1 Laboratory 2

Passive Elements

Summary: Introduction to microwave passive circuit design and analysis using MWO. Students will design a branch line coupler and Wilkinson power divider in MWO, provide fabrication outputs, assemble the routed circuits, and characterize them using the FFox. They will also experiment with impedance matching to a RC load at 4 GHz.

There are many potential system applications for the above components within RF Systems. Some examples are

- Corporate feed structures for arrays of patch antennas (Wilkinson).
- Local oscillator (LO) distribution (Wilkinson).
- Separation of Stoke's components within a polarimetric receiver (Branch Line).
- Hybrid for double balanced mixers (Branch Line).

1.1 Useful resources

`https://awrcorp.com/download/faq/english/docs/getting_started/ch05.html`
`https://awrcorp.com/download/faq/english/docs/getting_started/ch04.html`
`https://awrcorp.com/download/faq/english/docs/getting_started/ch05.html`
`https://www.johansontechnology.com/s-parameter`

1.2 Preparation

Note: Circuit artwork .dxf's must be received by Thursday at noon or they will not be available for the Friday lab. All circuits must be 1x1 inch.. It is strongly suggested that you complete the BranchLine circuit as quickly as possible and forward me your fabrication inputs for checking, to ensure that you have the process correct. Treat this only as a check, you can submit a final version anytime before Thursday noon.

Note: The inputs/outputs of your circuits must be routed so that they are at least 375 mils center to center, so that the SMA launchers (J502-ND) can be

mounted). It is advised that you allow for a little wider separation, say 500 mils, for ease of assembly.

1.2.1 Branch Line Coupler

1. Open MWO file Lab2Template.emp
2. There are two subcircuits contained within: BranchLine and Wilkinson.
3. Open up the branch-line schematic. Enter in the substrate definitions for Rodgers RO3210 (see Moodle site, week 2), 50 mils substrate thickness[1], and 35 μm copper thickness.
4. Using your class notes, set the lines widths and lengths to realize a 3 dB branch-line coupler centered at 5.9 GHz. Go to Tools$\rightarrow$TXLine to using MWO's transmission line tool to calculate the lengths and widths.
5. Simulate your circuit.
6. Your circuit response will not be centered exactly at 5.9 GHz. You can either tune the line lengths and widths manually, or use the *Tune* feature within MWO. This is easy to do, follow the hyper-link in the above resources to find out more about tuning.
7. **Once satisfied, round all your line lengths and widths to the nearest 1/2 mil, this will make layout and processing much easier.** It will not impact the performance of your circuit. Then go to View$\Rightarrow$View Layout to generate the layout.
8. When imported, all the elements come in scrambled, they need to be snapped together to form the correct physical representation. See the hyper-link in the

[1] 1 mil = 25.4μm.

resources listed to learn more about snapping and layout with MWO. Also note that you can rotate and flip individual pieces of artwork, should their orientation need to be modified.

9. The outputs must now be routed out to the edges of the required 1x1 inch circuit size. Using a combination of 50 Ω lines and miters (already in model but line lengths and widths need to be adjusted), route transmission lines to the circuit boundary, defined as 1x1 inch .

10. The final input/output traces need to be at least 375 mils (0.375 inch) center to center so that the SMA connectors can be soldered on (for mechanical information see the SMA datasheet on the moodle site). There also needs to be at least 200 mils distance from the center of any input/output trace to the edge of the 1X1 perimeter.

11. Export your circuit artwork as a flat .dxf, Layout⇒Export Layout. Select DXF Flat option. This will export the artwork as a flattened (all artwork at same vertical plane) Autocad compatible .dxf file. No other options can be used.

1.2.2 Wilkinson

1. Open up the Wilkinson schematic. The circuit elements have been included, but all line lengths and widths are incorrect.

2. The Wilkinson circuit is a power divider. It splits power received at its input equally between the two output ports. The phase response of the two outputs are also equal. The lengths of the lines are $\lambda/4$ at the design frequency.

3. Write down the [s] parameter matrix for an ideal Wilkinson, and include it in your lab write-up.

4. Using your notes from class, create two circuits, one for the even-mode and one for the odd-mode response.
5. From these two circuits, determine the widths of the lines and the resistor between the two outputs. **Hint: The odd-mode circuit is used to determine the resistor and the even-mode the line widths.**
6. Include the details of your analysis in your final write-up.
7. Place your calculated values into the model and optimize the circuit.
8. Note that the resistor between the output ports is not modeled in the layout window. The terminals for the resistor need to be separated by 40 mils so that a 0603 surface mount resistor can be soldered in later. Add in short lengths of microstrip line as required to bridge the gap.
9. Following optimization, route the circuit inputs and outputs to same 1x1 finished size as before.
10. Note that it is beneficial to separate the output lines as quickly as possible. 50 mils of transmission line is reasonable length of line to include at the outputs, before mitering them away. This limits the amount of unwanted coupling between output lines.
11. Export your artwork as before, as a flat .dxf as before.
12. Email both files to drussell@caltech.edu no later than Thursday at noon.

1.2.3 Matching Network

In this lab you will also experiment with matching to an RC network at 4 GHz. You will be handed a circuit board with the RC network already populated, measure its return loss, and use this information to create a matching network using lumped L's and C's. The circuit board is shown in Figure 1.

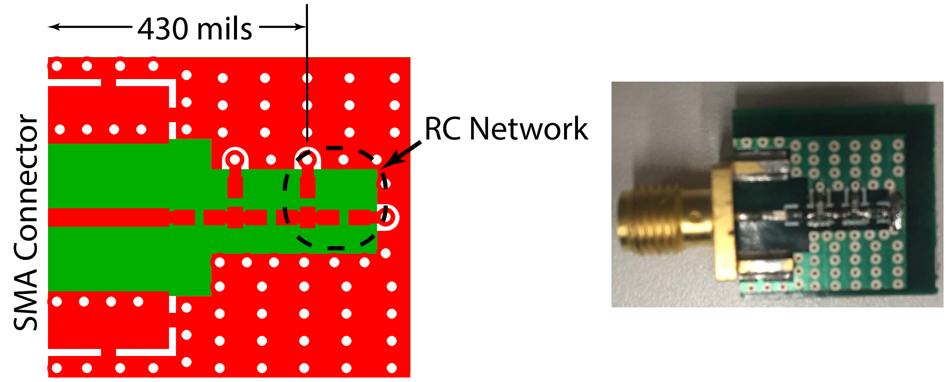

Figure 1: Matching circuit board artwork (Left) and populated circuit (Right).

It will be helpful to prepare a few items, prior to the lab, to ensure timely completion. The first of these is to calculate the electrical delay (in seconds) of the SMA connector attached to the PCB and the short run of $\approx 50\ \Omega$ line leading up to the RC network. The sum of these two lengths is the value of the port extension you enter into the FFox following calibration, to bring its reference plane forward, to the plane of the actual RC network. With this measurement you will be able to design the appropriate matching network. To do so, calculate the following using the TXLine tool within MWO:

- The electrical delay of a 290 mil long section of Teflon filled coaxial line. You can assume the outer diameter of the center conductor is 50 mils and the inner diameter of the outer conductor is 168 mils.
- The electrical delay of a 430 mil long section of microstrip on FR-4. You can assume the width of the trace is 20 mils, the trace thickness is 1.7 mils, and the thickness of the substrate 12 mils.

Add the two numbers together, this will be your port extension. As always, include the details of your calculations within your final report. It will also be useful to become familiar with the s-parameter files for the inductors and capacitors you will use to match your RC network. We will be using LC kit p/n L/C-402DS from Johnason Technology. Look up the contents of this kit (available through Digikey) and locate the corresponding s-parameter files at `https://www.johansontechnology.com/s-parameter`. Note that there is one s-parameter file for each component, I wouldn't suggest downloading them all now, but instead become familiar with their location so you can quickly access them later.

1.3 Required Equipment

Descrition	Model	Quantity	Notes
FFox	N9917A or N9918A	1	-
Calibration Kit	85052D	1	-
Cables	TM26-3131-36	2	-
SMA Connectors	J502-ND	7	Cinch
RF Resistor	FC0603-100BWCT	1	Vishay
L & C Design Kit	L/C-402DS	1	Johanson

Table 1: Required Equipment

1.4 Circuit Assembly

1.4.1 Branch Line Coupler

1. De-bur the edges of the board to allow the SMA launches to fit snugly up against the board edge.
2. Solder on the 4 SMA launches.

1.4.2 Wilkinson

1. De-bur and install the SMA launches as before.

2. Solder in the RF, 0603, resistor.

1.5 Branch Line and Wilkinson Measurement

1. Calibrate the FFOX using the same procedure as in Laboratory 1, but maximize the input power as you are measuring a passive circuit.
2. Characterize your Branch Line coupler measuring (3) 2-port responses, one for port 1 to port 2, port 1 to port 3, and port 1 to port 4.
3. Characterize your Wilkinson splitter, measuring (3) 2-port responses, one for port 1 to port 2, port 1 to port 3, and port 2 to port 3.
4. Take photos of your test setup for measurement of the Branch Line and Wilkinson circuits.

1.6 Matching Network

1. Connect the matching network to port 1 of the FFox.
2. Enter in the port extension you calculated during the laboratory preparation.
3. Save the measurement as a .s2p file.
4. Import the data into MWO and design a lumped LC matching network to optimize the match at 4 GHz.
5. Locate the corresponding s-parameter files for the closest values to inductance and capacitance within kit L/C-402DS. Create a second schematic within MWO and simulate the response when the lumped elements are replaced with their s-parameter equivalents.
6. You may need to experiment with adjacent values of L and C to best optimize the response at 4 GHz.

7. Your PCB has $0\ \Omega$ resistors soldered into the two series locations closest to the SMA connector. Remove at least one resistor so that you can solder in your LC network.

8. Measure the response with the FFox. Save the measurement as a .s2p file.

9. Import the measurement into MWO and compare it against your simulation. As time allows, play with the values of installed L and C to further optimize the match at 4 GHz. Note that you can also remove the resistor closest to the SMA connector and use it to place a compensating L or C as well.

10. Record the final values for your matching network and include them in your report.

11. Remember to take a photo of your measurement setup.

1.7 Data Analysis and Report

Reports are due by noon October 10th, emailed to drussell@caltech.edu and to dwinker@caltech.edu

Additionally, for this and future reports, you should include the following:

1. Response to any questions that were asked in the preparation section. Circuit derivations/calculations should be included.

2. Circuit diagrams (schematics) taken from MWO, formatted so that they are legible when pasted into your report.

3. Photos of both your test setups and your completed circuits.

Note: It is likely that your measured circuit performance did not exactly match that of your simulations. That is ok, these will be explored during the analysis and explained in *your report.*

- Compare your Branch-Line measurements to those of your simulation in MWO. Plot out the calculated and measured results, for both magnitude and phase.
- Comment on the differences. Some things to consider:
    1. The SMA-launches and circuit fabrication tolerances can de-tune the performance of your circuit. What fictitious LC elements do you need to add to the connector interfaces (same LC network at each interface) to better match the data over a range of 1-7 GHz?
    2. Vary the line widths of the coupler to make your your simulation match your measured performance over the same frequency range. What adjustments in length and width are necessary? Note that some adjustment is expected. There is a slight amount of machining tolerance in the circuit router and its tools. We have also used closed form representations of circuit elements, instead of a full 3D electromagnetic simulation.
    3. The RO3000 substrate has a thickness tolerance of ± 2 mils. Thicknesses outside of nominal can perturb your results.
- Repeat the above for the Wilkinson divider.
- Present your matching circuit for the RC network and the measured results, compared with simulation. Comment on the results. In case you ran out of time and were not able to optimize the network, comment on what steps you would have taken (i.e. decreased the value of series inductance to XX nH, etc).