# Microwave Circuits and Devices

Laboratory no. 2

A directional coupler is a device that allows the control of the transfer of energy between his ports. Typically, the couplers have four ports, an input port, the through port (or output, the port where the largest portion of the energy is directed), and the coupled port (to which a controlled portion of the input energy is directed). The fourth port is isolated, in ideal conditions no power is delivered to this port. In commercial devices quite often an external connector is not present for this port (it is internally terminated on an absorbing load).

Figure 7.4
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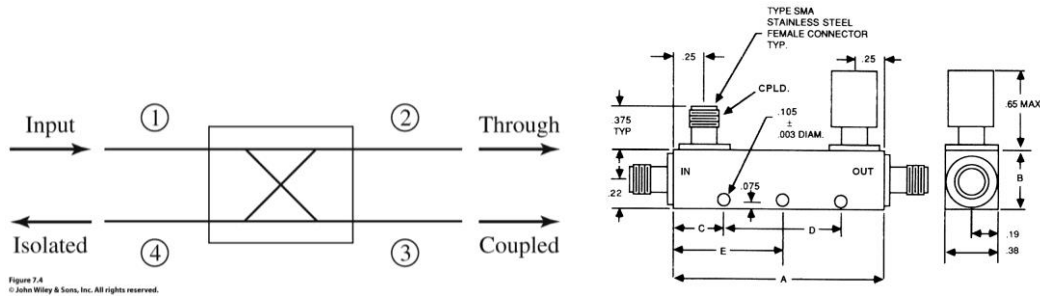
Coupler's parameters

The following quantities are used to characterize a directional coupler: C (coupling factor), D (directivity), I (isolation).

$$C = 10 \cdot \log \frac{P_1}{P_3} = -20 \cdot \log \beta = -20 \cdot \log |S_{31}|$$

$$D = 10 \cdot \log \frac{P_3}{P_4} = 20 \cdot \log \frac{\beta}{|S_{14}|}$$

$$I = 10 \cdot \log \frac{P_1}{P_4} = 20 \cdot \log |S_{14}|$$

$$I = 10 \cdot \log \frac{P_1}{P_4} = 10 \log \frac{P_1}{P_3} \frac{P_3}{P_4} = 10 \log \frac{P_1}{P_3} + 10 \log \frac{P_3}{P_4} = C + D$$

Notes

1. Although the numbers assigned to the ports can be modified, the traditional numbering scheme (corresponding to the formulas above!) is that from the first figure
2. The "official" definitions of the parameters (especially the coupling factor) are those in the above formulas. Definitions relate to signals power and are in logarithmic scale. If we consider the conservation of energy in the circuit $P_1 > P_3$, $P_3 > P_4$, $P_1 > P_4$ thus C[dB] > 0, D[dB] > 0, I[dB] > 0 in logarithmic scale, C > 1, D > 1, I > 1 in linear scale
3. Many times, the design formulas use the voltage coupling factor $\beta = |S_{31}|$ from above definition formulas (sometimes mistakenly also noted with C, a fact that generates confusion). From the definition formula β < 1, β[dB] < 0. Before using the design formulas, it is first necessary to make the right decision about which parameter to use (C or β). Additionally, ADS will display the S parameters, so the displayed values

will be voltage related coefficients (eg. a 3dB coupler will have C = +3dB but will be displayed in ADS as dB(S(2,1)) = -3dB)

4. The design formulas are accurate enough that in current lab assignment you should not need to adjust (tune) the lines to get the desired results. However, it is necessary to carry out the calculations with sufficient precision (the formulas with square root or square require that you use of at least 4-5 significant digits)

5. In low power applications the couplers are implemented in microstrip transmission lines technology (simplicity and precision).

6. For two of the couplers you will analyze for this lab assignment the design formulas use the normalized admittances. To obtain the characteristic impedances of the lines required in ADS:
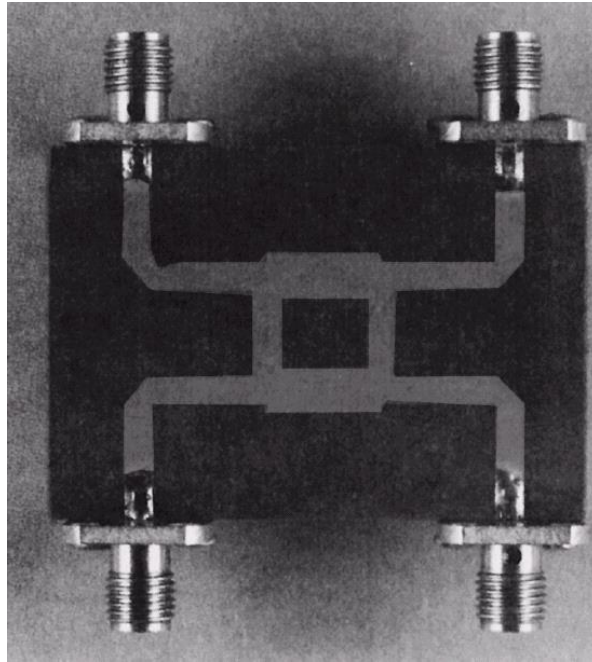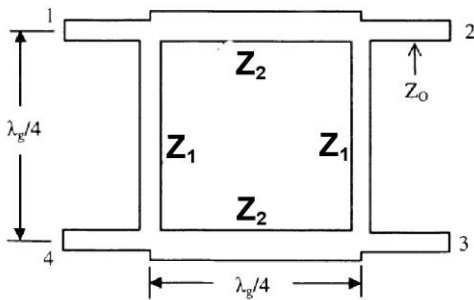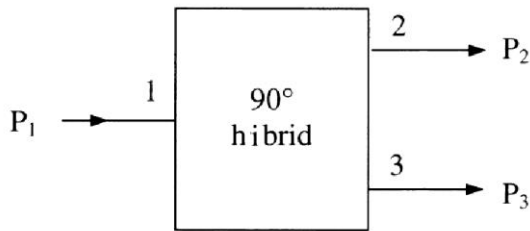
$$y = \frac{Y}{Y_0} = \frac{1/Z}{1/Z_0} = \frac{Z_0}{Z} \Rightarrow Z = \frac{Z_0}{y}$$

The quadrature (90°) hybrid

Design formulas:

$$y_2^2 = 1 + y_1^2, \ C = \frac{\sqrt{y_2^2 - 1}}{y_2}$$

where y_1 corresponds to Z_1 and y_2 to Z_2 in the next figure. We observe that the second relation is in linear scale and $C < 1$, so in fact it refers to the voltage coupling factor β.
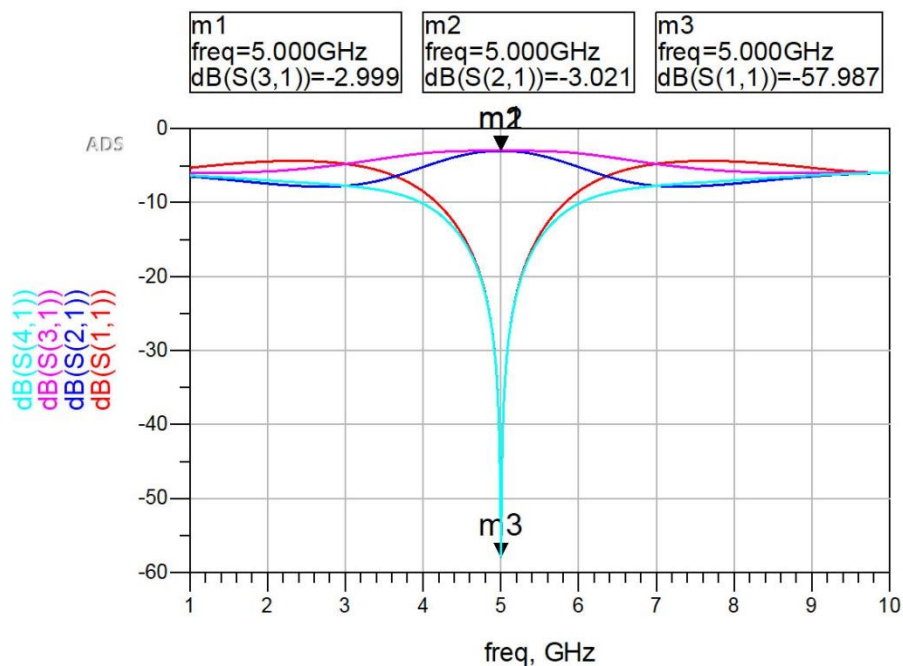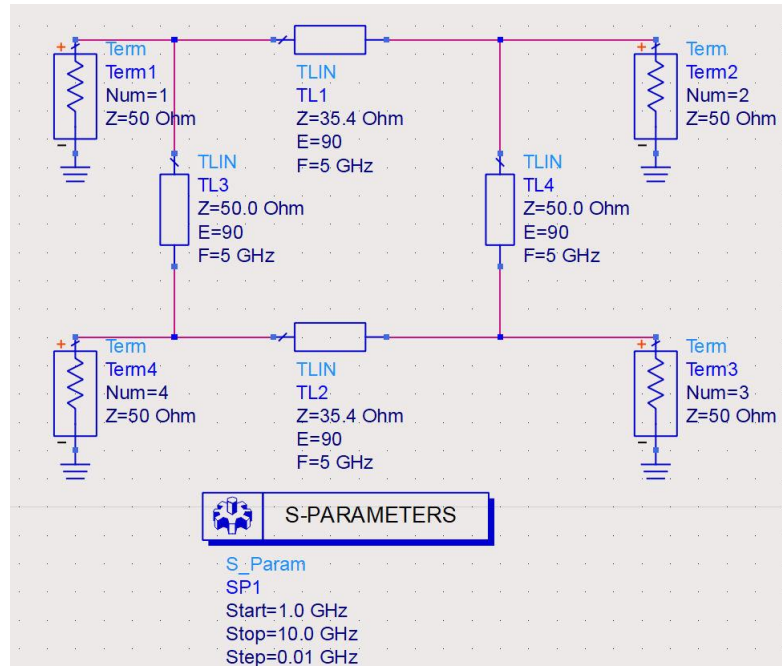

Example: A quadrature hybrid working on 50Ω, with a 3dB coupling factor at 5GHz.

$$\beta = 10^{-C[dB]/20} = \frac{1}{\sqrt{2}} = 0.7071 = \frac{\sqrt{y_2^2 - 1}}{y_2} \Rightarrow \sqrt{2} = 1.4142 = \frac{y_2}{\sqrt{y_2^2 - 1}}$$

$$2 \cdot (y_2^2 - 1) = y_2^2 \Rightarrow y_2 = \sqrt{2} = 1.4142 \qquad y_2^2 = 1 + y_1^2 \Rightarrow y_1 = 1$$

The individual data received in the lab will not consist in a 3dB coupling factor, so you will get a quadrature coupler, but not a hybrid one. As a result, instead of $\sqrt{2}$ (obtainable only for 3dB), you will use the numerical value corresponding to your individual data.

The 180° ring hybrid (rat-race)

Design formulas

$$y_2^2 + y_1^2 = 1, \quad C[\text{dB}] = -20 \cdot \log(\beta) = -20 \cdot \log(y_1)$$

where y_1 and y_2 correspond to the transmission lines denoted in next figure.

**Example:** A 180° ring hybrid working on 50Ω, with a 3dB coupling factor at 5GHz.

$$\beta = 10^{-C[dB]/20} = y_1 \Rightarrow y_1 = \frac{1}{\sqrt{2}} = 0.7071 \qquad\qquad y_2^2 + y_1^2 = 1 \Rightarrow y_2 = \frac{1}{\sqrt{2}} = 0.7071$$

Note

The individual data received in the lab will not consist in a 3dB coupling factor, so you will get an anti-phase coupler, but not a hybrid one. As in the previous case, $\sqrt{2}$ will have to be replaced with the numerical value corresponding to your individual data.
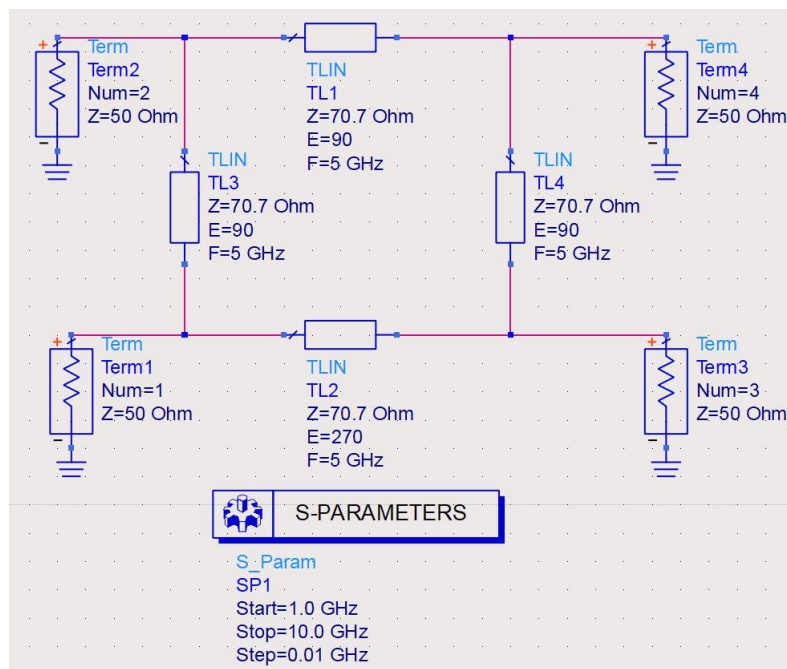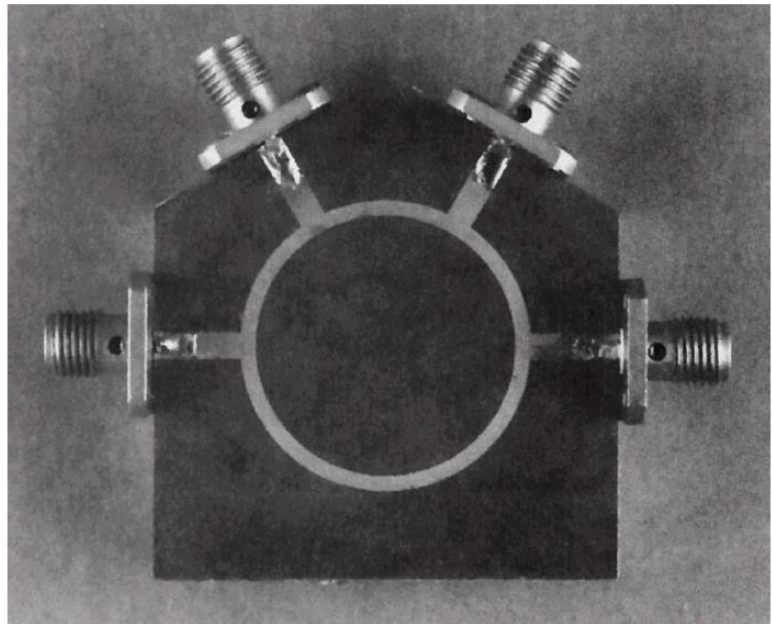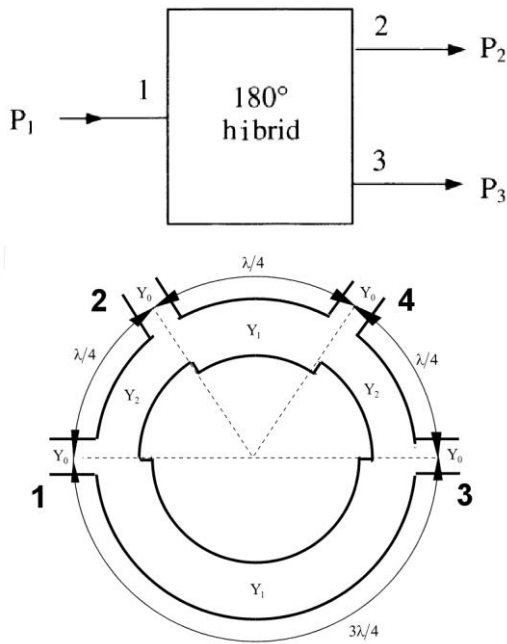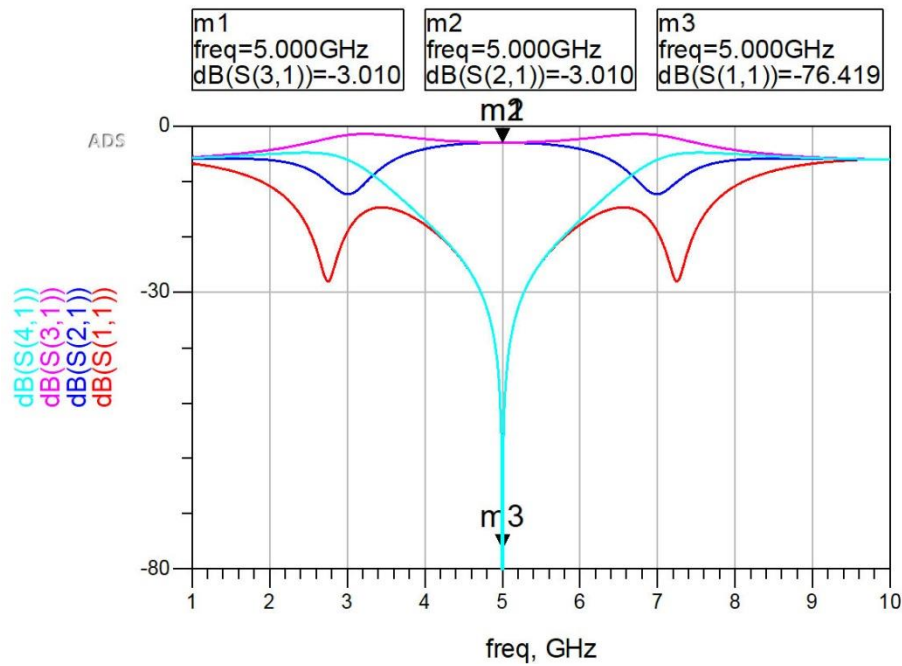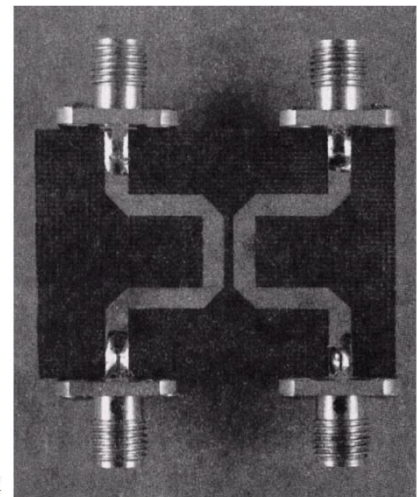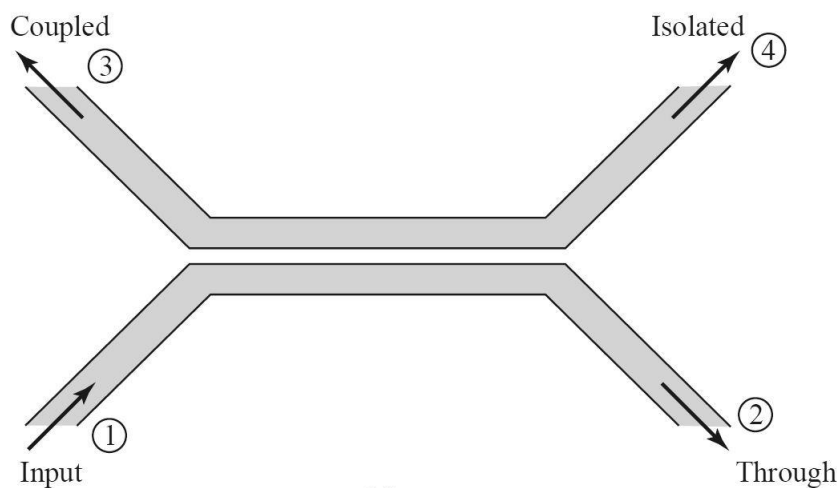
Additional steps: Find another valid signal input, and identify the output/coupled/isolation port when inserting signal power on the valid input port you found.

Coupled Line Coupler

Design formulas

$$Z_{ce}Z_{co} = Z_0^2 \ , \ C = \frac{Z_{ce} - Z_{co}}{Z_{ce} + Z_{co}}$$

We observe that the second relation is in linear scale and C < 1, so in fact it refers to the voltage coupling factor β.


Example: A coupled line coupler working on 50Ω, with a 3dB coupling factor at 10GHz.

$$\beta = 10^{-C[dB]/20} = \frac{1}{\sqrt{2}} = 0.7071 = \frac{Z_{ce} - Z_{co}}{Z_{ce} + Z_{co}} \ ; \ Z_{ce}Z_{co} = 2500 \ ;$$ we have a system of two equations with two

unknowns, solving it we get:

$$Z_{ce} = 120.71\ \Omega\ ;\ Z_{co} = 20.71\Omega$$

Note

As in the previous cases the individual data received in the lab will not consist in a 3dB coupling factor, so you will have to be replace $\sqrt{2}$ with the numerical value corresponding to your individual data. On the other hand the value $2500 = 50(\Omega) \cdot 50(\Omega)$ will be the same for all assignments.
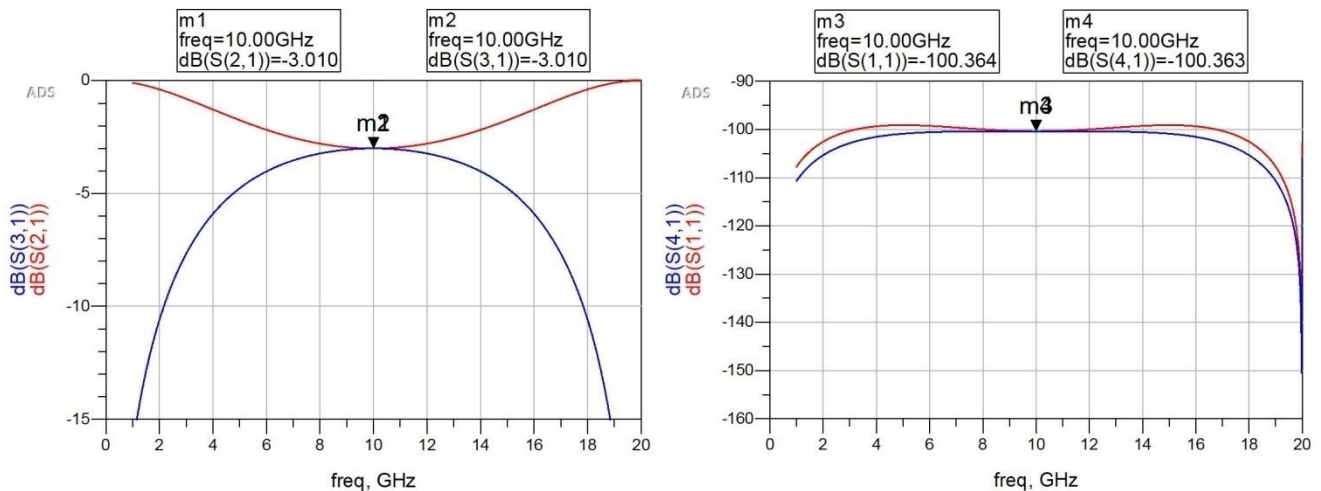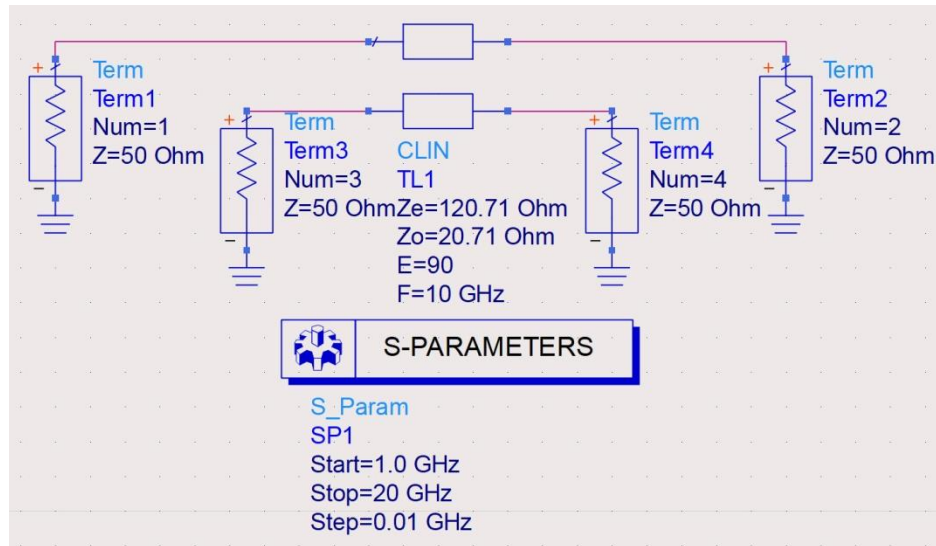

(Most important) Note:

In the lab you will receive 3 individual values for the coupling factors and you must design and simulate three couplers (quadrature, ring and coupled line). At the end of the lab you must hand over to the teacher the results sheets that **should** contain for each of the three couplers:

1. The ADS schematic, in which it is important to indicate the numbering scheme of the nodes (to avoid confusion generated by numbering schemes different from the standard one, any scheme is allowed but **must** appear on the schematic)
2. Graph of the simulation results (4 S parameters for a particular port chosen as input)
3. **Correct** identification of the ports (which one is input, output, coupled, isolation) in connection with the simulation results and the previously represented schematic and port numbering scheme

Additional activity (1p bonus to the final lab grade)

Design the previous coupled line coupler in microstrip technology, as in the next example:
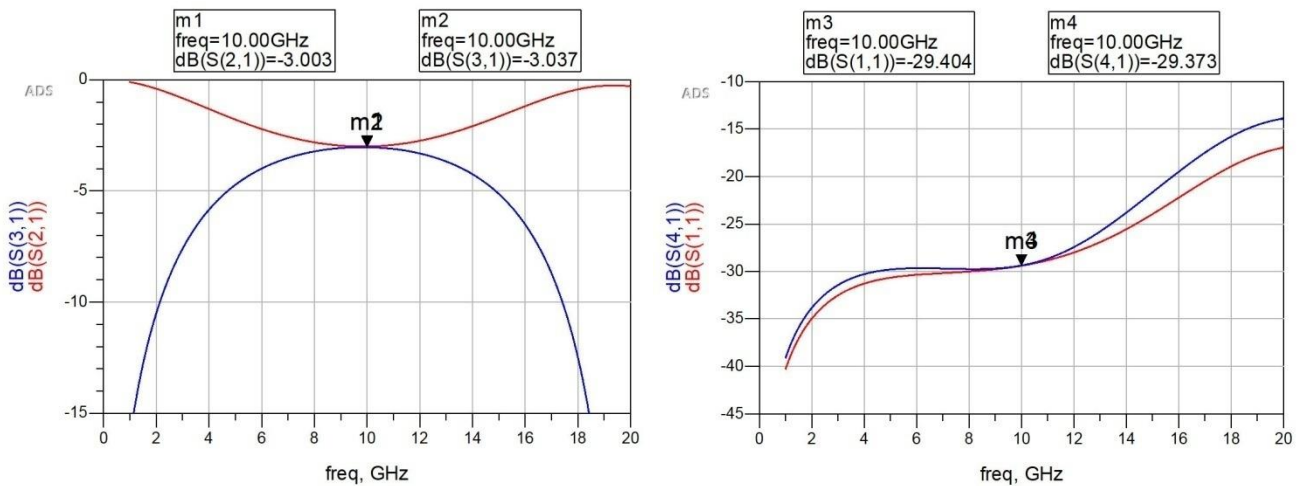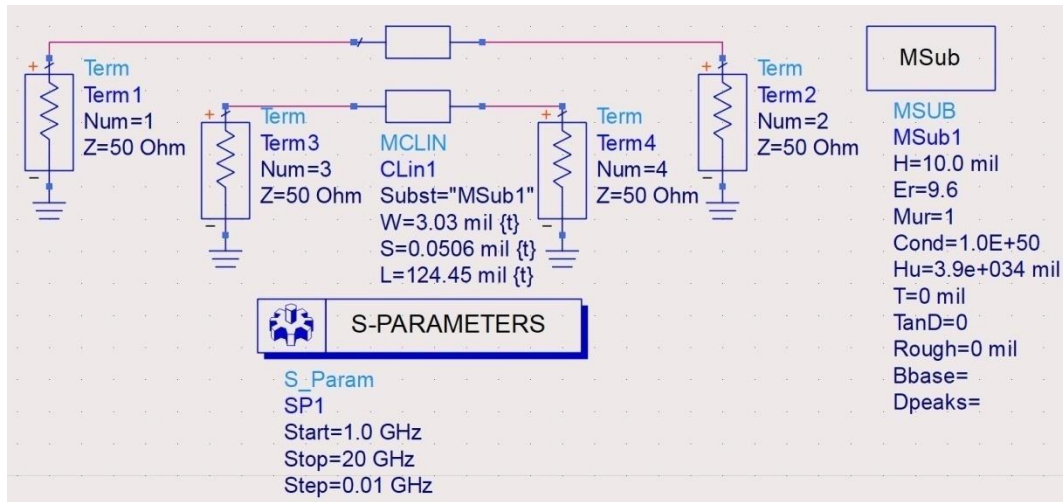
In microstrip technology Z_{ce} şi Z_{co} are dependent on lines geometry and can be estimated initially from the following figure. Usually, you must tune the parameters to get the appropriate values (the {t} code that appears in the microstrip coupled line model from the above schematic denotes a value selected for the Tune tool and must not be inserted manually – it shows automatically on specific versions of ADS).
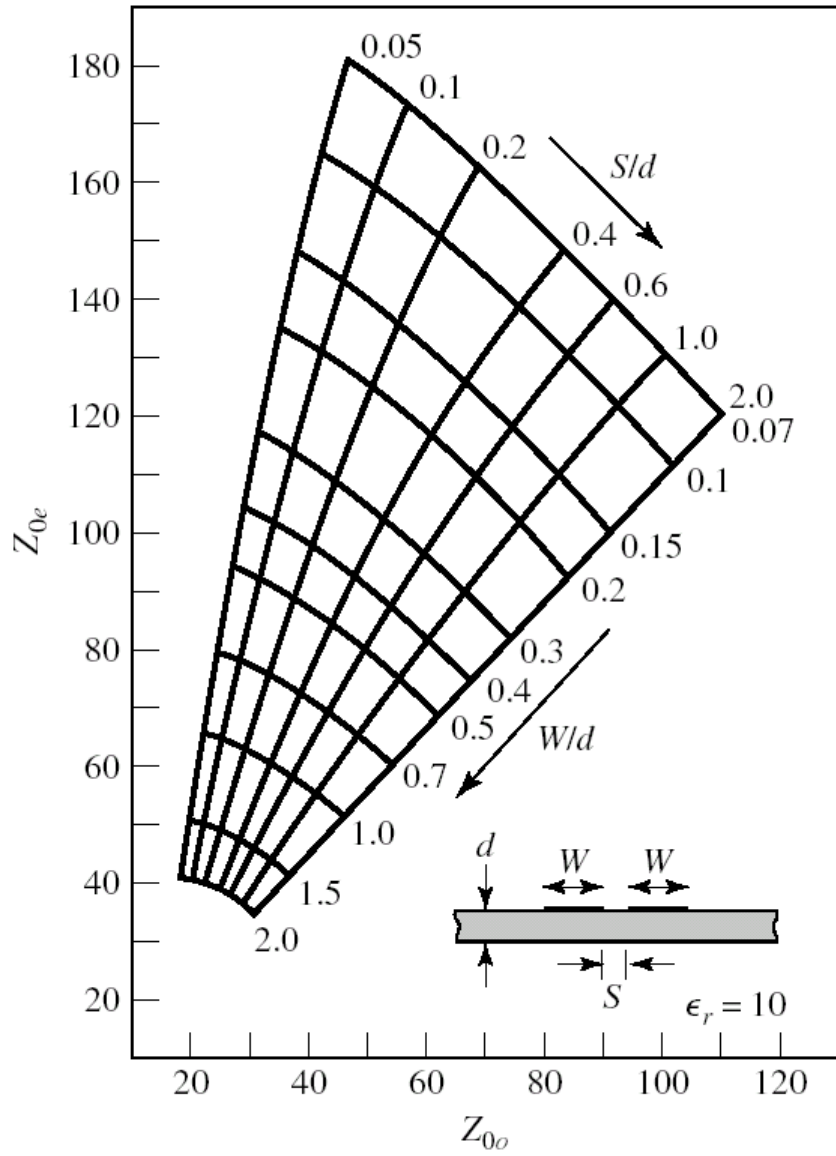
Even- and odd-mode characteristic impedance design data for coupled microstrip lines on a substrate with $\varepsilon_r = 10$.