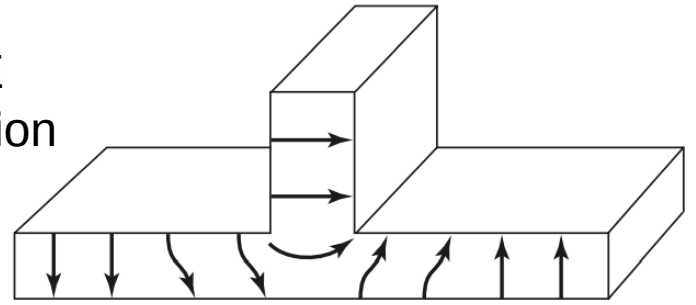




4.3 Properties of E plane Tee

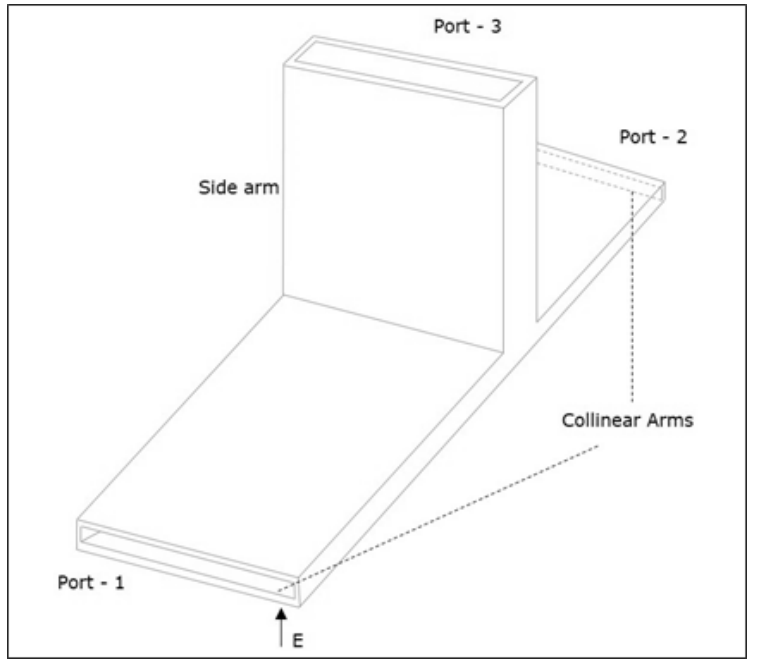
Waveguide E plane T junction

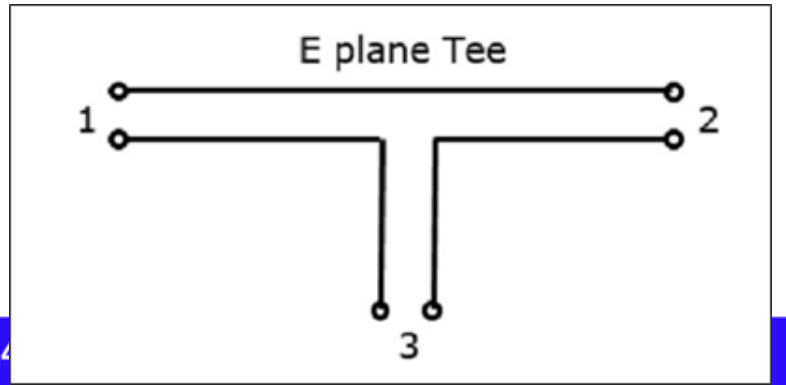


- $S_{11} = S_{12} = S_{22} \quad S_{13} = 1/\sqrt{2}$
- $R_1C_1: |S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 = 1$

$$|S_{11}|^2 + |S_{11}|^2 + 1/2 = 1 \quad : \quad S_{11} = 1/2 = S_{12} = S_{22}$$

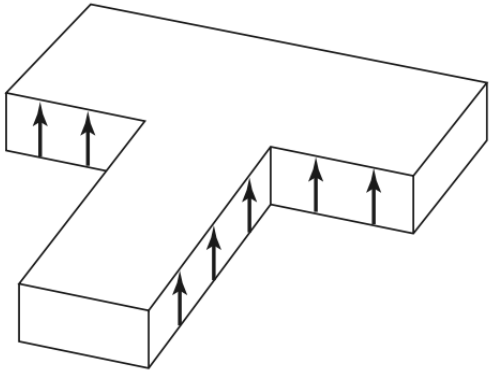
- $[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & -S_{13} \\ S_{13} & -S_{13} & 0 \end{bmatrix} = \begin{bmatrix} \frac{1}{2} & \frac{1}{2} & \frac{1}{\sqrt{2}} \\ \frac{1}{2} & \frac{1}{2} & -\frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & 0 \end{bmatrix}$
- $[b] = [S][a]$ (Voltages: Reflected b and incident a)
- $[b] = \begin{bmatrix} \frac{1}{2} & \frac{1}{2} & \frac{1}{\sqrt{2}} \\ \frac{1}{2} & \frac{1}{2} & -\frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & 0 \end{bmatrix} [a]$



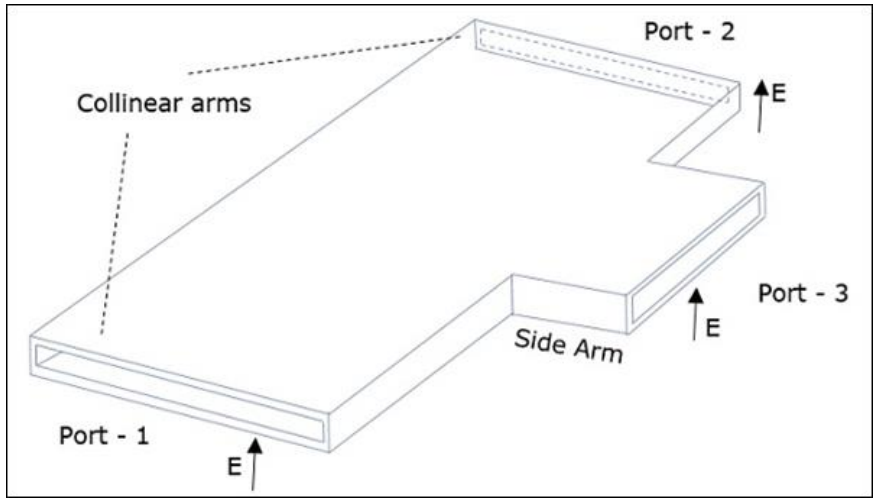


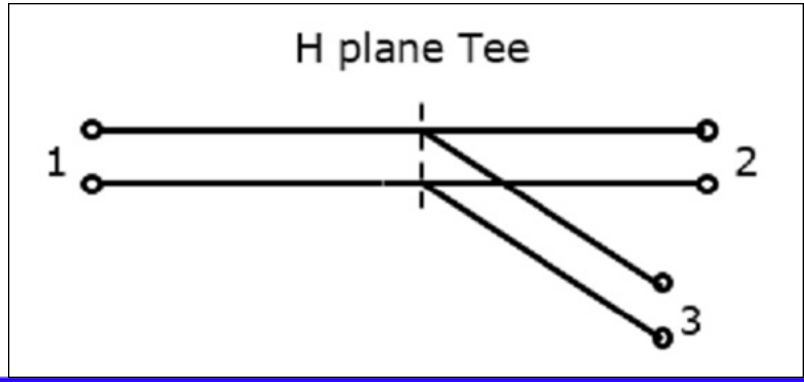
4.4 S-matrix analysis of H-Plane Tee

Waveguide H plane T junction



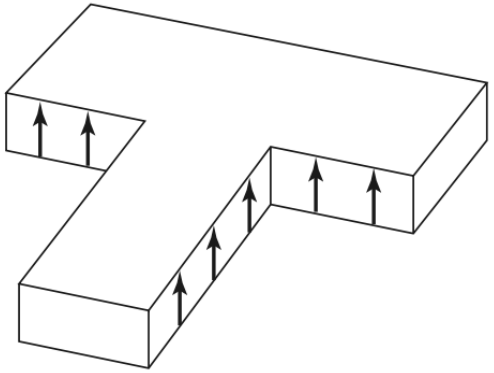
- Attaching simple waveguide (**port 3 – side arm: H-arm**) to the narrow dimension of rectangular waveguide (Ports 1 and 2 are collinear arms).
- Side arm is parallel to H field of collinear arms.
- Current junction or Shunt Tee.



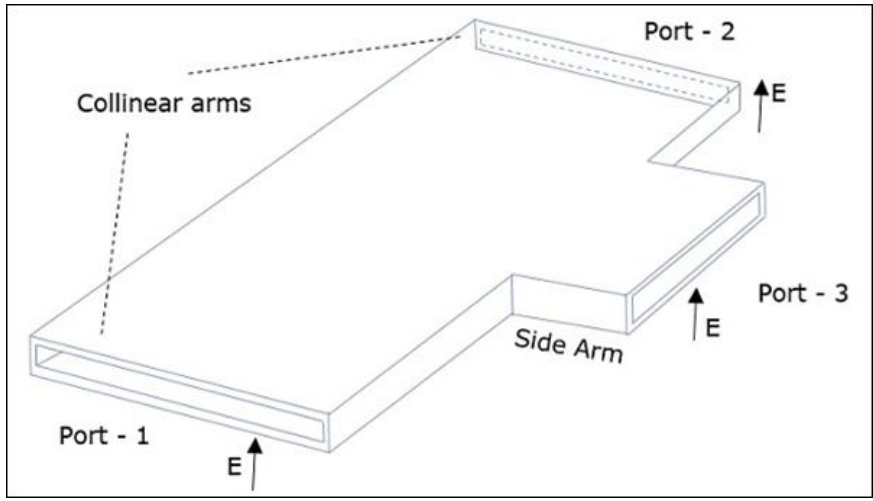


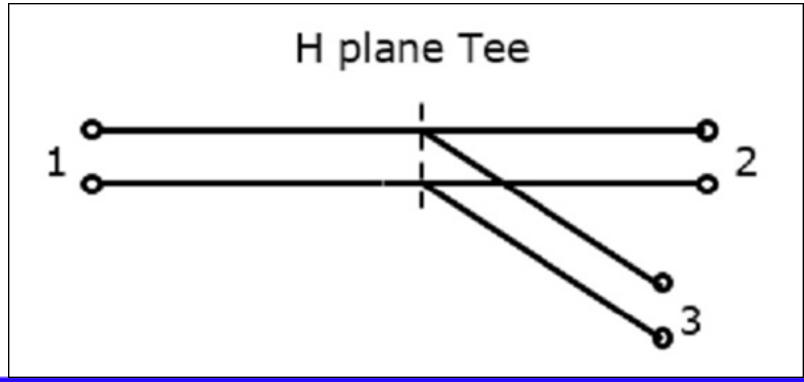
4.4 S-matrix analysis of H-Plane Tee

Waveguide H plane T junction



- Attaching simple waveguide (**port 3 – side arm: H-arm**) to the narrow dimension of rectangular waveguide (Ports 1 and 2 are collinear arms).
- Side arm is parallel to H field of collinear arms.
- Current junction or Shunt Tee.
- Ports 1 and 2 are in phase with each other.
- Connection made by side arm to bidirectional waveguide to form parallel port.

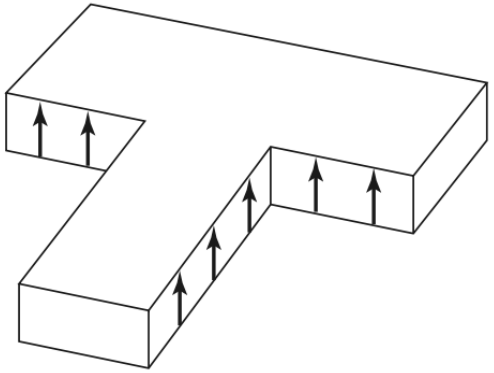


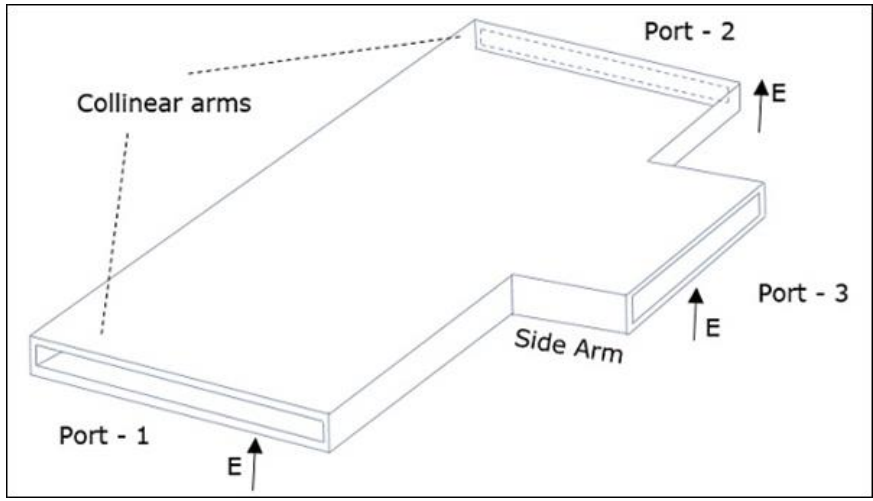


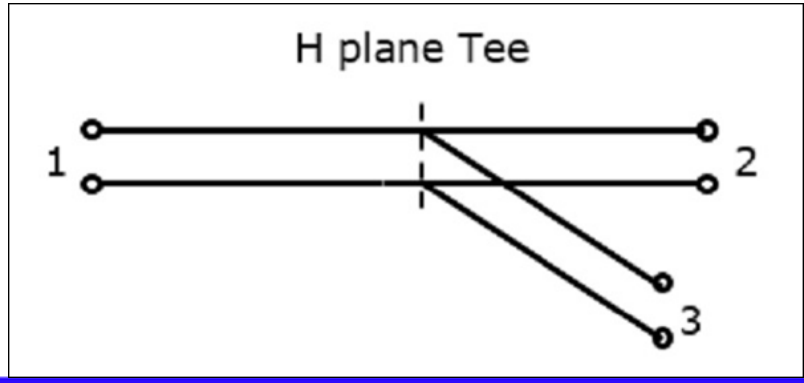
4.5 Properties of H plane Tee

- S matrix $[S]_{3\times3}$ matrix
- with $S_{13} = S_{23}$ (in phase collinear arms.

Waveguide H plane T junction

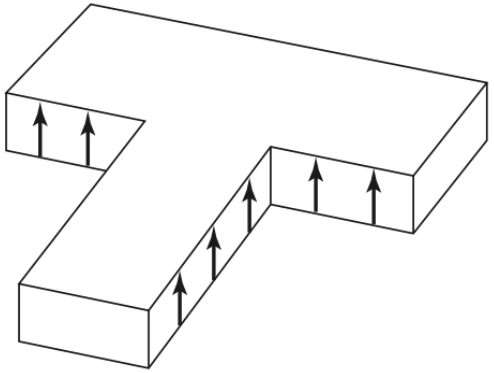






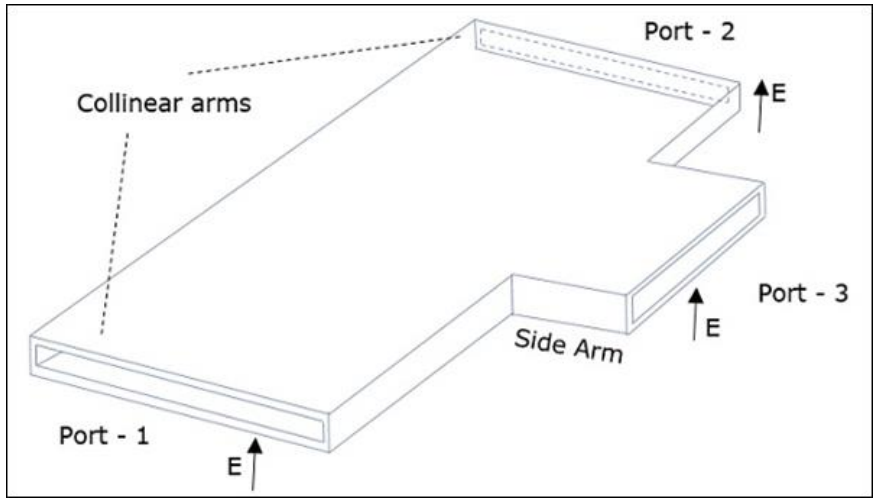
4.5 Properties of H plane Tee

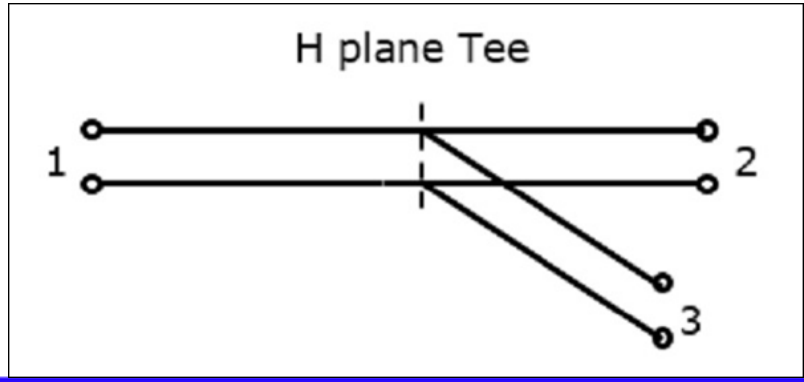
Waveguide H plane T junction



- S matrix $[S]_{3\times3}$ matrix
- with $S_{13} = S_{23}$ (in phase collinear arms.
- At port 3 – perfectly matched, $S_{33} = 0$
- Symmetric property $S_{ij} = S_{ji}$

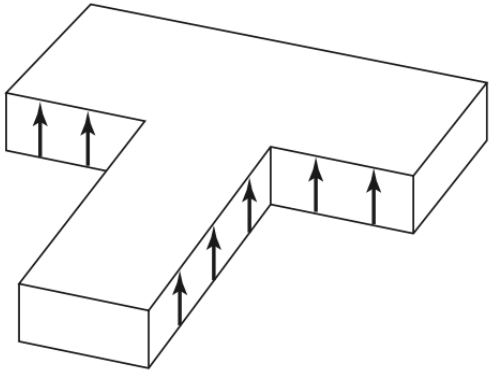
$$S_{12} = S_{21}\ ;\quad S_{23} = S_{32}\quad ;\quad S_{13} = S_{31}$$





4.5 Properties of H plane Tee

Waveguide H plane T junction



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- with $S_{13} = S_{23}$ (in phase collinear arms.
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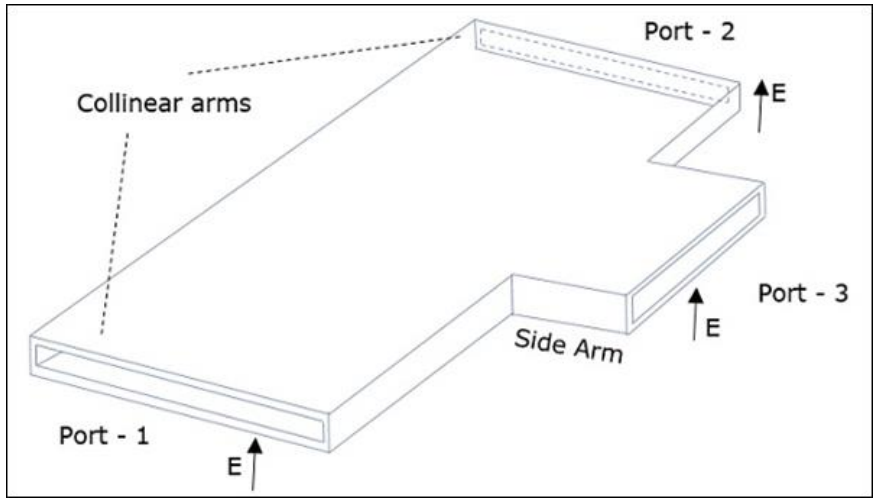
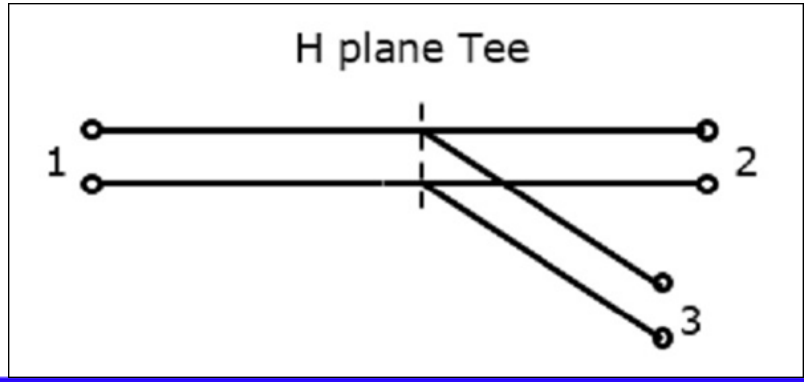
- Symmetric property $S_{ij} = S_{ji}$

$$S_{12} = S_{21}\ ; \quad S_{23} = S_{32} \quad ; \quad S_{13} = S_{31}$$

- $$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{13} \\ S_{13} & S_{13} & 0 \end{bmatrix}$$

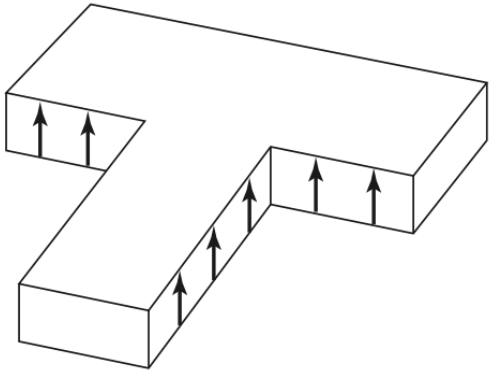


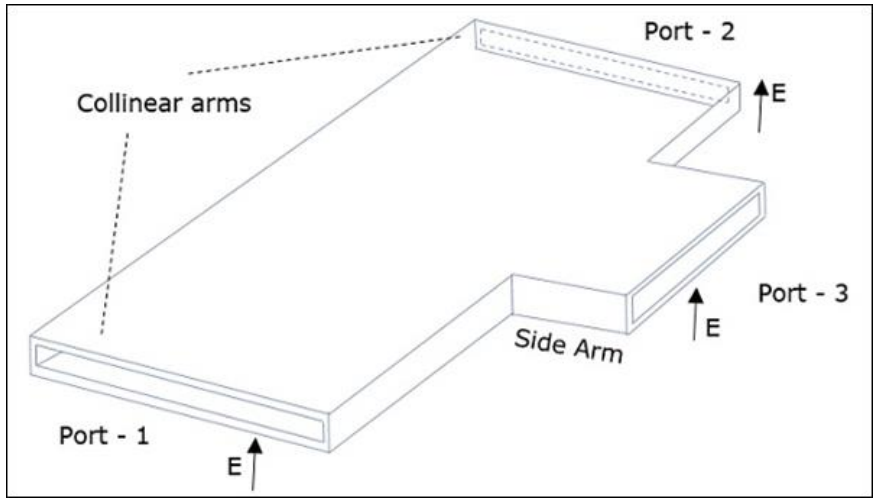


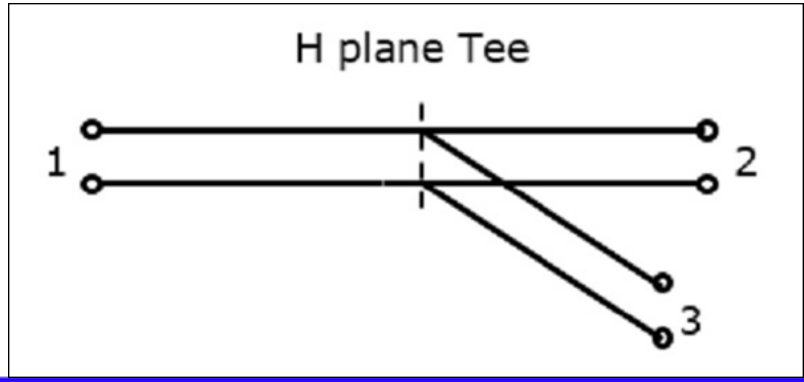
4.5 Properties of H plane Tee

- $[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{13} \\ S_{13} & S_{13} & 0 \end{bmatrix}$
- With unitary property $[S][S]^* = [I]$
- $\begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{13} \\ S_{13} & S_{13} & 0 \end{bmatrix} \begin{bmatrix} S_{11}^* & S_{12}^* & S_{13}^* \\ S_{12}^* & S_{22}^* & S_{13}^* \\ S_{13}^* & S_{13}^* & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$

Waveguide H plane T junction

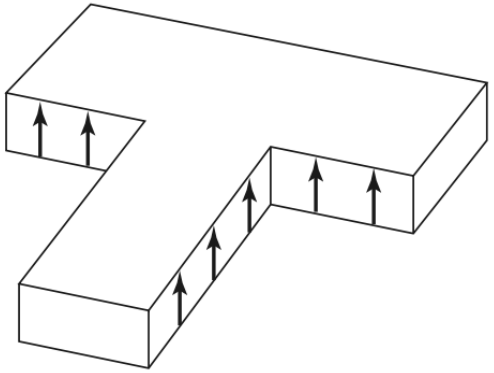




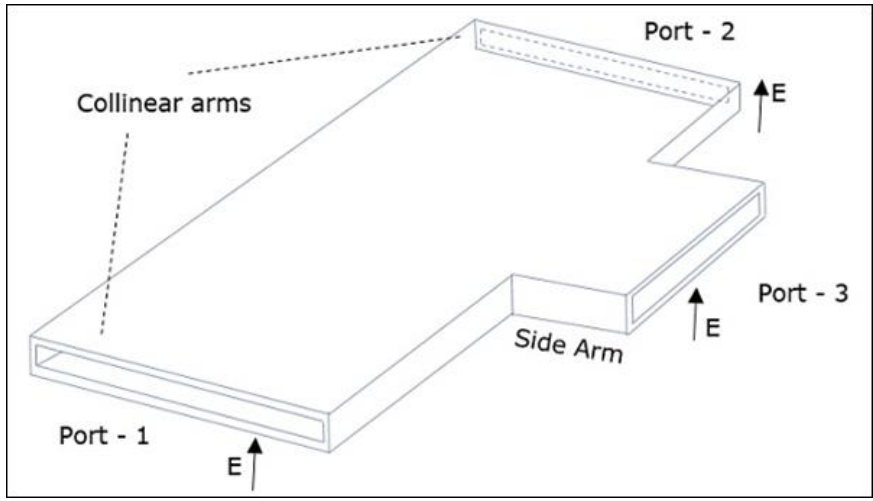


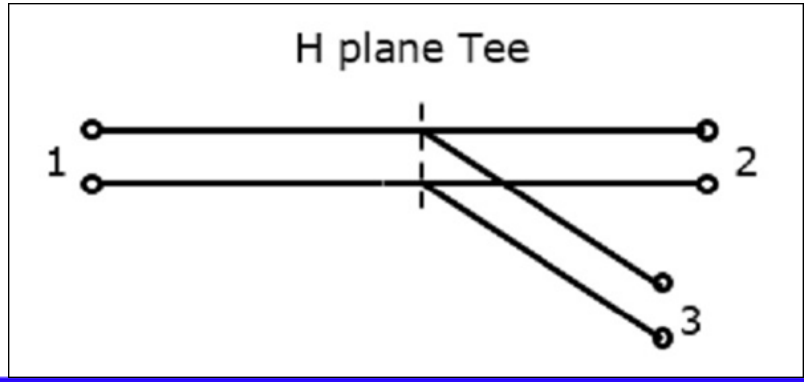
4.5 Properties of H plane Tee

Waveguide H plane T junction



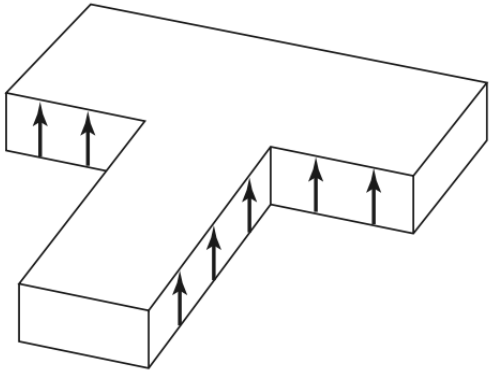
- $[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{13} \\ S_{13} & S_{13} & 0 \end{bmatrix}$
- With unitary property $[S][S]^* = [I]$
- $\begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{13} \\ S_{13} & S_{13} & 0 \end{bmatrix} \begin{bmatrix} S_{11}^* & S_{12}^* & S_{13}^* \\ S_{12}^* & S_{22}^* & S_{13}^* \\ S_{13}^* & S_{13}^* & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$
- R_1C_1: $|S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 = 1$
- R_2C_2: $|S_{12}|^2 + |S_{22}|^2 + |S_{13}|^2 = 1 \quad S_{11} = S_{22}$



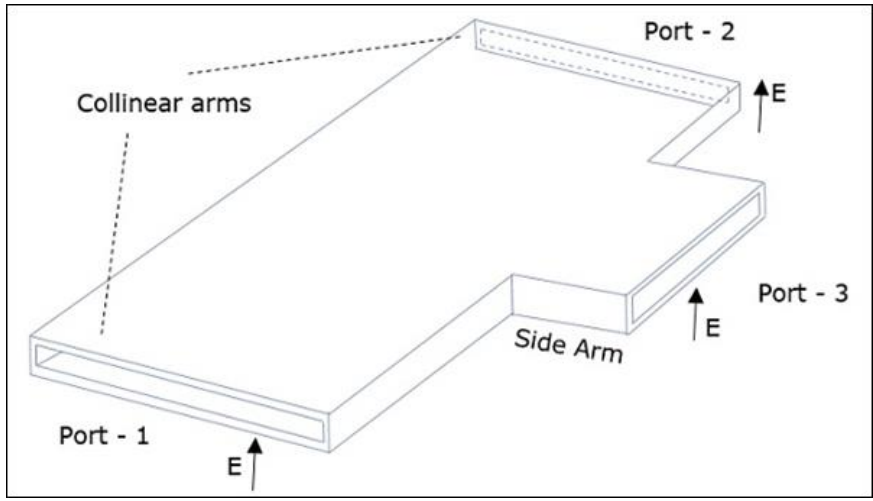


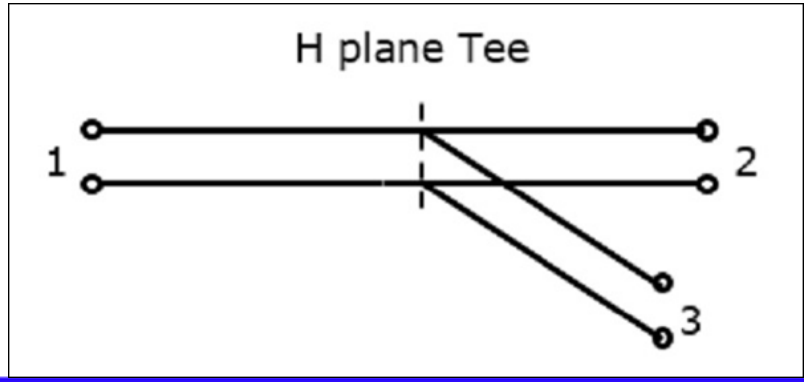
4.5 Properties of H plane Tee

Waveguide H plane T junction



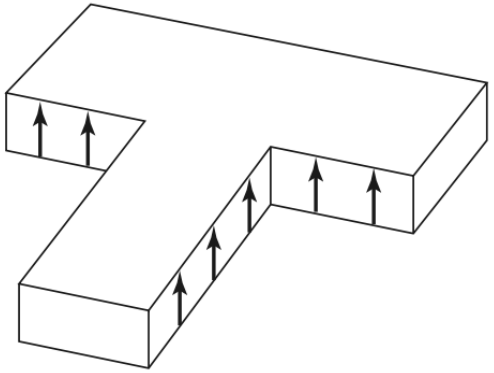
- $[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{13} \\ S_{13} & S_{13} & 0 \end{bmatrix}$
- With unitary property $[S][S]^* = [I]$
- $\begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{13} \\ S_{13} & S_{13} & 0 \end{bmatrix} \begin{bmatrix} S_{11}^* & S_{12}^* & S_{13}^* \\ S_{12}^* & S_{22}^* & S_{13}^* \\ S_{13}^* & S_{13}^* & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$
- R_1C_1: $|S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 = 1$
- R_2C_2: $|S_{12}|^2 + |S_{22}|^2 + |S_{13}|^2 = 1 \quad S_{11} = S_{22}$
- R_3C_3: $|S_{13}|^2 + |S_{13}|^2 = 1 \quad : S_{13} = 1/\sqrt{2}$





4.5 Properties of H plane Tee

Waveguide H plane T junction



- $[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{13} \\ S_{13} & S_{13} & 0 \end{bmatrix}$
- With unitary property $[S][S]^* = [I]$
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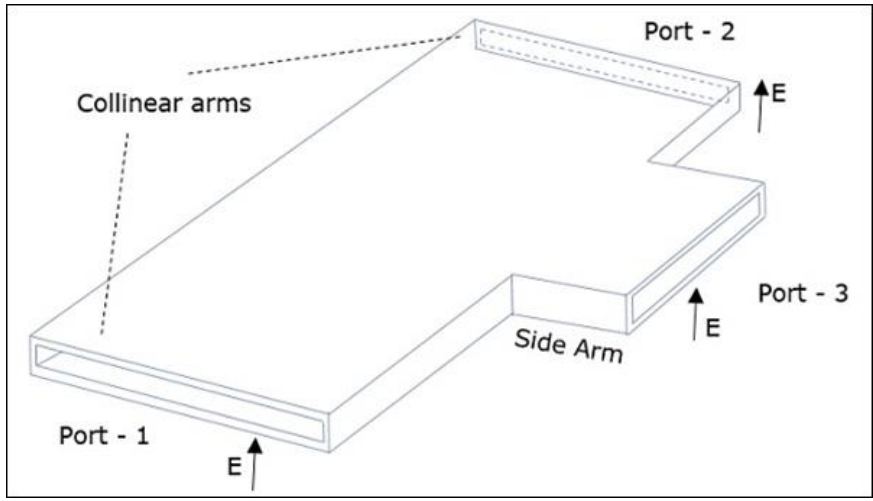
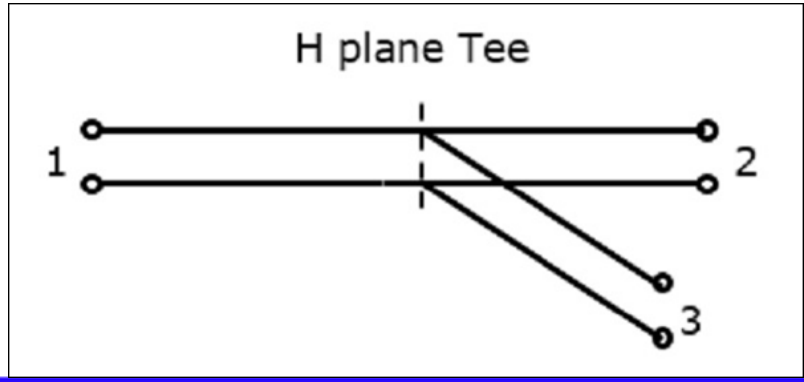
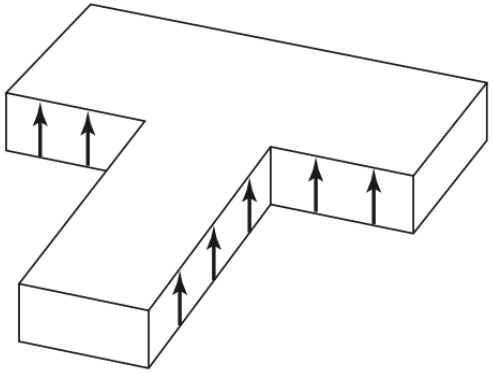
- R_1C_1: $|S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 = 1$
- R_2C_2: $|S_{12}|^2 + |S_{22}|^2 + |S_{13}|^2 = 1 \quad S_{11} = S_{22}$
- R_3C_3: $|S_{13}|^2 + |S_{13}|^2 = 1 \quad : S_{13} = 1/\sqrt{2}$
- R_3C_1: $S_{13}(S_{11}^* + S_{12}^*) = 0 \quad : S_{11} = -S_{12}$





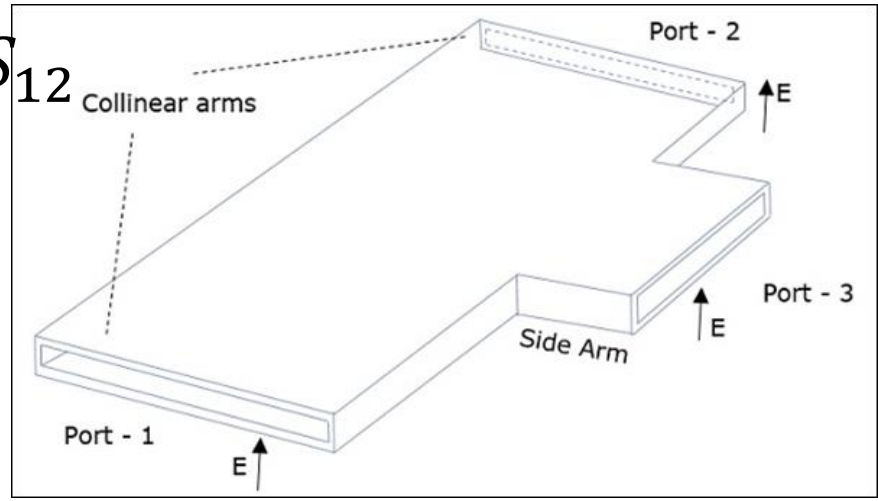
4.5 Properties of H plane Tee

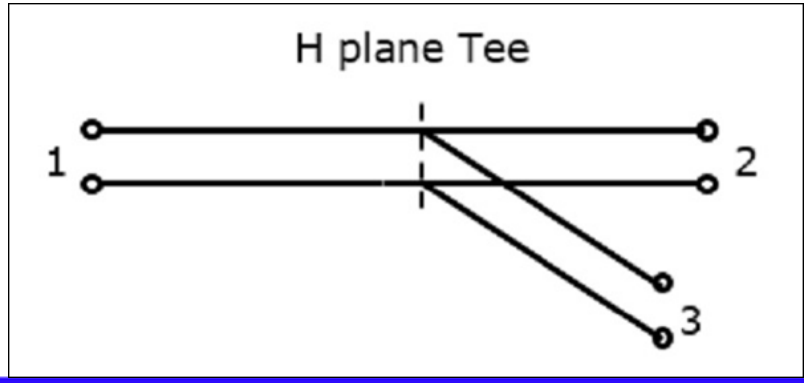
Waveguide H plane T junction



- $S_{11} = S_{22} = -S_{12}$ $\quad S_{13} = 1/\sqrt{2}$
- $R_1C_1: |S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 = 1$

$$|S_{11}|^2 + |S_{11}|^2 + 1/2 = 1 \quad : S_{11} = \frac{1}{2} = S_{22} = -S_{12}$$





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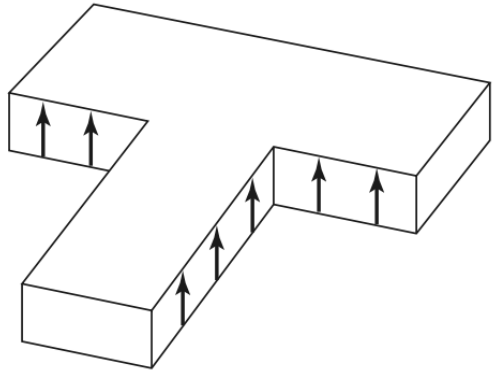
Waveguide H plane T junction



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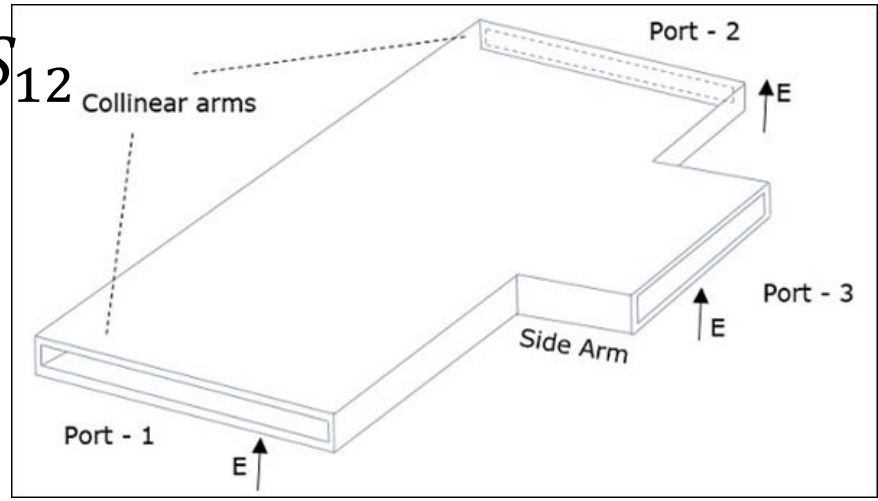

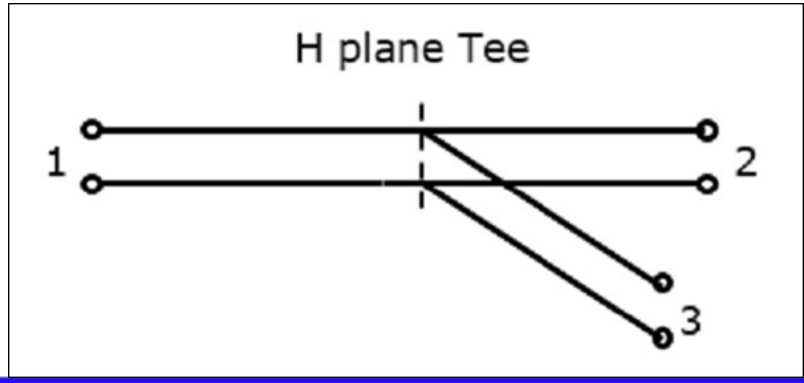

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$$|S_{11}|^2 + |S_{11}|^2 + 1/2 = 1 \quad : S_{11} = \frac{1}{2} = S_{22} = -S_{12}$$

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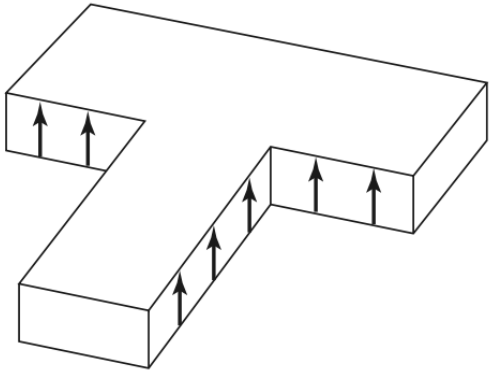
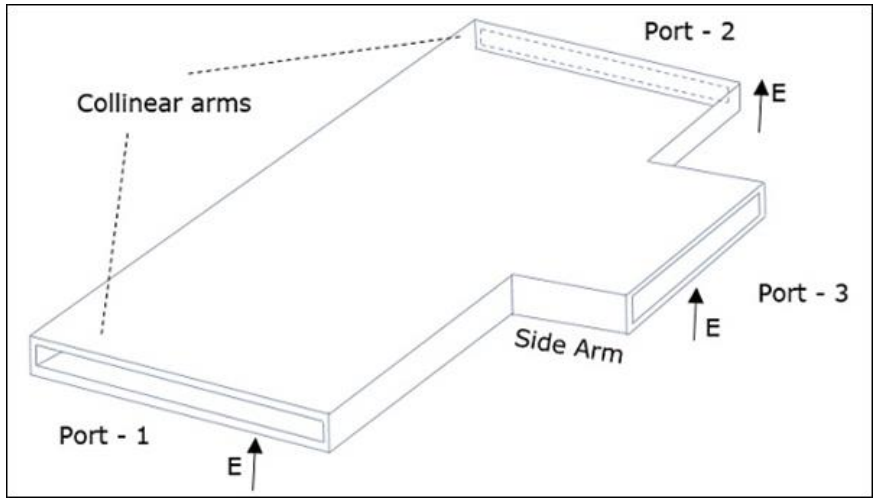
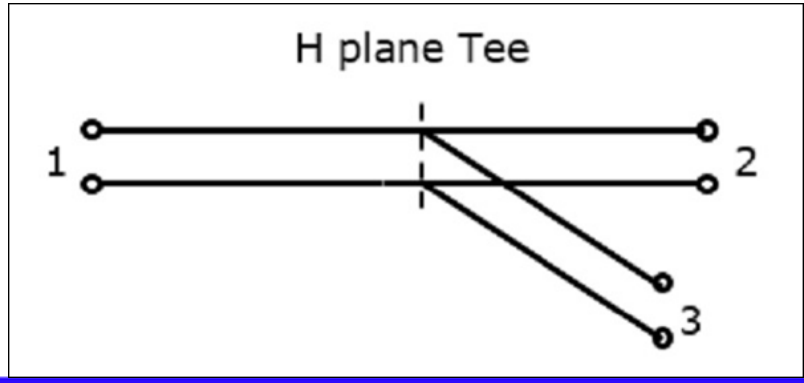
- $[b] = [S][a]$
- $$[b] = \begin{bmatrix} \frac{1}{2} & -\frac{1}{2} & \frac{1}{\sqrt{2}} \\ -\frac{1}{2} & \frac{1}{2} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 0 \end{bmatrix} [a]$$

Waveguide H plane T junction

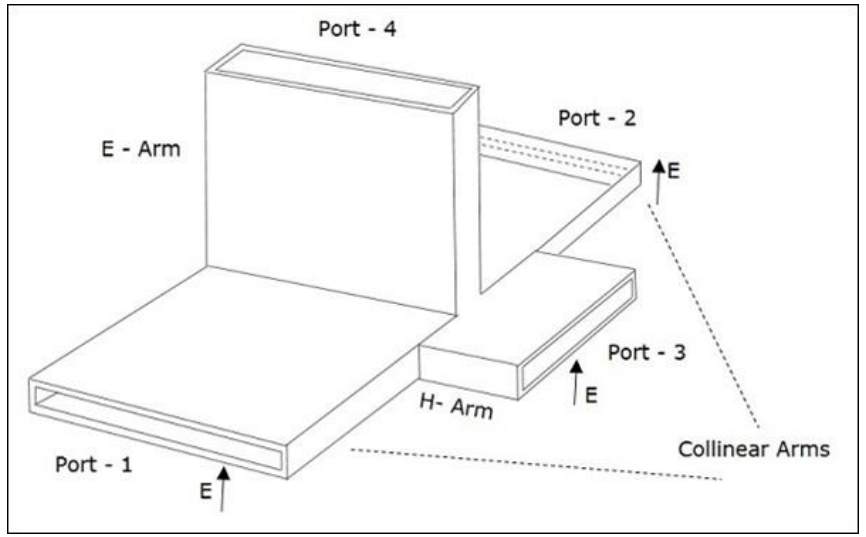


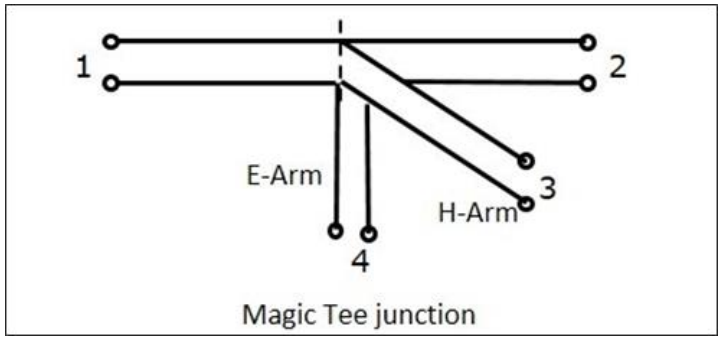




5.1 E-H Plane TEE / MAGIC TEE

- Collinear ports of the wave guide (1,2)
- Port 3: H arm or SUM port (Parallel port)
- Port 4: E arm or Difference port (Series port)
- Side arms are connected to the bi-directional waveguide to form both parallel and serial ports.

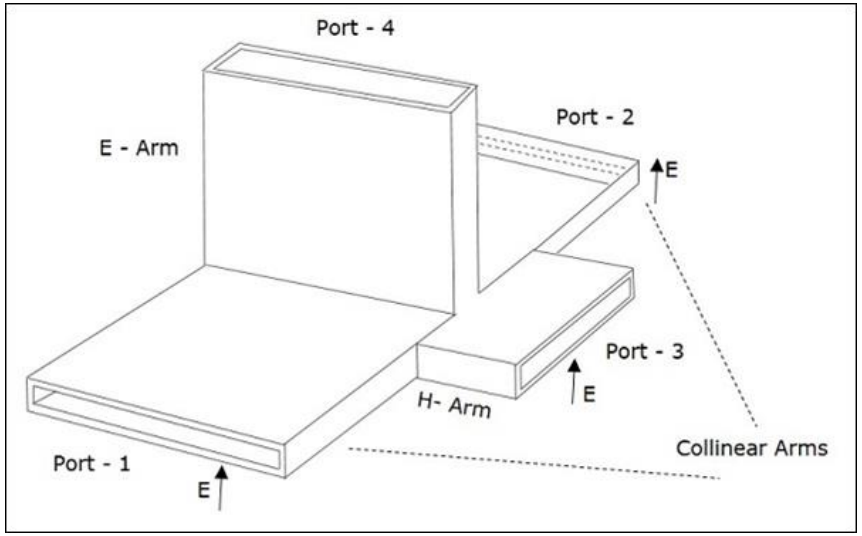


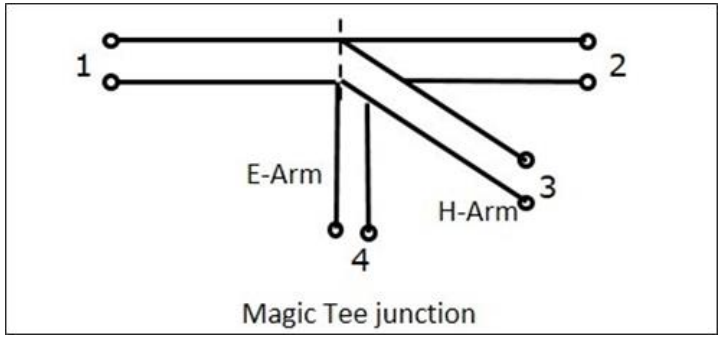


Magic Tee junction

5.2 Characteristics of MAGIC TEE

- If a signal of equal phase and magnitude is sent to port 1 and port 2, then the output at *port 4* is *zero* and the output at port 3 will be the sum of both the ports 1 and 2.





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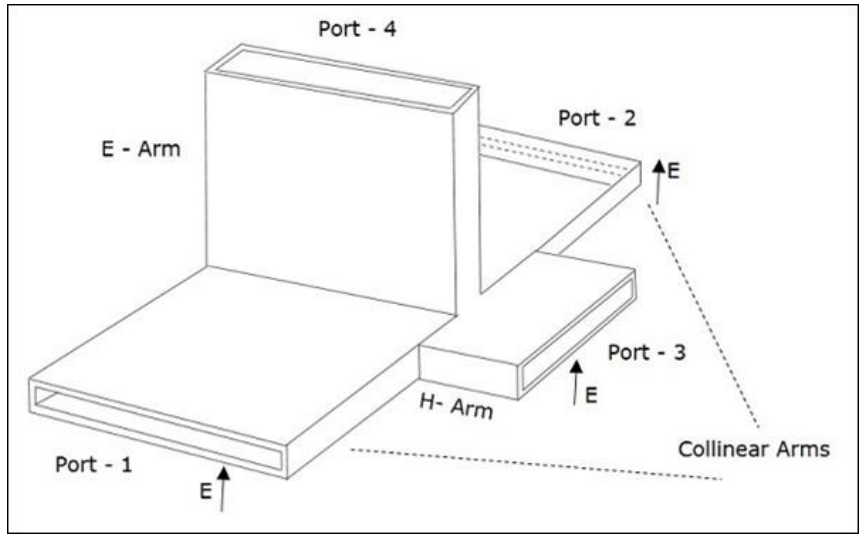
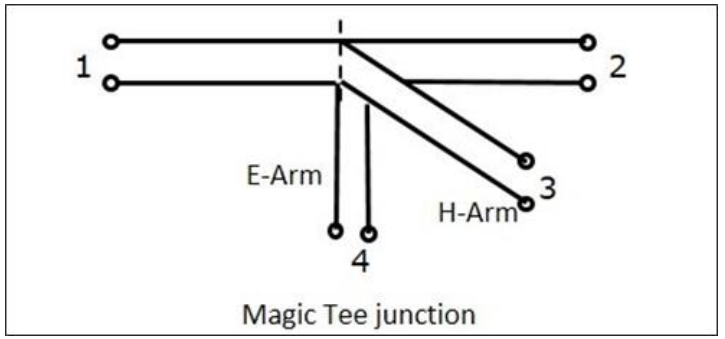
- If a signal of equal phase and magnitude is sent to port 1 and port 2, then the output at *port 4* is *zero* and the output at port 3 will be the sum of both the ports 1 and 2.
- If a signal is sent to port 4, E−arm then

  power is divided between port 1 and 2 equally

  but in opposite phase,

  no output at port 3. Hence, $S_{34} = 0$





Magic Tee junction

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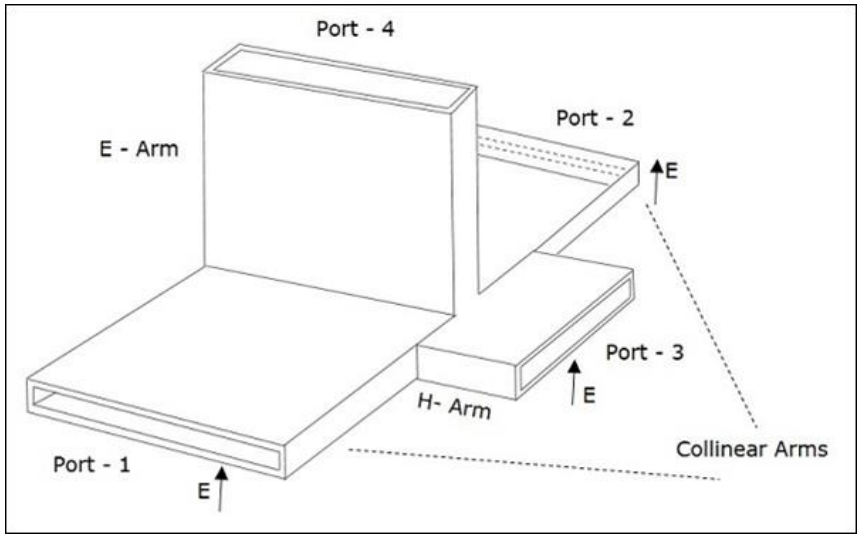
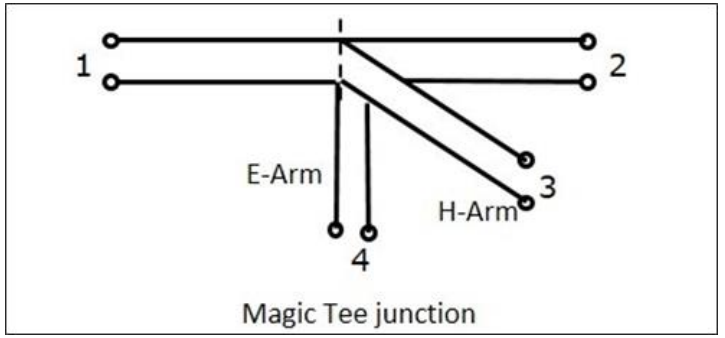
- If a signal of equal phase and magnitude is sent to port 1 and port 2, then the output at *port 4* is *zero* and the output at port 3 will be the sum of both the ports 1 and 2.
- If a signal is sent to port 4, E−arm then
  power is divided between port 1 and 2 equally
  but in opposite phase,
  no output at port 3. Hence, $S_{34} = 0$
- If a signal is sent to port 3, H−arm then
  power is divided between port 1 and 2 equally
  and in same phase,
  no output at port 4. Hence, $S_{43} = 0$



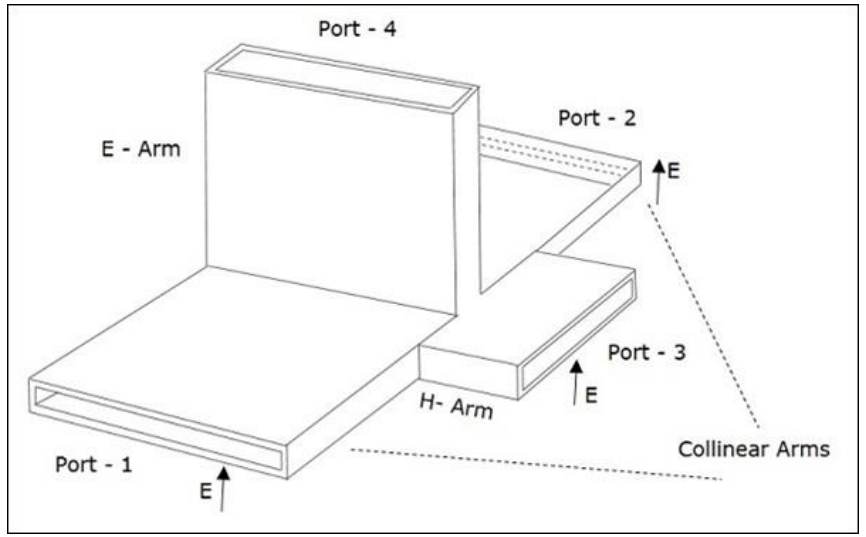


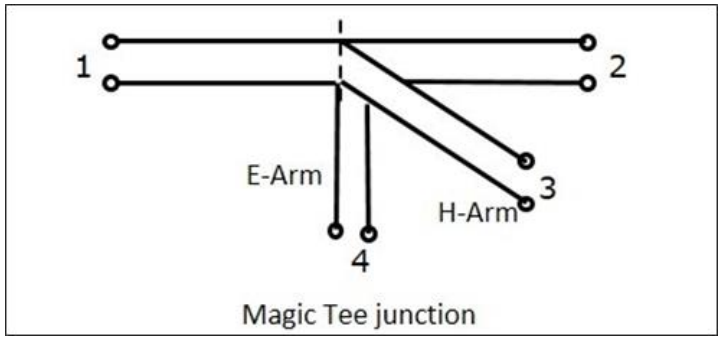
5.2 Characteristics of MAGIC TEE

- If a signal is fed at one of the collinear ports,

  no output at the other collinear port, as the E-arm produces a phase delay and the H-arm produces a phase advance.

$$S_{12} = S_{21} = 0$$



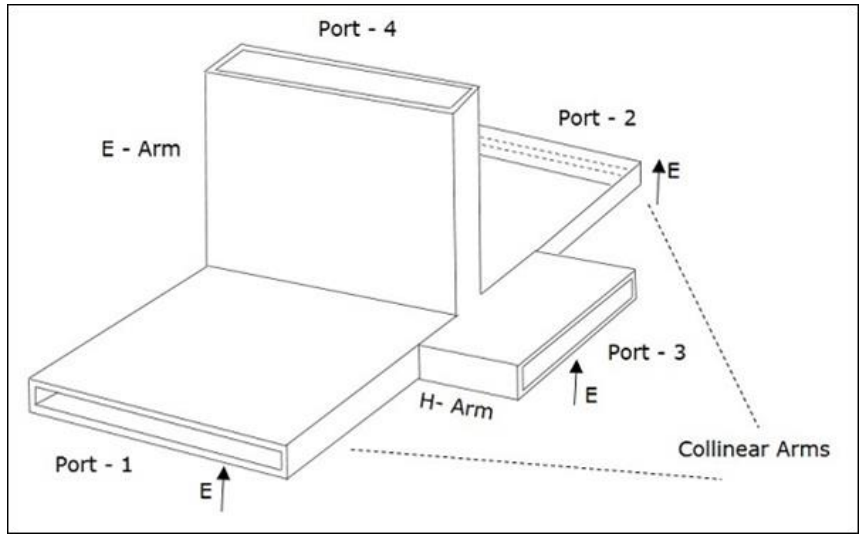


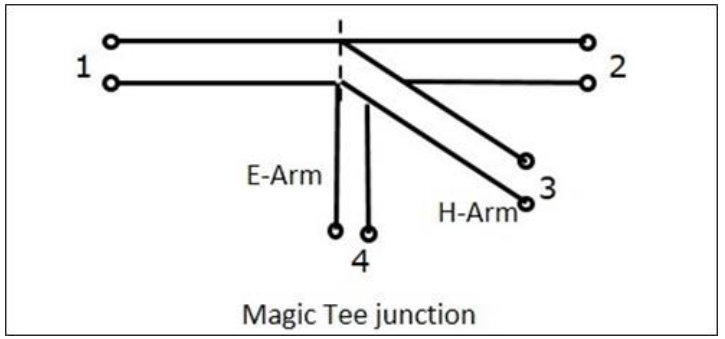
Magic Tee junction

5.3 S matrix properties of MAGIC TEE

$S_{34} = 0 = S_{43}$ and $S_{12} = S_{21} = 0$

It has a H plane Tee section: $S_{13} = S_{23}$, $S_{33} = 0$





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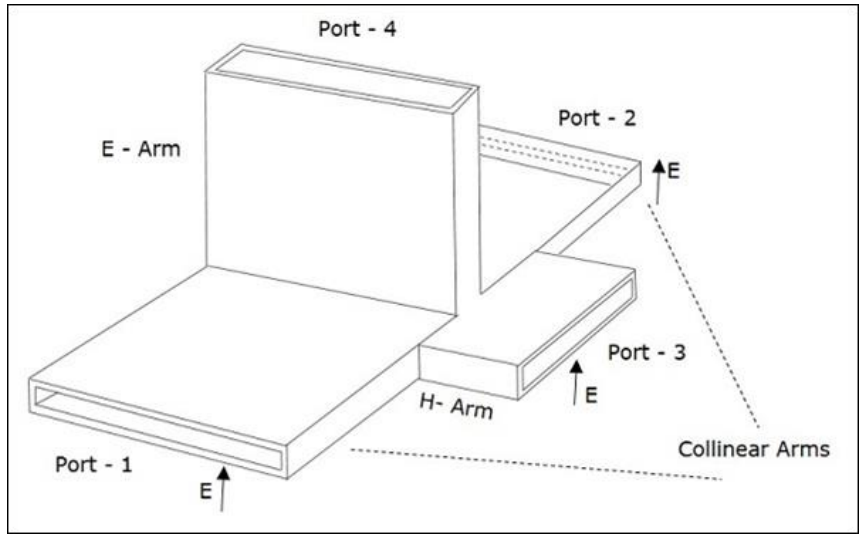

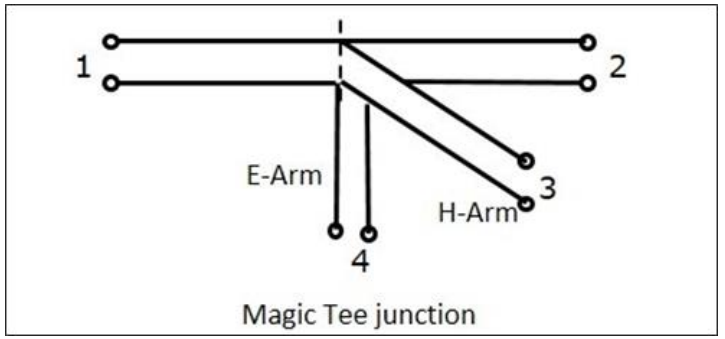

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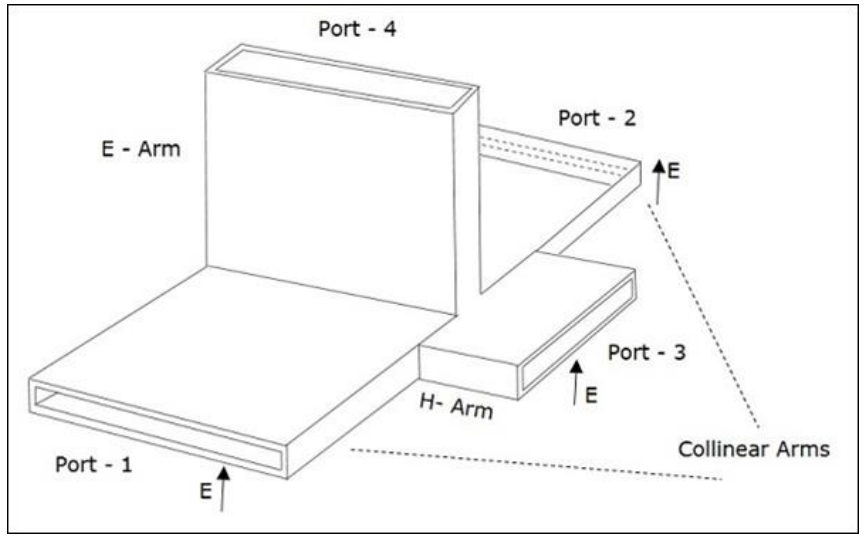
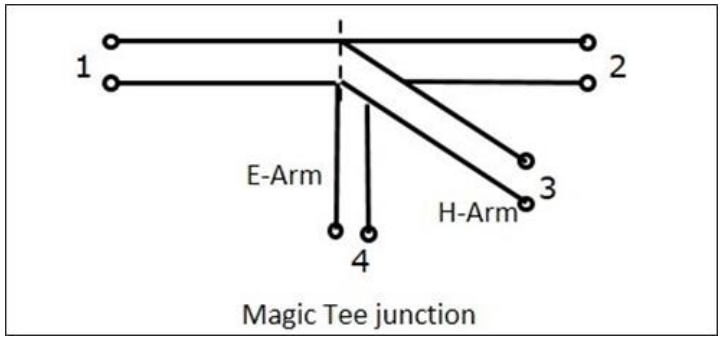
Symmetry property: $S_{ij} = S_{ji}$

$S_{12} = S_{21}$ $S_{13} = S_{31}$ $S_{14} = S_{41}$

$S_{23} = S_{32}$ $S_{24} = S_{42}$ $S_{34} = S_{43}$





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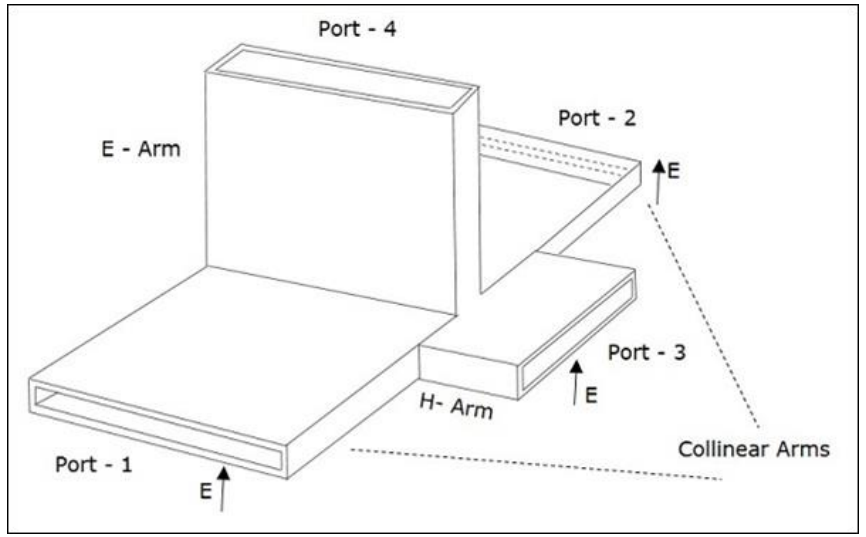
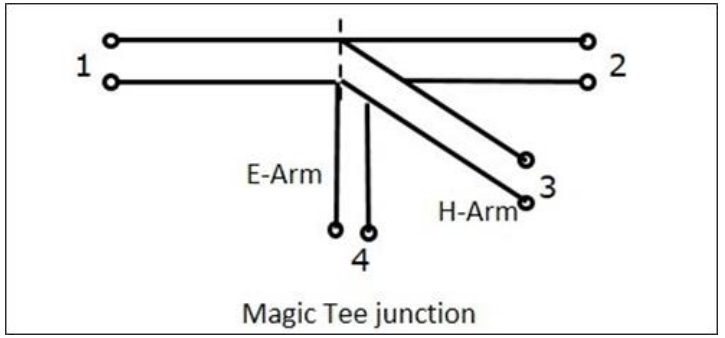


$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & S_{13} & -S_{14} \\ S_{13} & S_{13} & 0 & 0 \\ S_{14} & -S_{14} & 0 & 0 \end{bmatrix}$$

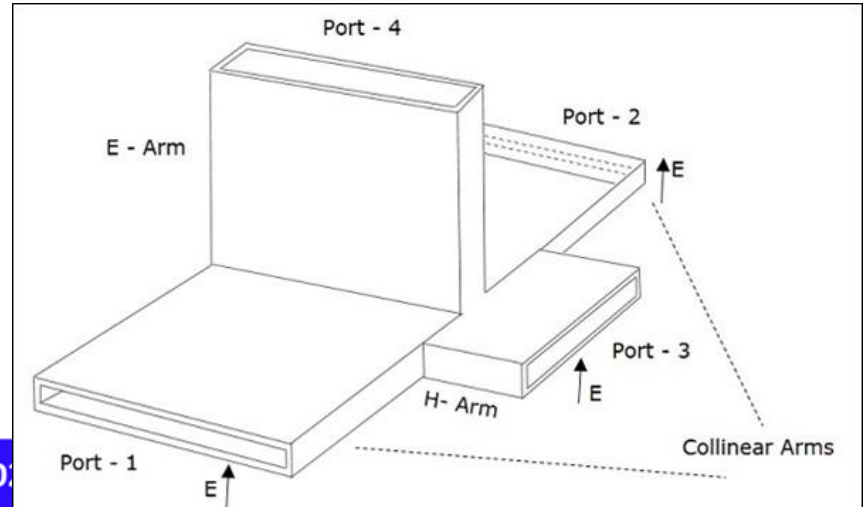


Magic Tee junction

5.3 S matrix properties of MAGIC TEE

Apply Unitary property: $[S][S]^* = [I]$

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & S_{13} & -S_{14} \\ S_{13} & S_{13} & 0 & 0 \\ S_{14} & -S_{14} & 0 & 0 \end{bmatrix} \begin{bmatrix} S_{11}^* & S_{12}^* & S_{13}^* & S_{14}^* \\ S_{12}^* & S_{22}^* & S_{13}^* & -S_{14}^* \\ S_{13}^* & S_{13}^* & 0 & 0 \\ S_{14}^* & -S_{14}^* & 0 & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



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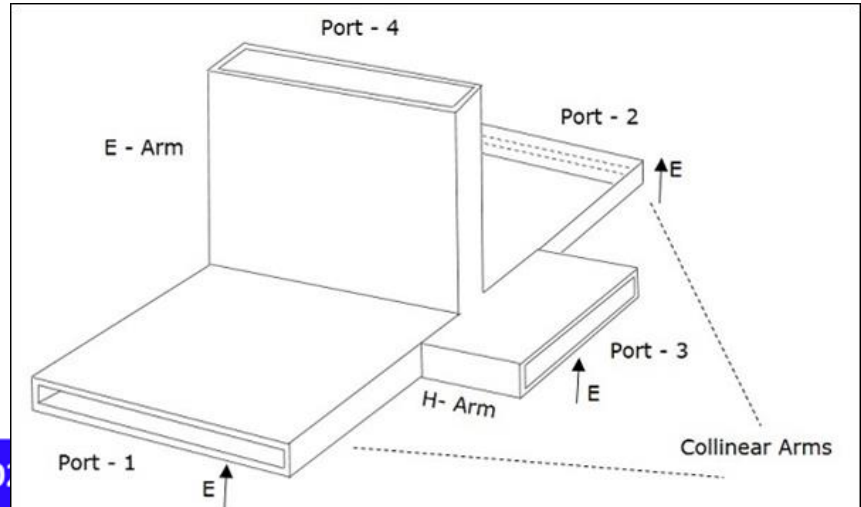
R_1C_1: $|S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 + |S_{14}|^2 = 1$

R_2C_2: $|S_{12}|^2 + |S_{22}|^2 + |S_{13}|^2 + |S_{14}|^2 = 1$ $\quad S_{11} = S_{22}$



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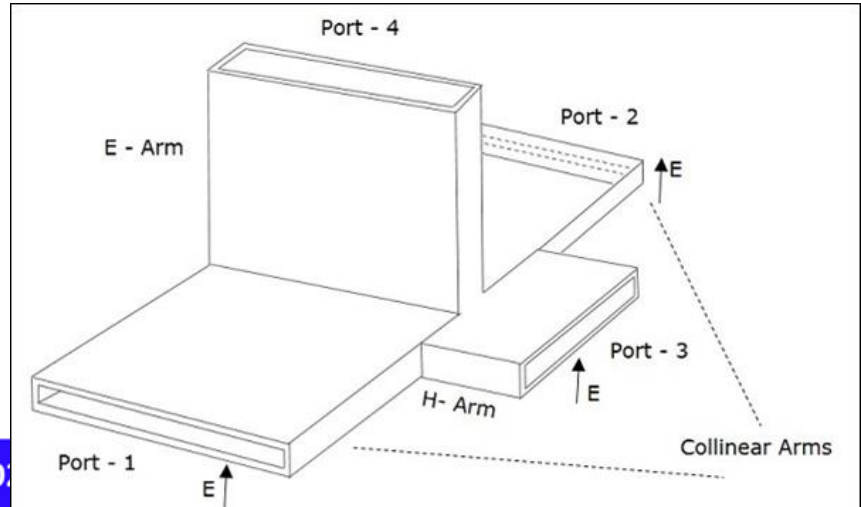
R_3C_3: $|S_{13}|^2 + |S_{13}|^2 = 1 \;:\; S_{13} = 1/\sqrt{2}$

R_4C_4: $|S_{14}|^2 + |S_{14}|^2 = 1 \;:\; S_{14} = 1/\sqrt{2}$



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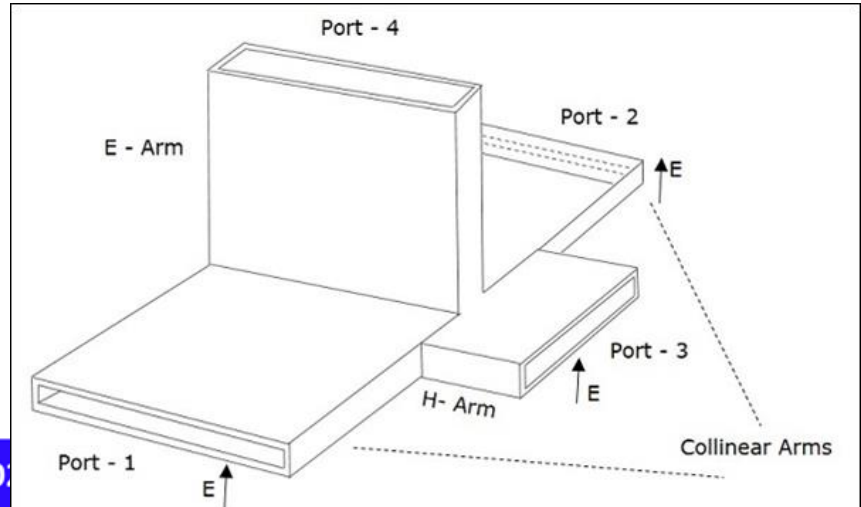
$|S_{11}|^2 + |S_{12}|^2 = 0$ Magnitudes are zero



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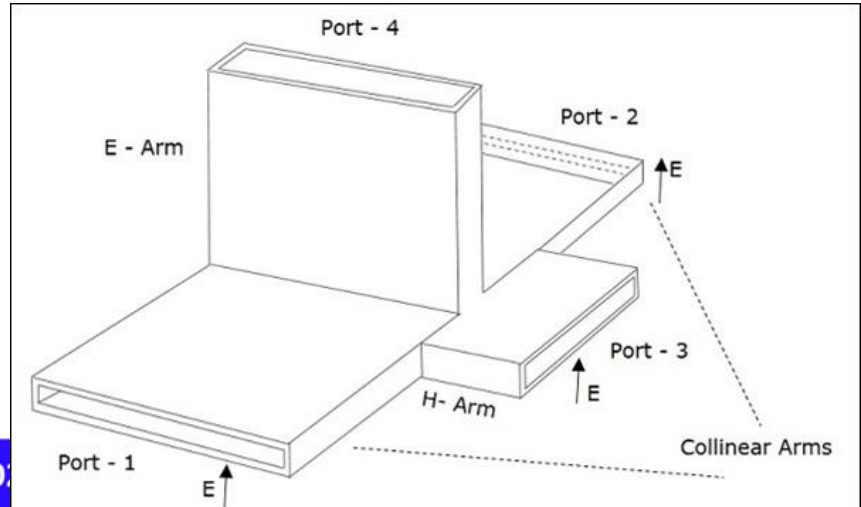

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$S_{14} = 1/\sqrt{2}$ *and* $S_{13} = 1/\sqrt{2}$ and

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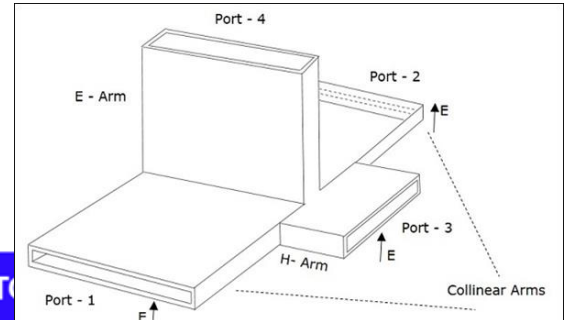

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The S matrix becomes

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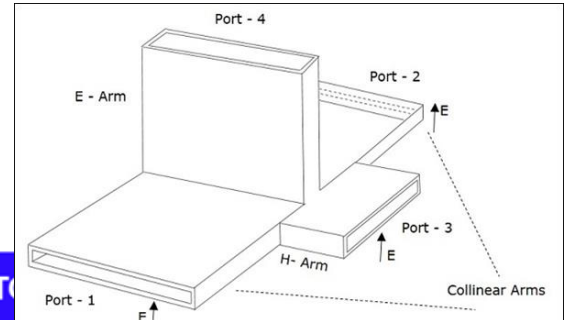

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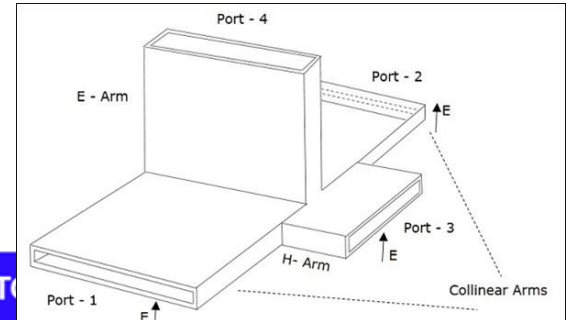
$$[b] = [S][a]$$



5.1 E-H Plane TEE / MAGIC TEE

- To measure the impedance − A null detector is connected to E-Arm port while the Microwave source is connected to H-Arm port. The collinear ports together with these ports make a bridge and the impedance measurement is done by balancing the bridge.

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- To measure the impedance − A null detector is connected to E-Arm port while the Microwave source is connected to H-Arm port. The collinear ports together with these ports make a bridge and the impedance measurement is done by balancing the bridge.
- Used as a duplexer − A duplexer is a circuit which works as both the transmitter and the receiver, using a single antenna for both purposes. Port 1 and 2 are used as receiver and transmitter where they are isolated and hence will not interfere. Antenna is connected to E-Arm port. A matched load is connected to H-Arm port, which provides no reflections. Now, there exists transmission or reception without any problem.

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- A mixer − E-Arm port is connected with antenna and the H-Arm port is connected with local oscillator. Port 2 has a matched load which has no reflections and port 1 has the mixer circuit, which gets half of the signal power and half of the oscillator power to produce IF frequency.