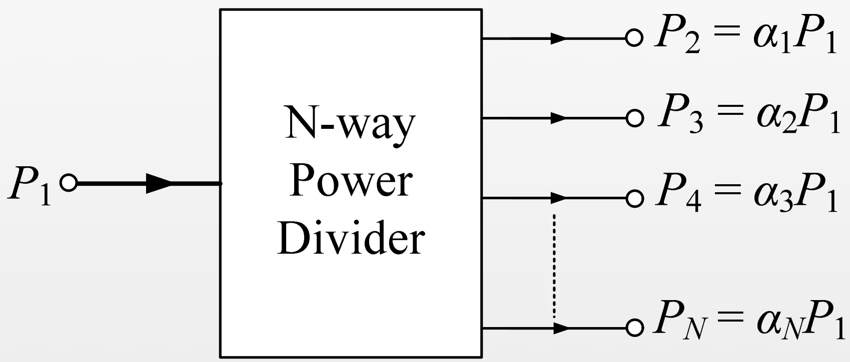
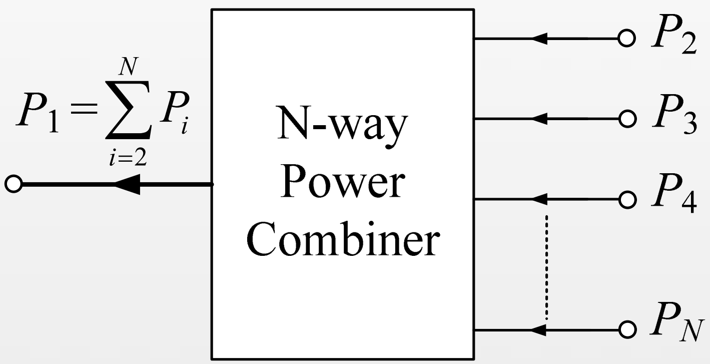
Chapter 7
Power Divider and Directional Coupler

Prof. Jeong, Yongchae





Learning Objectives

- Understanding why microwave power divider is required?
- Know about T-junction power divider
- Understanding T-junction power divider design examples

Learning contents

- Why Microwave Power Divider is Required?
- T-junction Power Divider
- Design Examples of T-junction Power Divider

1 Why Microwave Power Divider is Required?

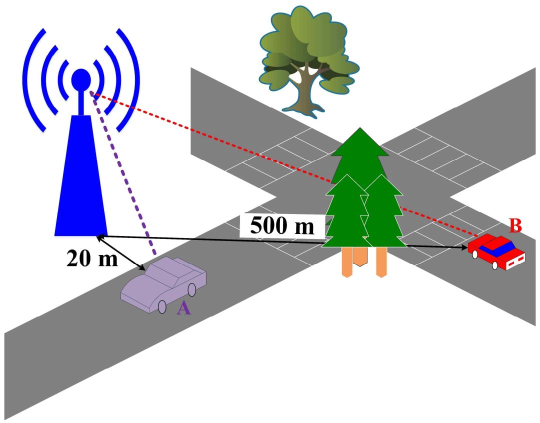
- Near-far problem (path loss): propagation power loss due to distance (d) between mobile communication base-station and mobile unit

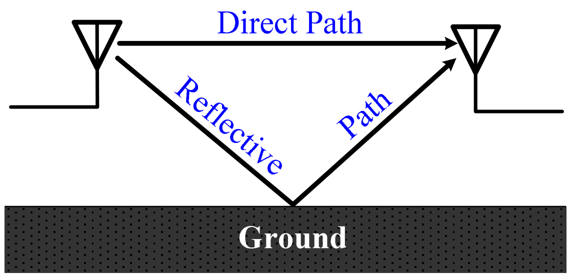
  receiving power $= f(1/d^2)$ @ ideal case

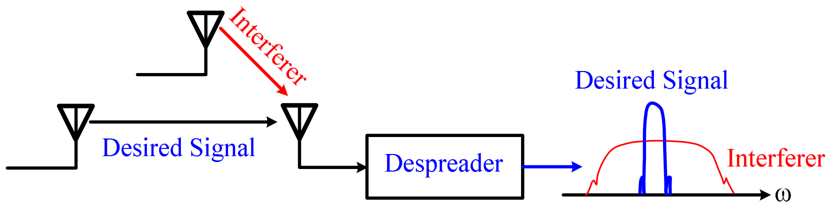
  $= f(1/d^4)$ @ real case

- Propagation of signals in mobile communication environment is quite complex: fadings due to direct, indirect, and reflective paths

- Multiple access: how to minimize the interferers?





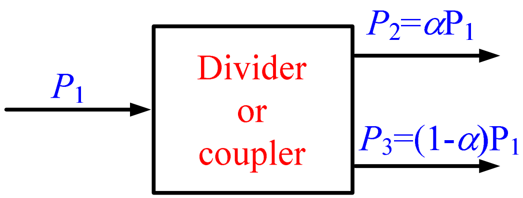


Effect of strong interferer in CDMA

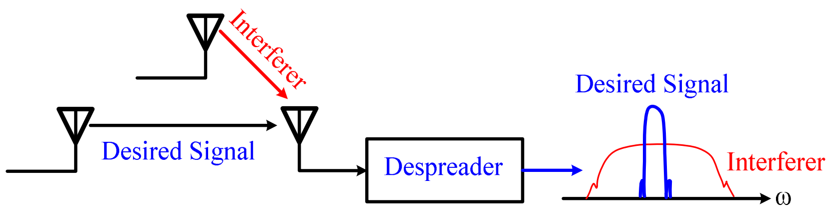
1 Why Microwave Power Divider is Required?

- Multiple access

  - Suppose the desired signal power received at a point is much lower than that of an unwanted transmitter due to relatively long distance
  - Even after despreading, the strong interferer greatly raises the noise floor, degrading the reception of the desired signal.
  - For multiple users, one higher power transmitter can virtually halt communications among others, especially relative to CDMA communications.
  - When many CDMA transmitters communicate with a receiver, each transmitter must adjust its radiated RF output power such that the receiver senses roughly equal signal levels.



($\alpha << 0.1$, typ.)

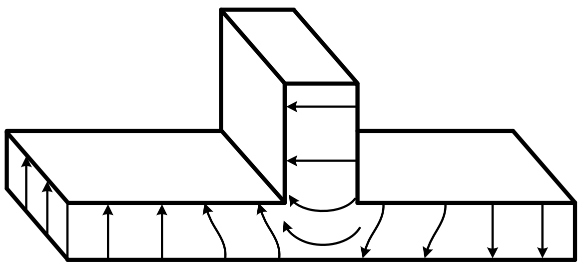


Effect of strong interferer in CDMA

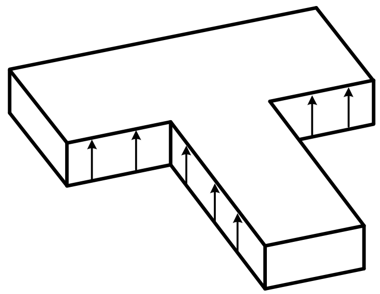
Ex.] If $\alpha = 0.01$, $P_2 = 0.01P_{in}$ (monitoring power) and $P_2 = 99 \times P_3$ (real radiated power)

2 T-junction Power Divider

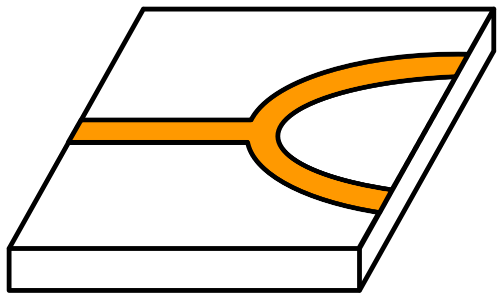
- The T-junction power divider is a simple 3-port network and can be implemented in any kinds of transmission medium such as microstrip, stripline, coplanar waveguide, and others.
- Even though the T-junction power divider is lossless and reciprocal, it cannot be perfectly matched at all ports.
- The T-junction power divider can be modeled as a junction of three transmission arms or transmission lines as shown in below figures.



(E-plane waveguide T)



(H-plane waveguide T)



(Microstrip T-junction)

2 T-junction Power Divider

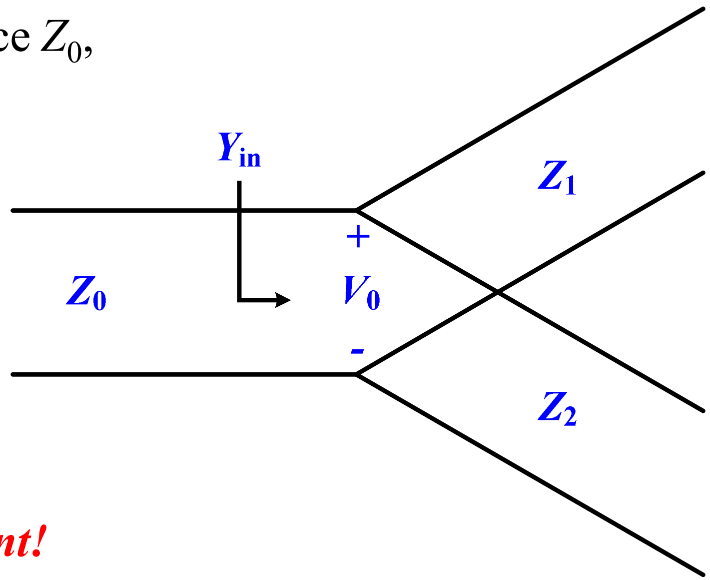
- **Lossless Divider**

- The lossless T-junctions can be simply modeled as a junction of three transmission lines.

- Fringing fields and higher order modes associated with the discontinuity at such a junction leading to **stored energy**. → lumped susceptance, *B*.

- In order for matched divider at input line of characteristic impedance Z_0,

$$Y_{\text{in}} = jB + \frac{1}{Z_1} + \frac{1}{Z_2} = \frac{1}{Z_0}$$



- Assuming $B = 0$ for simplicity,

$$\frac{1}{Z_1} + \frac{1}{Z_2} = \frac{1}{Z_0}$$

- In practice, jB can't be negligible. → ***Need reactive tuning element!***

2 T-junction Power Divider

- **Advantages**

- ***Simplicity:*** making it easy to construct and integrate into circuits.
- ***Cost-effective:*** due to its straightforward design, it is cost-effective and suitable for low-budget applications.
- ***Broadband operation:*** operate over wide range of frequencies, providing versatility for various applications.

- **Limitations**

- ***Poor isolation:*** has poor isolation between output ports → **Signals can leak from one output port to the other.**
- ***High insertion loss:*** higher than more advanced power dividers like Wilkinson power divider.
- ***Impedance matching difficulty:*** difficult to get perfect impedance matching → **Potential signal degradation due to high reflections.**

2 T-junction Power Divider

- **Example 1:** A lossless T-junction power divider with source impedance of 50 [Ω].

  a) Find the output characteristic impedances Z_1 and Z_2 so that the output powers are 4:1 ratio division.

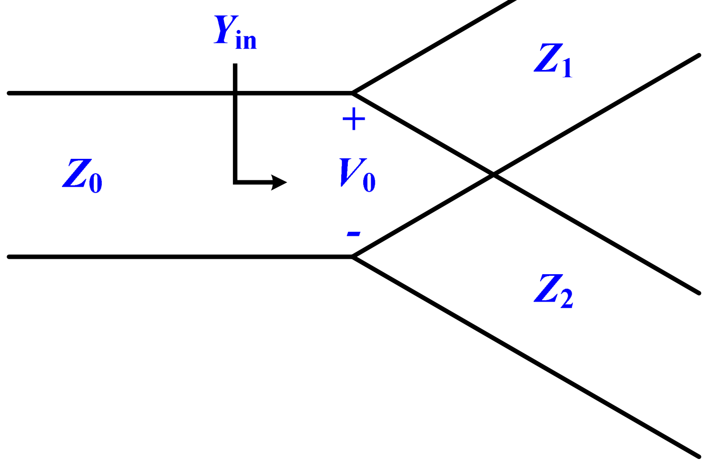
  b) Compute reflection coefficients seen looking into output ports.

  Solution:

  a) Find Z_1 and Z_2

  - Input power for the matched divider: $P_{in} = \frac{1}{2}\frac{V_0^2}{Z_0}$

  - Output powers:



$$\begin{cases} P_1 = \frac{1}{2}\frac{V_0^2}{Z_1} = \frac{1}{5}P_{in} = \frac{1}{5}\times\frac{V_0^2}{2Z_0} = \frac{V_0^2}{10Z_0} \\ P_2 = \frac{1}{2}\frac{V_0^2}{Z_2} = \frac{4}{5}P_{in} = \frac{4}{5}\times\frac{V_0^2}{2Z_0} = \frac{2V_0^2}{5Z_0} \end{cases}$$

$$2Z_1 = 10Z_0 \Rightarrow Z_1 = 5Z_0 = 5(50) = 250\ [\Omega]$$

$$2Z_2 = \frac{(5Z_0)}{2} \Rightarrow Z_2 = \frac{5Z_0}{4} = \frac{5}{4}(50) = 62.5\ [\Omega]$$

2 T-junction Power Divider

b) Reflection coefficient

- Input impedance to junction:

$$Z_{\text{in}} = 250//62.5 = 50 \ [\Omega] \quad \leftarrow \text{Matched!}$$

- Load impedance looking into output transmission line of $Z_1 = 250$ [Ω]:

$$Z_{L1} = 50 \ // \ 75 = 27.78 \ \Omega$$

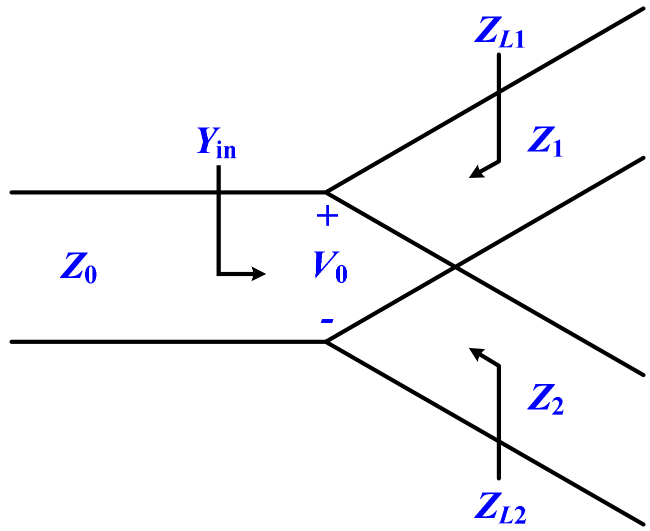
- Load impedance looking output transmission line of $Z_2 = 62.5$ [Ω]:

$$Z_{L2} = 50 \ // \ 250 = 41.67 \ \Omega$$

- Reflection coefficient looking into the output ports:

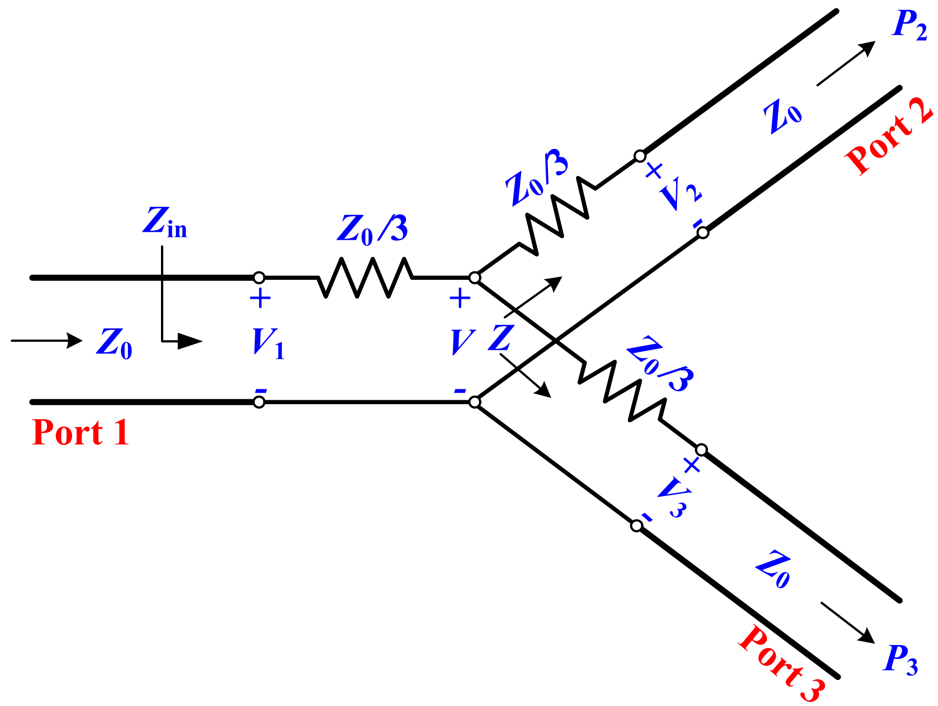
$$\Gamma_1 = \frac{Z_{L1} - Z_1}{Z_{L1} + Z_1} = \frac{27.78 - 250}{27.78 + 250} = -0.8 \leftarrow Z_{L1} = Z_0 // Z_2 = 50//62.5 = 27.78$$

$$\Gamma_2 = \frac{Z_{L2} - Z_2}{Z_{L2} + Z_2} = \frac{41.67 - 62.5}{41.67 + 62.5} = -0.2 \leftarrow Z_{L2} = Z_0 // Z_1 = 50//250 = 41.67$$



2 T-junction Power Divider

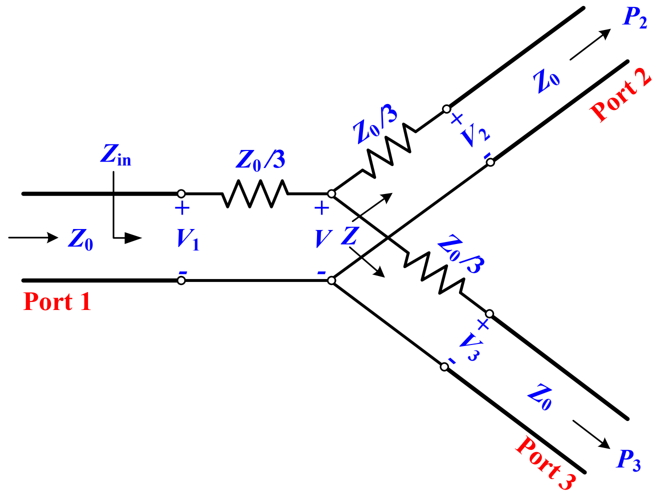
- **Resistive Divider**
  - Contains lossy components
  - Matched at all ports
  - Non-isolated two output ports
  - An equal-split (–3 dB) divider and unequal power division ratios
  - Equal-split 3-port resistive power divider ($P_2 = P_3$)



2 T-junction Power Divider

- Assuming that all ports are terminated with Z_0, the impedance Z, seen looking into the $Z_0/3$ resistor followed by the output transmission line can be determined as:

$$Z = \frac{Z_0}{3} + Z_0 = \frac{4Z_0}{3}$$



- Input impedance of divider:

$$Z_{in} = \frac{Z_0}{3} + \left(\frac{4Z_0}{3} // \frac{4Z_0}{3}\right) = Z_0$$

- Since $Z_{in} = Z_0$, the input port is matched.
- Since the network is symmetric from all three ports, the output ports are also matched.

$\rightarrow S_{11} = S_{22} = S_{33} = 0$

- If the voltage at port 1 is V_1, the voltage V at the center of the junction is:

$$V = V_1 \frac{Z//Z}{Z_0/3 + (Z//Z)} = V_1 \frac{2Z_0/3}{Z_0/3 + 2Z_0/3} = \frac{2}{3} V_1$$

2 T-junction Power Divider

- Output powers:

$$V_2 = V_3 = V\frac{Z_0}{Z_0/3+Z_0} = \frac{3}{4}V = \frac{3}{4}\frac{2}{3}V_1 = \frac{1}{2}V_1$$

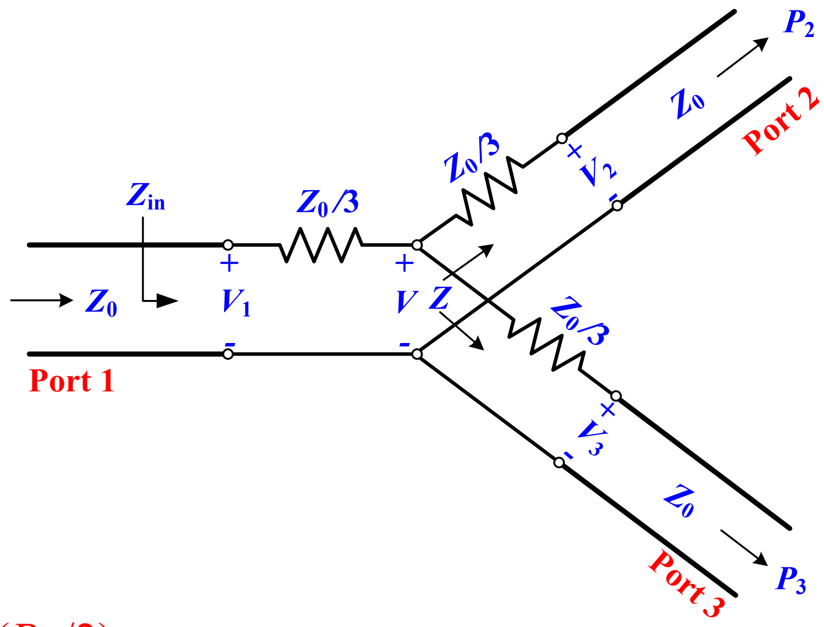
- Scattering matrix: symmetric network: $[S]=\frac{1}{2}\begin{bmatrix}0 & 1 & 1\\ 1 & 0 & 1\\ 1 & 1 & 0\end{bmatrix}$

- Power delivered to input of divider:

$$P_{in} = \frac{1}{2}\frac{V_1^2}{Z_{in}} = \frac{1}{2}\frac{V_1^2}{Z_0}$$

- Output powers: $P_2 = P_3 = \frac{1}{2}\frac{V_2^2}{Z_0} = \frac{1}{2}\frac{(V_1/2)^2}{Z_0} = \frac{1}{8}\frac{V_1^2}{Z_0} = \frac{1}{4}P_{in}$

$$P_L = P_2 + P_3 = \frac{1}{2}P_{in}$$



→ The half of the supplied power is dissipated at the resistors ($P_{in}/2$).

→ The output powers are 6 dB below the input power level.

3 Design Examples of T-junction Power Divider

- **Lossless T-junction power divider**

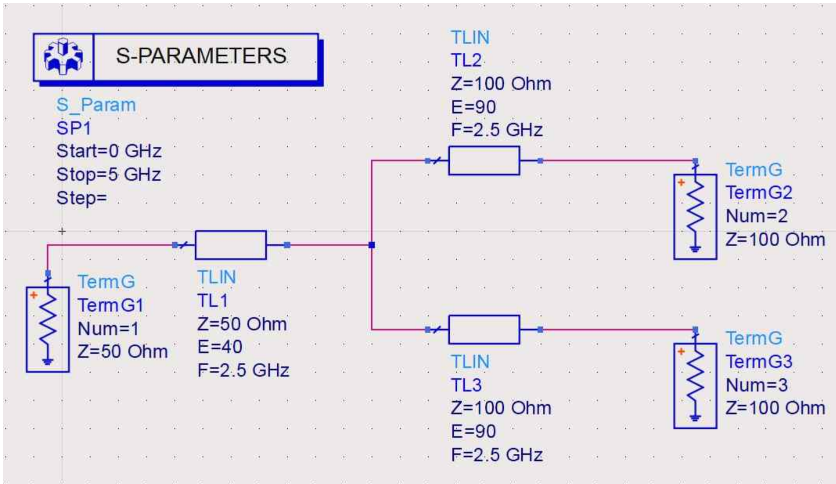
  - Set the $Z_0 = 50$ [Ω] and power division ratio of 1:1.

  - Center frequency: 2.5 GHz.

  - Electrical length of transmission lines: 90° (or $\lambda/4$)

  - Input power:

$$P_{\text{in}} = \frac{1}{2}\frac{V_0^2}{Z_0}$$

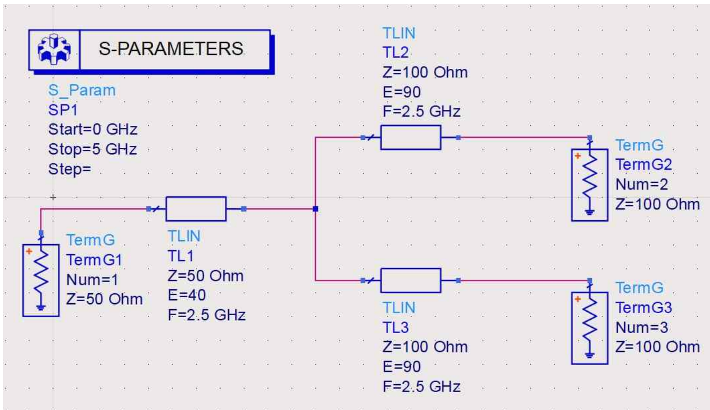


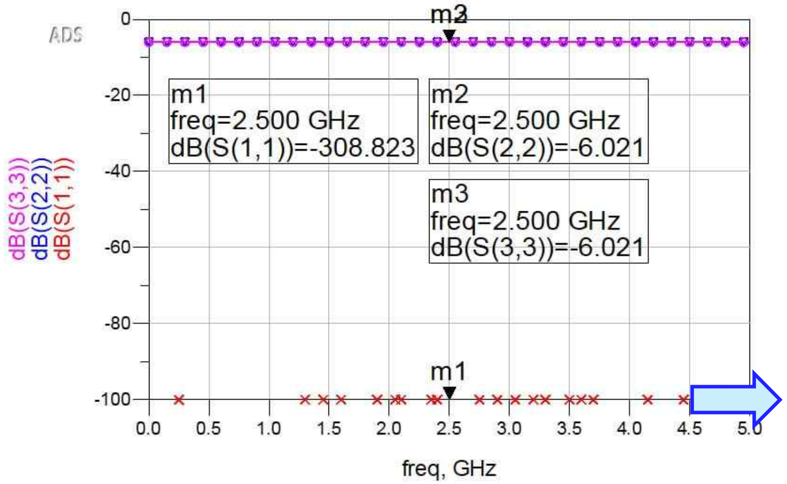
- Output power at ports 2 and 3:

$$\begin{cases} P_2 = \frac{1}{2}\frac{V_0^2}{Z_1} = \frac{1}{2}P_{\text{in}} = \frac{1}{2}\times\frac{V_0^2}{2Z_0} = \frac{V_0^2}{4Z_0} \\ P_3 = \frac{1}{2}\frac{V_0^2}{Z_2} = \frac{1}{2}P_{\text{in}} = \frac{1}{2}\times\frac{V_0^2}{2Z_0} = \frac{V_0^2}{4Z_0} \end{cases} \Leftrightarrow \begin{array}{l} 2Z_1 = 4Z_0 \quad \Rightarrow \quad Z_1 = 2Z_0 = 2(50) = 100\ [\Omega] \\ 2Z_2 = 4Z_0 \quad \Rightarrow \quad Z_2 = 2Z_0 = 2(50) = 100\ [\Omega] \end{array}$$

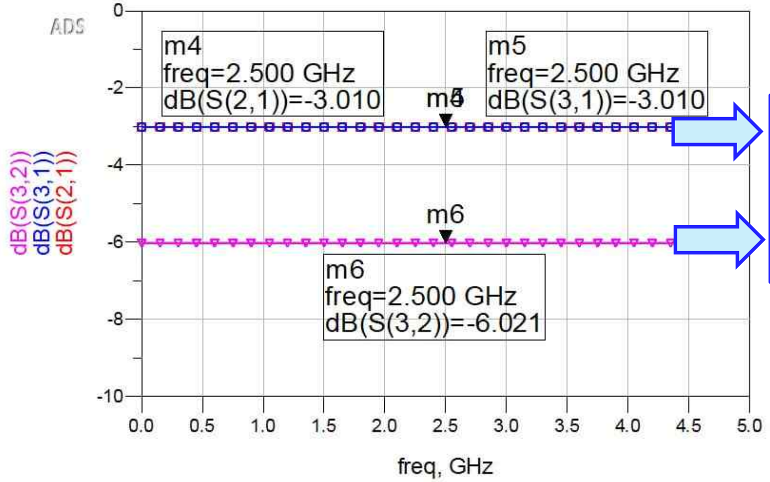
3 Design Examples of T-junction Power Divider

- **Lossless T-junction power divider**
  - Ideal simulation results using ADS software
  - *S*-parameters presented in [dB] scale
  - According to S_{22} and S_{33}, ports 2 and 3 are not matched.
  - The output powers are around -3 dB.





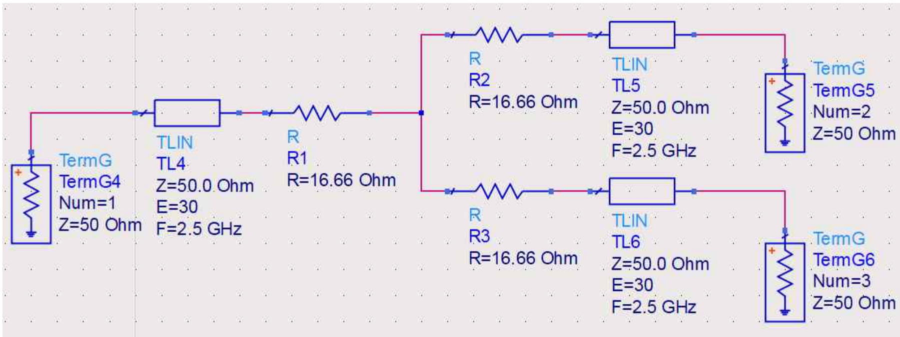
Return losses of each ports

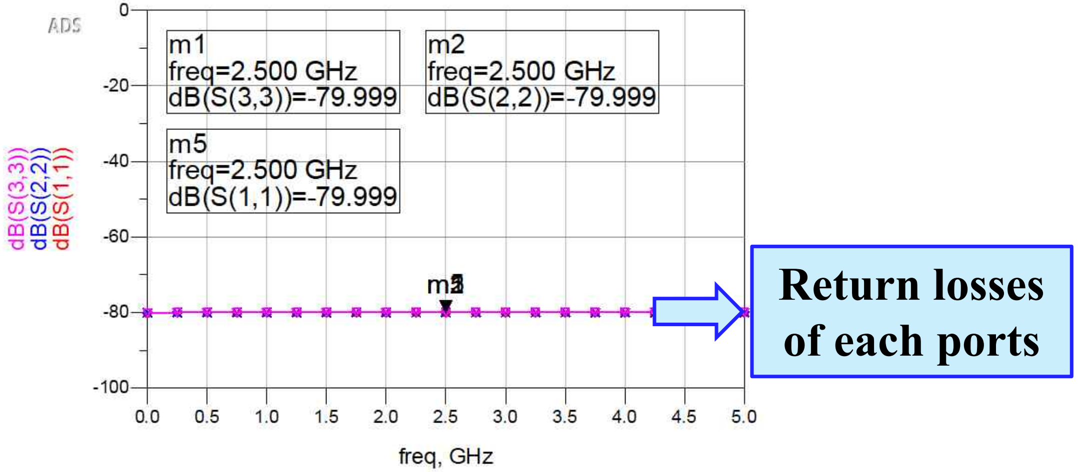


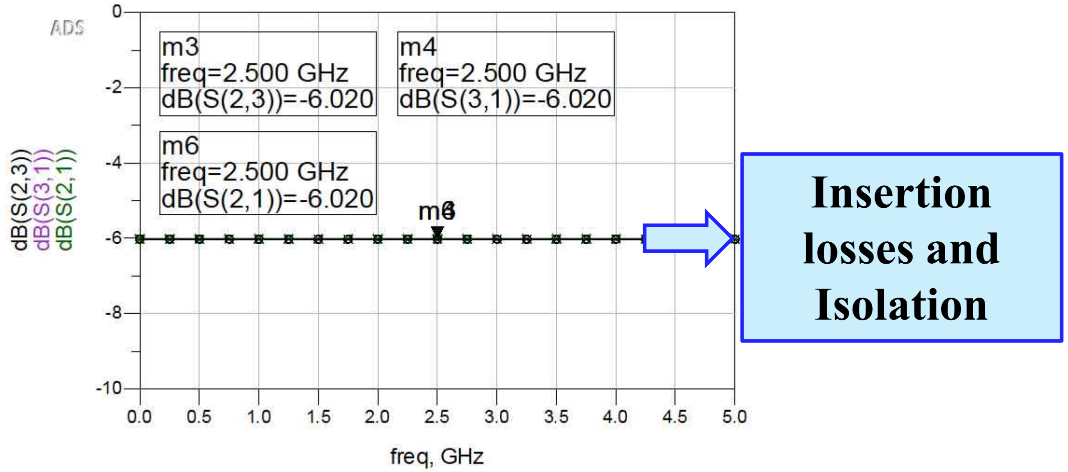
Insertion losses and Isolation

3 Design Examples of T-junction Power Divider

- **Resistive power divider: 2-way splitter**
  - Selection of $Z_0 = 50\ \Omega \rightarrow R = 50/3 = 16.66\ \Omega$.
  - Based on S_{11}, S_{22}, and S_{33}, all ports are perfectly matched.
  - Isolation between ports 2 and 3 (S_{23}): poor
  - The output powers are 6 dB less than input power level.

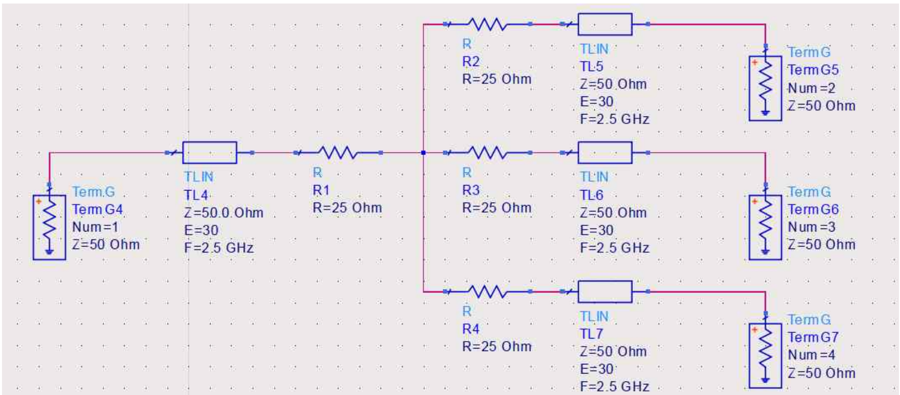


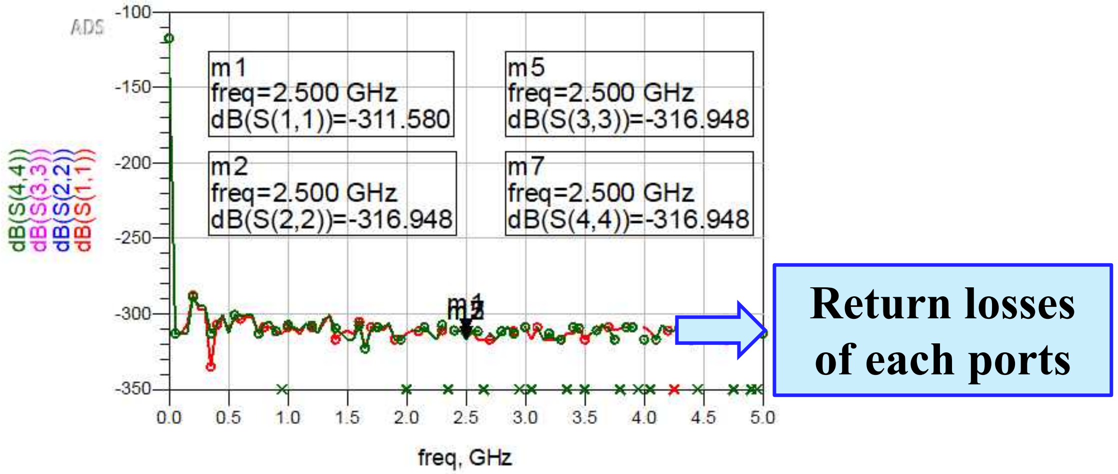


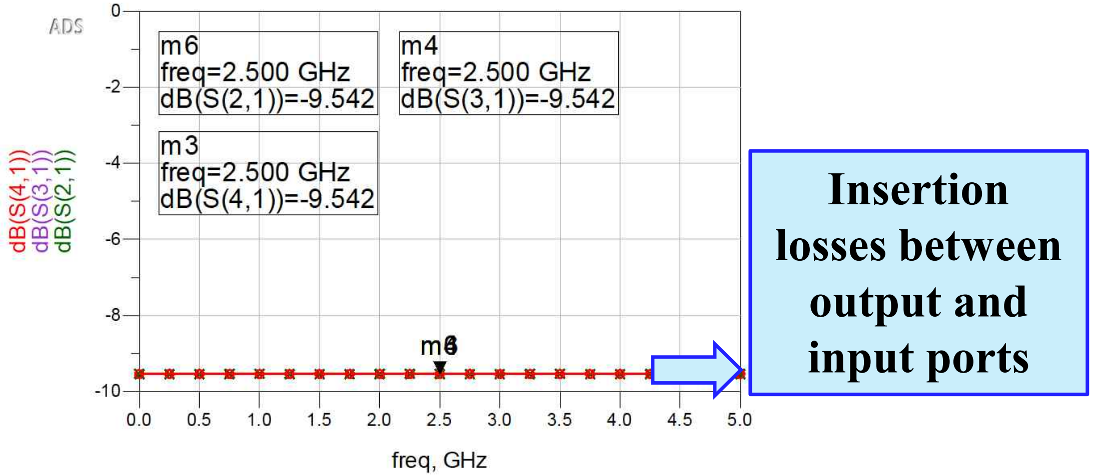


3 Design Examples of T-junction Power Divider

- **Resistive power divider: 3-way splitter**
  - Connection resistance: $R = Z_0 \times (n-1)/(n+1)$
    $\rightarrow R = 50 \times (3-1)/(3+1) = 25\ [\Omega]$
  - Based on S_{11}, S_{22}, S_{33}, and S_{44}, all ports are perfectly matched.
  - The output powers are 9.54 dB less than input power level.







3 Design Examples of T-junction Power Divider

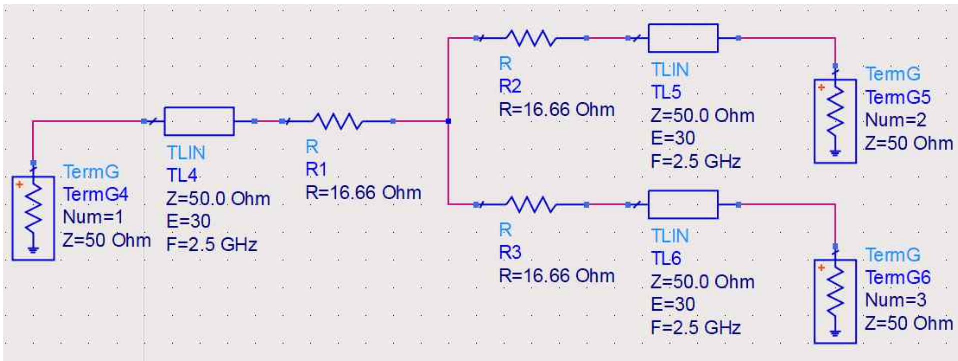
- **Resistive power divider:**

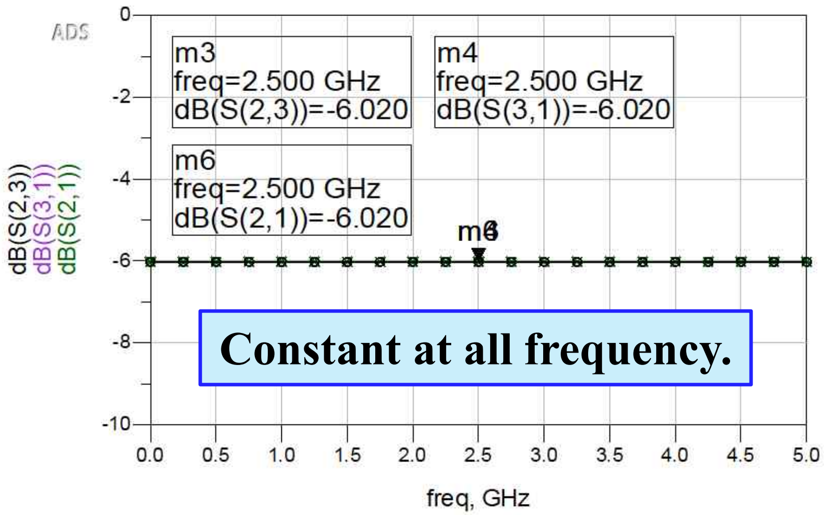
  - The resistive power divider generally have the **widest frequency bandwidth** because there is no frequency dependent components in the network.

  - The **handling power capability** of the network is mainly depended on the rated power capacity of resistor.

  - The major disadvantage is the **power loss via the series resistors** between the input and output ports.

  - Most applications for this divider use relatively low power.





4 Review

- T-junction power divider
- Resistive T-junction power dividers