ELC 4383 -RF/Microwave Circuits I
Laboratory 6: Quadrature Hybrid Coupler

Note: This lab procedure has been adapted from a procedure written by Dr. Larry Dunleavy and Dr. Tom Weller at the University of South Florida for the WAMI program in the RF/Microwave Circuits I course and from related procedures written for the WAMI Laboratory. It has been modified for use at Baylor University by Dr. Charles Baylis.

Printed Name:____________________

Please read the reminder on general policies and sign the statement below. Attach this page to your Post-Laboratory report.

General Policies for Completing Laboratory Assignments:

For each laboratory assignment you will also have to complete a Post-Laboratory report. For this report, you are strongly encouraged to collaborate with classmates and discuss the results, but the descriptions and conclusions must be completed individually. You will be graded primarily on the quality of the technical content, not the quantity or style of presentation. Your reports should be neat, accurate and concise (the Summary portion must be less than one page). Laboratory reports are due the week following the laboratory experiment, unless notified otherwise, and should be turned in at the start of the laboratory period. See the syllabus and/or in-class instructions for additional instructions regarding the report format.

This laboratory report represents my own work, completed according to the guidelines described above. I have not improperly used previous semester laboratory reports, or cheated in any other way.

Signed: ________________________________

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Laboratory 6: Quadrature Hybrid Coupler

Laboratory Assignment:

<u>Overview</u>

In this laboratory assignment, you will design and simulate a quadrature hybrid coupler. You will first simulate an "ideal" coupler using transmission line models. Second, you will simulate a "real" coupler using microstrip line elements. You will then modify the dimensions of the microstrip design to emulate the ideal results as closely as possible.

<u>Procedure</u>

A. Ideal Coupler

1. Open ADS and create ne new schematic, titled "quad_ideal_1_4port.dsn."

2. Create a schematic for the quadrature hybrid coupler using ideal transmission lines. Your design frequency for the coupler will be 2.5 GHz. The TLIN (ideal transmission line) elements are available from the "TLines-Ideal" Palette. Make sure your ports are numbered appropriately as shown below:

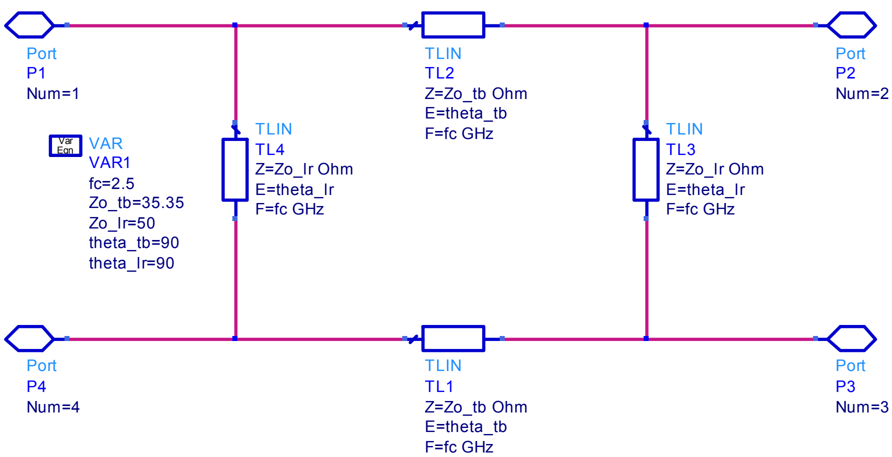

Figure 1: Ideal quadrature hybrid coupler schematic

B. Higher-Level Schematic

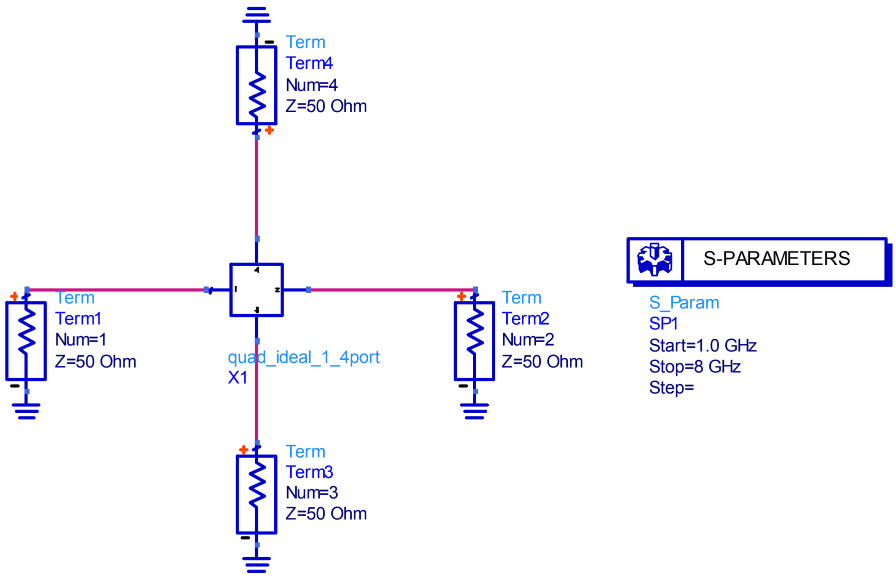

Figure 2: Higher level schematic with 50 Ohm terminations and s-parameter simulation block

1. Create a new schematic, to be used as the higher level, called "quad_main_1.dsn".

2. Add a reference to the coupler network created with ideal transmission line elements in the previous section (quad_ideal_1_4port).

3. Attach 50 ohm terminations to the four ports of the network. Make sure your termination numbers match the port numbers.

4. Add an S-parameter simulation block to allow simulation from 1 GHz to 8 GHz in steps of 0.05 GHz.

5. Simulate the circuit.

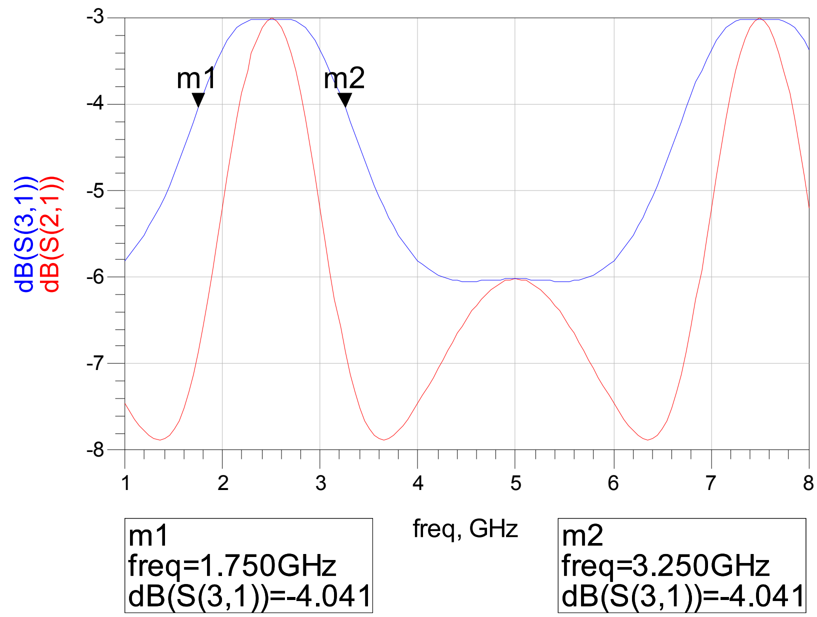

Figure 3: Graph of S21 and S31 with markers at -4dB

6. Determine the bandwidth for which |S21| and |S31| are greater than or equal to -4 dB by using markers. You can place a marker on your plot that will show the y-axis value for the corresponding x-axis value at which it is placed by selecting Marker → New and then clicking on the trace.
Record the bandwidth values here and include the plot with verifying markers in your report. NOTE: ONLY LIST THE BANDWIDTH IN THE 2.5 GHZ REGION. YOU MAY SEE ANOTHER BAND FOR WHICH THESE SPECIFICATIONS ARE SATISFIED, BUT DO NOT INCLUDE IT IN THE NUMBERS GIVEN IN STEPS 6 AND 7.

Bandwidth for which |S21| ≥ -4 dB = ______________________________

Bandwidth for which |S31| ≥ -4 dB = ______________________________

7. Determine the bandwidth over which the isolation is greater than or equal to 20 dB: Remember that the isolation can be measured by S41.

Bandwidth for which Isolation ≥ 20 dB = _______________________________

8. Add a plot displaying the phase of S21 and S31 in degrees.

9. Place the plots of the S-parameter magnitudes (with markers) and the phase of S21 and S31 into your report.

10. Between what two frequencies is the phase difference between S21 and S31 within +/- 5 degrees of 90 degrees (keep in mind that you will have to account for the fact that all angles are plotted between -180 degrees and 180 degrees)?

f1 = ______________________________ f2 = _________________________________

11. Disconnect the termination from port 4 and deactivate it. Replace it with a grounded 50 Ω resistor.

12. Re-simulate the circuit. You will need to delete the S41 parameters from the plots. How do the the S11, S21, and S31 results differ from the previous simulation. How do S11, S21, and S31 change in magnitude and phase?

13. Change the value of the resistor to 0 Ω. Does the circuit still function as a coupler at the design frequency of 2.5 GHz? How does the circuit's behavior change as you move away from the design frequency compared to the previous case? How do these results confirm or contradict the presence of isolation between port 1 and port 4?

14. Delete the resistor and reconnect the Term4 element. Re-simulate and S41 back to the appropriate plots.

15. Save your display window.

C. Microstrip Coupler

1. Create a new schematic with the title "quad_real_1_4port.dsn".

2. Place a microstrip substrate (MSUB) element into the schematic, and change the parameters to those shown below. Notice that many of the settings are expressed in mils.

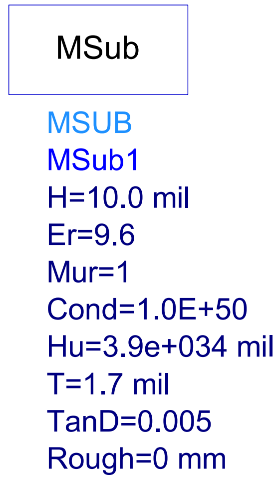

Figure 4: Microstrip line substrate parameters

3. Start Linecalc by going to Tools → Linecalc → Start Linecalc. The Linecalc pop-up window will appear.

4. Adjust the transmission line settings to match those of the MSUB element you placed in the schematic. Determine and record the following dimensions for use in setting up your microstrip coupler:

Width of a 50 Ω microstrip line = ______________________ mm

Physical length of a 50 Ω microstrip line that is 90 degrees long at 2.5 GHz = __________________mm

Width of a 35.3 Ω microstrip line = ________________________mm

Physical length of a 35.3 Ω microstrip line that is 90 degrees long at 2.5 GHz = _________________mm

5. Save the Linecalc setup for later use using File → Save As. Close Linecalc and return to the schematic window.

6. Add a Var block to the microstrip quadrature coupler schematic. The following variables should be specified:

W_tb = the width of the microstrip lines on the top and bottom branches of the coupler (as found by your Linecalc simulations)

W_lr = the width of the microstrip lines on the left and right branches of the coupler

W_50 = the width of a 50 Ω microstrip line

L_tb = the length of the microstrip lines on the top and bottom branches

L_lr = the length of the microstrip lines on the left and right branches

Keep in mind that W_lr should equal W_50 because the left and right lines are 50 Ω lines.

7. Create the coupler layout using the Tlines-Microstrip palette. Use MLIN and MTEE elements.

8. Add ports to the network, numbering the ports appropriately.

9. Obtain a copy of the completed schematic, including the VAR block, for your report.

The construction of the microstrip coupler for simulations should appear as follows:

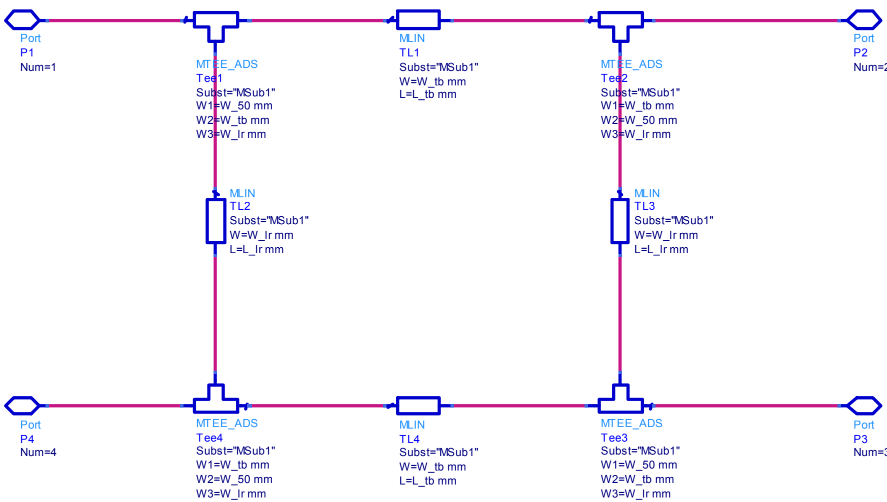

Figure 5: Microstrip quadrature hybrid coupler schematic

D. Analysis and Optimization of the Microstrip Quadrature Coupler

1. Return to the higher-level schematic and add a reference to the microstrip quadrature coupler schematic (quad_real_1_4port). Add 50 ohm terminations to each port with appropriate numbering. Allow Term5 to correspond with Port 1 of the lower-level schematic, Term 6 to Port 2, etc.

2. Perform and S-parameter simulation. Add two new plots to the previously used display window. Display S55, S65, S75, and S85 in dB format in the first plot, setting the y-axis minimum to -40 dB and the maximum to 0 dB. In the second plot, display the phase of all of these S-parameters.

3. Record the magnitude and phase values of these 4 S-parameters at 2.5 GHz. They correspond to the measured S11, S21, S31, and S41 of the microstrip coupler:

|S11| (dB) of Microstrip Coupler = ________________________ <S11 (degrees) = _________________

|S21| (dB) of Microstrip Coupler = ________________________ <S21 (degrees) = _________________

|S31| (dB) of Microstrip Coupler = ________________________ <S31 (degrees) = _________________

|S41| (dB) of Microstrip Coupler = ________________________ <S41 (degrees) = _________________

4. Add another plot to the display window that shows the magnitude of the diference between the S-parameters of the ideal coupler and the microstrip coupler. After dragging the plot into the window, select "Advanced" in the Plot Traces and Attributes menu. Enter the following in the blank area: mag(S(1,1) – S(5,5)). Click on OK. Also add the following expressions: mag(S(2,1) – S(6,5)), mag (S(3,1)-S(7,5)), and mag (S(4,1) – S(8,5)). Exit the dialog window and view the plot.

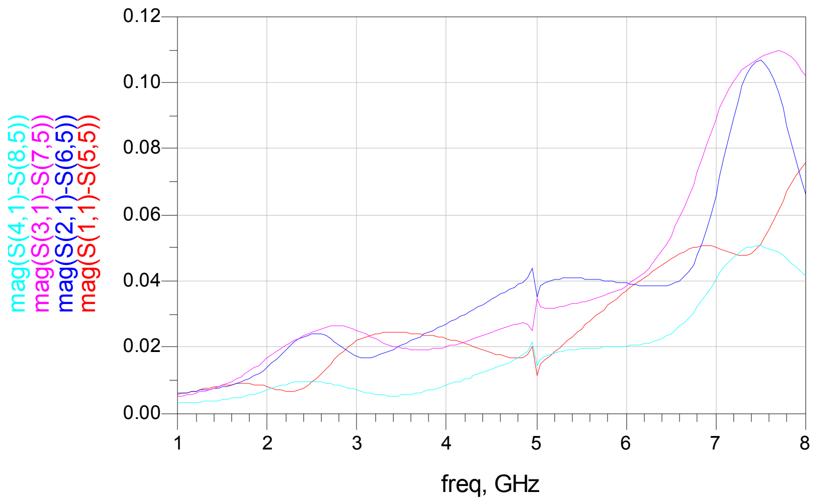

Figure 6: Real and Ideal quadrature hybrid coupler simulation magnitude differences

5. Use markers in the plot to find the values of the 4 magnitude differences and record them below:

mag(S(1,1) – S(5,5)) = ___________________________________

mag(S(2,1) – S(6,5)) = ___________________________________

mag(S(3,1) – S(7,5)) = ___________________________________

mag(S(4,1) – S(8,5)) = ___________________________________

6. Place a copy of the plots in the display window in your report.

7. Return to the higher-level schematic. Add optimization goals to try to force the differences between all four of the S-parameters of the microstrip coupler to equal those of the ideal coupler. Go to the Optim/Stat/DOE palette to find the necessary items to place in the schematic. Also, go back to the quad_real_1_4port.dsn higher level schematic and make the appropriate variables optimizable.

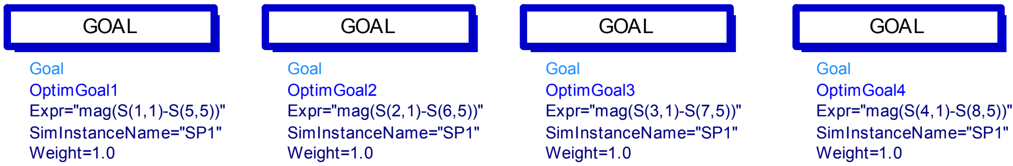

Figure 7: Goal optimization blocks

8. Input an optimization block to attempt to optimize the microstrip coupler so the following performance specifications are met:

1) Return Loss = at least 25 dB at the center frequency
2) The amplitude match between S21 and S31 should be excellent and each should be as close to -3 dB as possible (e.g. -3 +/- 0.5 dB).
3) The phase difference between S21 and S31 should be in the range of 90 +/- 5 degrees or better.
4. Isolation = at least 25 dB near the center frequency.

In this exercise, we use the difference between the S-parameters of the ideal coupler and those of the microstrip coupler as our function to be minimized. We will attempt to make all four difference magnitudes below 0.05.

9. Keep in mind that you should "Update Optimization Values" after each optimization run. If necessary, you can reduce the bandwidth over which the optimization is performed by changing the band over which the simulation is performed. If, after optimizing, you have difficulty in obtaining a more desirable response from the "real" network, check the limits on your optimization variables. It is possible that one of the variables to be optimized has encountered a limit.

10. After successfully modifying the microstrip coupler, obtain a plot of the final schematic, the S-parameters of the optimized coupler, and the final plot showing the four S-parameter magnitude differences over frequency (up to 8 GHz).

11. Go into your quad_real_1_4port schematic and disable the optimization on the variables. This will "fix" the final values in case you use the schematic in a later design.

Laboratory Report

Your laboratory report should contain the following:

1) Printout of the graphics display window showing the S-parameters of the ideal transmission line coupler with the information about the 90-degree phase difference frequency range for S21 and S31. Include identifying information on the printout.

2) Printout of the microstrip quadrature coupler schematic <u>prior to performing any design modifications</u>. Include identifying information on the printout.

3) Printout of the S-parameters of the microstrip quadrature coupler, prior to performing any design modifications, along with the 4 S-parameter magnitude differences. Include identifying information on the printout.

4) Values for S55, S65, S75, and S85 at 2.5 GHz of the microstrip couler, prior to performing any design modifications, along with the value of the 4 S-parameter magnitude differences at 2.5 GHz.

5) Printout of the microstrip quadrature coupler schematic after optimization. Include identifying information on the printout.

6) Printout of S-parameters of the microstrip quadrature coupler, after optimization, along with the 4 S-parameter magnitude differences. Include identifying information on the printout.

Discussion of Results:

1) What process worked best for optimizing the response of the microstrip coupler (i.e. what type of optimization did you use, approximately how long/how many simulations did it require to get good values for the microstrip coupler.
2) Before the optimization of the microstrip coupler was performed, what trends (if any) did you notice in the 4 S-parameter magnitude differences? If so, what might be the cause of these trends?