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1 1.2.1

The length of the transmission lines is calculated using $\frac{\lambda}{4}$. This conditions allows the $tan(\beta * l)$ term to dominate and inturn vanish in the $\lambda/4$ wave transformer, similarly we require the same.

The expressions for coupling factor can be taken from Collin's textbook, and they are in dB.

$$C = 20 \log_{10} \frac{1}{|S_{31}|}$$

Directivity is similarly defined in dB units.

$$D = 20 \log_{10} \frac{|S_{31}|}{|S_{41}|}$$

The simulation of this ideal 3-db coupler is presented in the graph below. Notice the high isolation at the design frequency and every other integer multiple of the design frequency. Also notice the coupling and through loss to be exactly 3dB. In order to simulate the device we used:

$$\begin{aligned} Z_1 &= 35.35\Omega \\ Z_2 &= 50.00\Omega \\ Z_3 &= 35.35\Omega \\ Z_4 &= 50.00\Omega \end{aligned} \qquad \text{and} \qquad \theta = \frac{\pi}{2} \quad \text{at 4GHz} \tag{1}$$

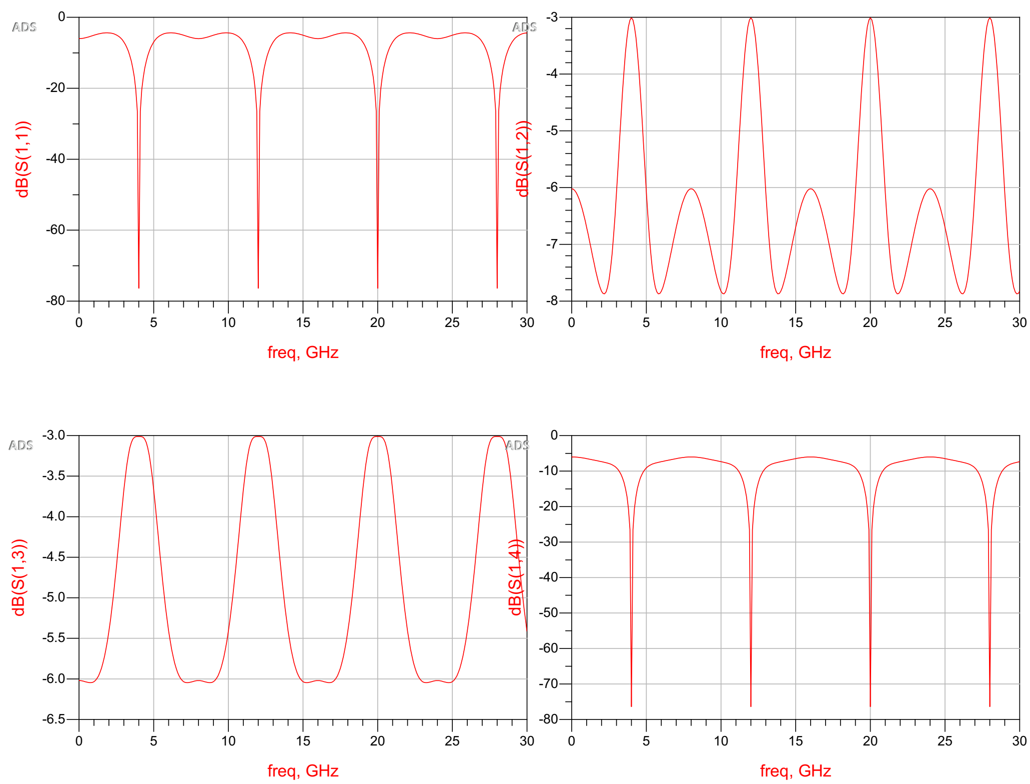

Figure 1: Simulation of generic 3dB directional coupler for f=4GHz

2 1.2.2

The principle is to break the circuit about its symmetry line, and only consider one image, simplifying the analysis.

Let the original excitation be equal to $a = 1$. In the "even" mode we can break the excitation into two positive halves, $a1e = 1/2, a2e = 1/2$. What happens is we'll have the same voltage above as we have below, since there is no voltage difference no current will be able to flow and as such the joining of the circuit is effectively an open circuit. So we can simply replace it with an open circuit and make analysis simpler.

Similarly for the odd mode we can break the excitation into one positive half and one negative half, $a1o = 1/2, a2o = -1/2$. In the middle of the circuit we will have a negative voltage meeting a positive voltage of the same magnitude, as such the current will flow from positive to negative and will have a point of 0 volts in the middle, as such the middle of the circuit can be grounded, again simplifying the analysis.

This procedure is valid only when the even and odd mode combine to give the original excitation.

3 1.2.3

We get the S_{31} from the following equation considering the coupling factor assigned to our group (Group 5, C = 3.25 dB).

$$|S_{31}| = 10^{-\frac{C}{20}} = 0.688 \tag{2}$$

Then using the equation from the Collin's textbook.

$$\frac{Y_2}{Y_1} = |S_{31}| \tag{3}$$

Another available equation for the branch line coupler is:

$$Y_1^2 - Y_2^2 = Y_c^2 \tag{4}$$

These equations can be combined, and solving for Y_1, the admittance of the upper transmission line is:

$$Y_1 = \frac{Y_c}{\sqrt{1 - |S_{31}|^2}} = 0.0275\mathrm{S} \tag{5}$$

and this implies that

$$Y_2 = |S_{31}|Y_1 = 0.188\mathrm{S} \tag{6}$$

Therefore the impedances for the lines are

$$Z_1 = 36.285\Omega \qquad Z_2 = 52.98\Omega \tag{7}$$

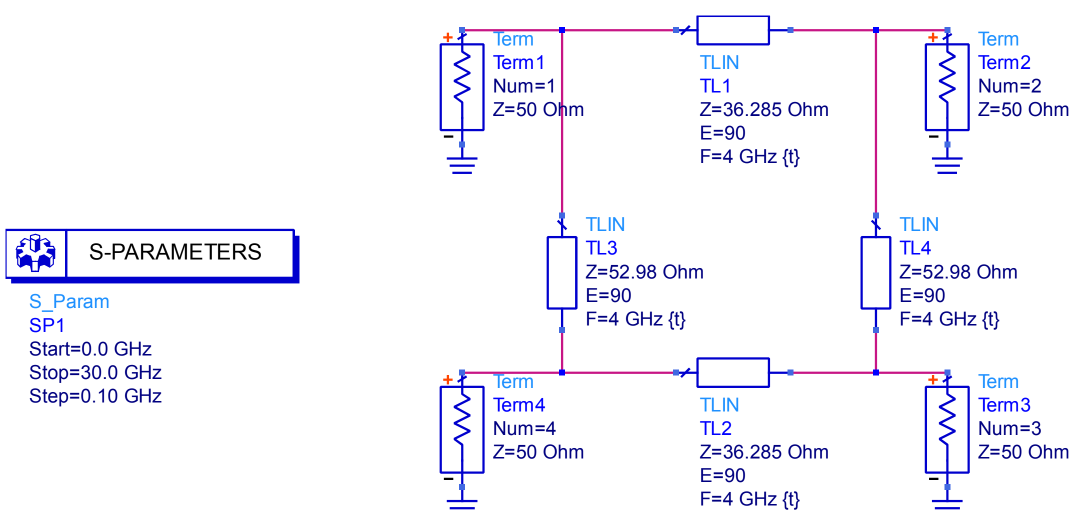

Figure 2: Electric circuit of a 3.25dB directional coupler for f=4GHz

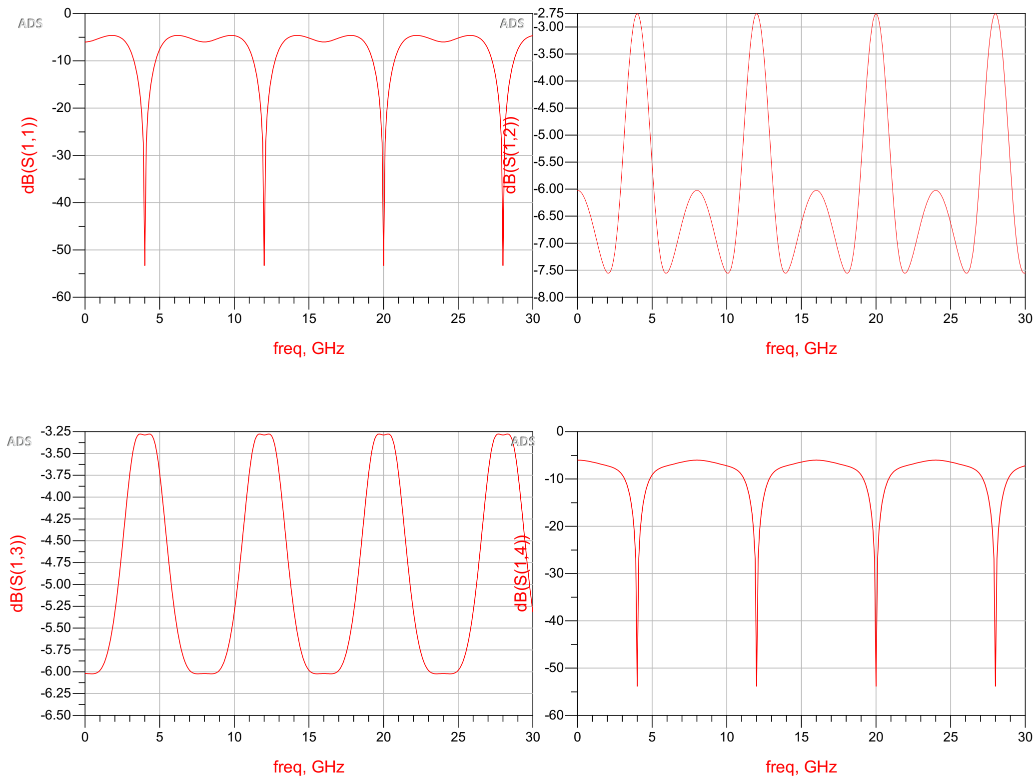

Figure 3: Simulation of 3.25dB directional coupler for f=4GHz

In the above graphs we can see the coupling is -3.25 dB (between Port 1 and Port 3), at the design frequency of 4GHz. Using the formula in the tutorial we get

$$\frac{w}{h} = 2.6566 \tag{8}$$

and this means

$$w = 2.07 \pm 0.07\text{mm} \tag{9}$$

and the wavelength (supposing a TEM mode)

$$\lambda = \frac{2\pi}{k} = \frac{c}{f\sqrt{\epsilon}} = 4.84\text{cm} \tag{10}$$

that implies the length of the transmission line to be

$$\frac{\lambda}{4} = 1.21\text{cm} \tag{11}$$

4 Verifying results

In order to verify the calculation of the length of the transmission lines , we decided to simulate the coupler with "physical" transmission lines in which we specify the dielectric constant, the length and the loss tangent.

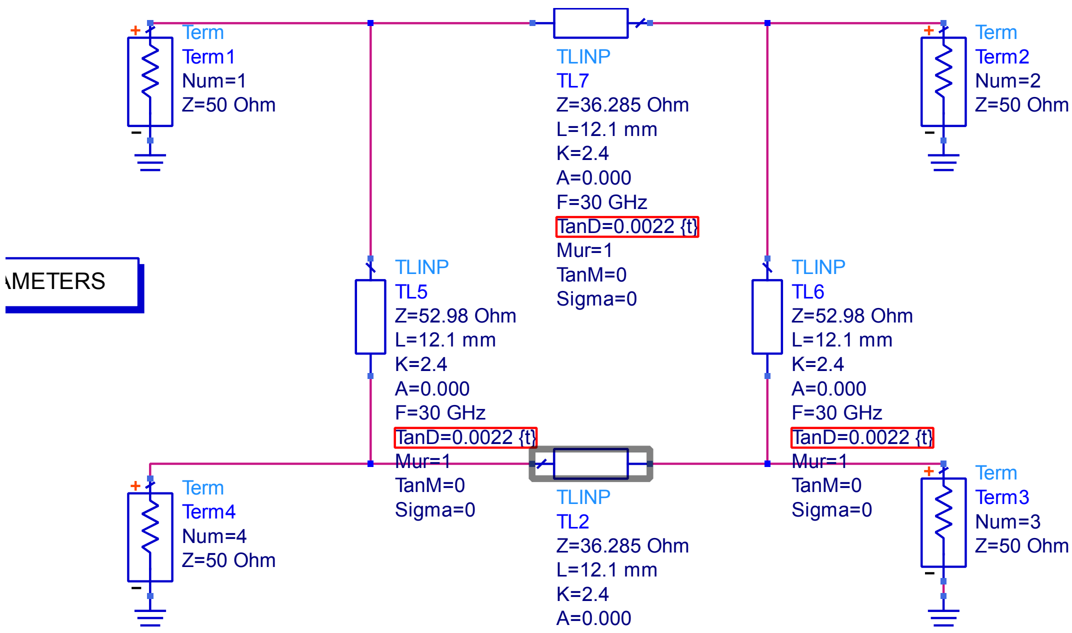

Figure 4: Electric circuit of a 3.25dB directional coupler for f=4GHz using "physical" transmission lines

The results show that the lengths are correct, and that the losses produce a skewing of the plateau in S_{13}.

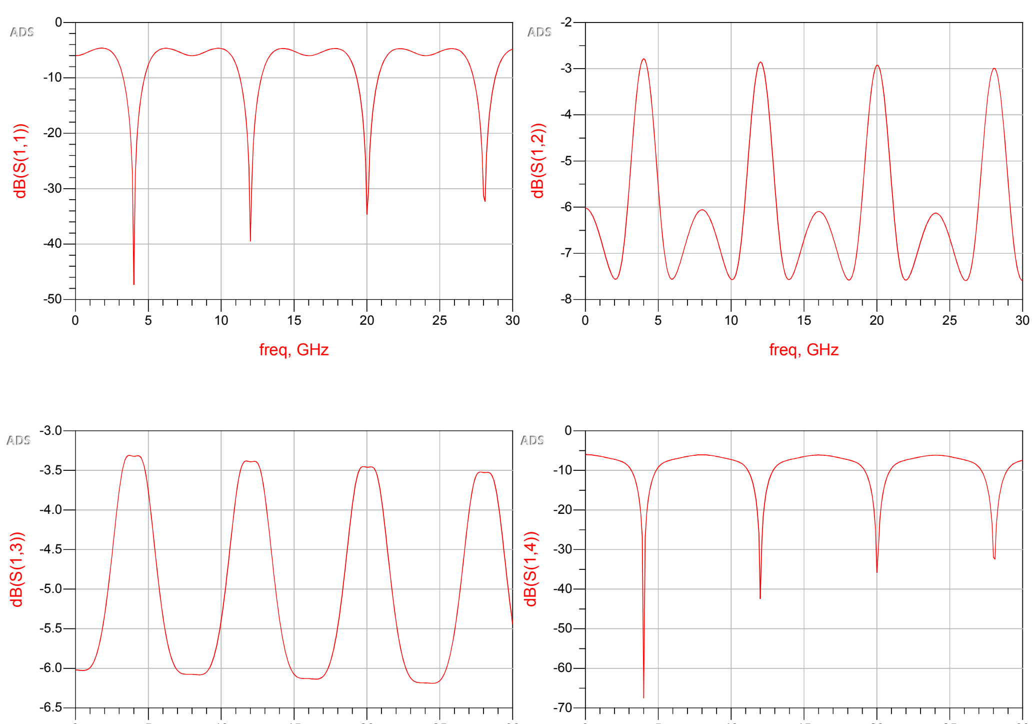

Figure 5: Simulation of 3.25dB directional coupler for f=4GHz with "physical" transmission lines.