ECEG 497 Wireless System Design Lab Spring 2025

Mini-Project #1: Coupled-Resonator Band-Pass Filter

Introduction

Band-pass filters are vital parts of almost all wireless systems. However, their design and construction are often some of the most challenging tasks an RF engineer can face. Stray reactances can degrade the performance of even the most carefully designed filter, and they can render useless more esoteric designs that look good on paper. For this mini-project, you will design and assemble a VHF band-pass filter using surface mount technology (SMT) devices. Randomly generated project groups are listed at the end of this handout. Deadlines will be somewhat flexible to accommodate PC board fabrication lead times and parts orders.

Theoretical Background

Two types of band-pass filters, known as coupled-resonator filters, are shown in Figure 1. The capacitors placed next to the input and output ports of the filters are known as coupling capacitors, and their purpose is to combine with the source and load resistances (not shown; assumed to be real) to decrease the loading on the filter, which in turn increases the network Q and therefore reduces the bandwidth. A practical filter accomplishes this task using L and C values that are neither unreasonably large nor unreasonably small for the fabrication technology being used. Details on designing coupled-resonator filters can be found in the supplemental readings available at the course Moodle site.

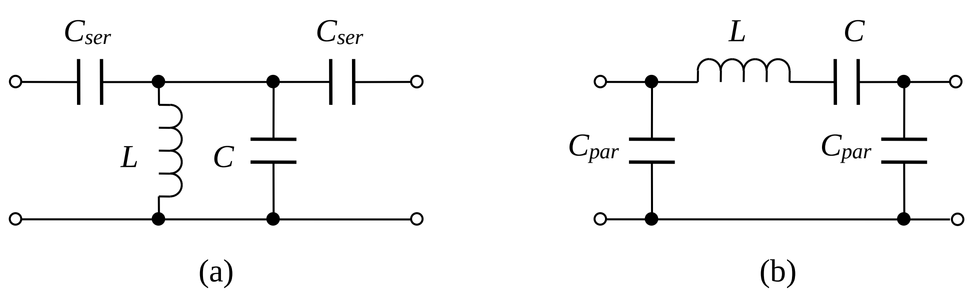

Figure 1. Coupled-resonator band-pass filters based on (a) a parallel LC circuit, and (b) a series LC circuit.

Experimental Procedure

The tasks you will need to complete are listed below. Please note that there could be lead times involved with PC board fabrication and/or parts procurement. Your deliverables are listed as bold-faced item numbers in the procedural description below. Scores will be quantized as indicated next to each item number. Items are due at the time(s) indicated on the Laboratory page at the course web site.

- Design a coupled resonator filter for a 50 Ω system with cut-off frequencies of roughly 115 MHz and 140 MHz. This encompasses the aircraft communication band, which spans 118–137 MHz. Choose the topology in Figure 1 that uses reasonable component values in the sense that they minimize the effects of stray reactance and are close to available values. To address the latter requirement, consider setting the inductive reactance in the resonator somewhere in the 40–200 Ω range. One major constraint is the limited number of SMT component values available to you; a current list will be maintained on the Laboratory page. You might want to automate your design procedure using a Matlab script (m-file), Mathematica, Python, or some other mathematical analysis software so that you can try different inductive reactances and quickly determine the required component values that result. If you wish, you may consider substituting an inductor for one of the coupling capacitors to obtain good roll-offs in the frequency response on both sides of the passband. Make sure, though, that the required inductive reactance is reasonable.

- Using software, plot the frequency response ($|S_{21}|$ in dB vs. frequency) and input reflection coefficient ($|S_{11}|$ in dB) of the filter that you have designed over the 50–300 MHz frequency range. Assume that the components are ideal. Label the axes, include units, and make sure that the cut-off frequencies are easy to determine from the plot. You might want to add a "3 dB" line to the plot. Consider adding appropriate commands to make the plot text more readable, add grid lines, etc. Submit copies of the plot and the circuit diagram for design verification before you fabricate your PC board.

  Item #1 [0, 5, 8, 10%]: E-mail to me a fully labeled tentative circuit diagram in PDF format. The diagram may be hand-drawn. Add your group members' names, the course number (ECEG 497), semester (Spring 2025), and project number to all submitted items.

  Item #2 [0, 5, 8, 10%]: E-mail to me a copy of the frequency response plot ($|S_{21}|$ and $|S_{11}|$) for the tentative filter design and a copy of the software code or analysis session that generated it. The code/session should be well commented so that the steps are easy to follow.

- Prepare a PC board layout for your filter using your preferred layout software in consultation with Matt Lamparter in the Maker-E. The input and output ports should be edge-mounted female type SMA connectors (available via the ECE Department component database). Dimensional information on the connectors is available on the Laboratory page. The circuit board traces leading from the filter input and output nodes to the SMA connectors should be 50 Ω microstrip lines; their widths should therefore be chosen carefully. A microstrip characteristic impedance calculator is available on the Laboratory web page. Double-check the size of the SMT components available to you (probably 0805). Consider fabricating the inductors using powdered-iron toroid cores; they tend to work better than prefabricated SMT inductors. The PC board layout must be e-mailed to me for approval before the PC board is ordered or milled. Include a list of the SMT components and inductor toroid core size(s) that you will need. You do not need to include the SMA connectors on the list.

  Item #3 [0, 5, 10, 15, 20%]: E-mail to me the PC board layout and parts list.

- Assemble the filter on the circuit board after it arrives. Add board-edge SMA connectors to serve as the input and output ports. The ground tabs of the SMA connectors must be soldered to the pads on the trace side of the board *and* to the ground plane on the other side of the board; this is necessary to provide a good transition from the coaxial geometry of the SMA connector to the microstrip transmission line on the board. The SMA connector is larger than most components and made almost entirely of metal, so it will take a while for the solder to flow well around it.

- Use an Agilent N9320A spectrum analyzer in tracking generator mode to measure the frequency response of the filter ($|S_{21}|$ only) over the 50–400 MHz frequency range. Spectrum analyzers should be available in the Maker-E. Determine whether the peak of the filter's frequency response (i.e., the frequency of least attenuation) is close to its design value, and determine the loss at that frequency. Identify the 3 dB frequencies relative to the actual response peak (i.e., not the absolute −3 dB levels), and determine whether they are close to their design values. If the performance of the filter is not satisfactory, take reasonable measures to fix the problem, and then check the filter response again. Instructions for using the spectrum analyzer are available on the Laboratory page at the course web site.

- Arrange to meet with me at a mutually agreeable time to demonstrate the measured frequency response of your working filter. All group members must be present. During the demonstration, identify the 3 dB frequencies.

  Item #4 [0, 5, 10, 15, 20%]: In-person demonstration of working filter.

- Capture a screen image from the spectrum analyzer and save it to a USB flash drive so that you can submit it later. If you can, save the trace data (i.e., table of numerical values) as well so that you can plot it in software.

- Modify your code or run another analysis session to plot your measured data and the ideal (calculated) frequency response on the same axes. Use a legend to distinguish between the two traces. If you can't save the trace data on the spectrum analyzer, then try to match your calculated frequency response plot to the screen image (e.g., use the same horizontal and vertical axis limits and try to match the plots' aspect ratios).

  Item #5 [0, 10%]: E-mail to me a PDF copy of the screen shot of the measured frequency response.

  Item #6 [0, 5, 10, 15, 20%]: E-mail to me a PDF copy of the plot of the final ideal and measured frequency responses ($|S_{21}|$). The axes should be labeled (including units) and have a descriptive title (not a y-axis-vs-x-axis title like "Attenuation vs. Frequency"). Include a PDF copy of the final version of your code or analysis session. It should be well commented so that the calculation steps are easy to follow. Remember to include the course number, semester, and project number on all submitted items

- After you complete the lab exercise, leave your circuit board with me.

  Item #7 [0, 10%]: Submit assembled filter circuit board.

<u>Group Assignments</u>

The randomly generated groups for this project are listed below:

Amsili-Youn
Paccione-Regec-Theosmy