UNIVERSITY OF UTAH
ELECTRICAL AND COMPUTER ENGINEERING DEPARTMENT

ECE 5320/6322 LABORATORY #5

DESIGN AND TESTING OF A COUPLED-LINE BAND-PASS MICROSTRIP FILTER

Introduction and Goal

Band Pass (BP) Filters are especially useful in microwave communications because they allow only a selected band of frequencies to pass through. For microwave receivers, this helps to eliminate the effects of extraneous signals and especially noise so that the receiver signal-to-noise ratio is maximized. For multiplexed system carriers that combine many sub-carrier signals into a single wide band system, BP filters play a pivotal role (in combining and separating the multiple sub-carriers.

In BP filter applications, it is usually desirable to pass the signals over a selected narrow band (typically 1 to 10%) and then to have a sharp roll-off on each side so as to reject out-of-band signals. We have found in our previous experience with this lab that for narrow bandwidths, the process of transforming and scaling low-pass filter prototypes (described in Pozar, Example 8.4 _ Band Pass Filter Design) gives inductance values that are fairly large and not easily achievable with microstriplines without using fairly long lengths that do not behave as lumped elements. To reach inductance values that can be approximated with microstriplines requires much wider bandwidths of nearly 100%. At this time, we do not know a way to make narrow band BP filters with connected microstrip elements although we suspect that it may be possible using the composite filter approach with a tandem pair of LP and HP filters which overlap in frequency to create the pass band.

Because of this, a commonly-used BP filter is the so-called "coupled-line filter" that is based on 4-port coupled-line elements as described in Pozar Text , Section 8.7 . Another view of this type of filter is that it consists of a set of **half-wave resonating elements** that are coplanarly coupled by the fringing electric and magnetic fields of the resonators. From this viewpoint, the filter is very similar to another filter in Pozar based on "capacitively-coupled resonators" shown in Fig. 8.50 . In this latter case, the half-wave resonators are coupled by fringing electric fields at the ends of the resonant lines instead of side-by-side fields. In either case, these types of filters emphasize the point that a set of resonant elements which are coupled together can make very good BP filters at frequencies near the resonance. Many other types of resonant element filters can be found in the literature and they are especially common in waveguide media because of the relatively low loss that is achievable.

The **goal** of this lab is (1) to carry out the electrical design of a coupled-line BP filter, (2) to use LINECALC to define the geometries needed to implement the filter in our microstrip geometry and to use ADS to simulate and optimize the result, and (3) to build and test the filter.

Preliminary Designs:

In conjunction with this lab, you should finish reading Pozar Section 8.7 so that you understand and can apply the filter design process required. The design equations are very simple to apply as illustrated by Pozar's Example 8.7 (pp. 425-426).

As a preliminary exercise, carry out the electrical design of four different filters: two maximally flat designs and two 0.5 dB equal ripple designs. Give each pair of filters two different bandwidths of say 5% and 10% with N = 3 and 5, respectively. (MATLAB can make this much easier than doing it by hand.) Carry out the designs to the point where you obtain the characteristic impedance level and the coupling level for each coupled-line 4-port element in the filter. When you finish, you will have four tables similar to the table in Example 8.7 (pp. 425-426). Your tables should be extended, however, with two more columns: one for Z_{0n} and one for C_n. The reason that you need to obtain Z_{0n}, and C_n is because these are the design input values required for the LINECALC coupled-line designs. In your designs, you should pick a center frequency of 5 GHz with the thought in mind that this could be a fairly long circuit and that a higher frequency design for 5 GHz will be shorter. You should also find the predicted attenuation for your filter at frequencies of (f_1 - Δf) and (f_2 + Δt) where $\Delta f = f_2 - f_1$ is the design pass band.

From your experience with coupled lines, you may recall that larger coupling values (those at about 0.1 and above) produced line separation values that were too small to build. Look over your tabulated design values and pick out the largest values of C. When you get to the lab, you will want to first test these elements in LINECALC and see if it is feasible to build the filter designs. You should also use the element lengths from LINECALC to predict the overall length of your filter. (Remember the 3-inch limit for fabrication.) In the lab, you only need to pick one design for full definition and ADS simulation; just make sure that it is a design that you can actually implement in our microstrip media.

Laboratory Procedure:

If you have measurements to do from Lab 4, you should finish them and get them out of the way. Make sure to test for proper calibration as you start.

In Lab 5, you should proceed as follows:

1. From your preliminary electrical designs for the BP filters, make some observations about the design and performance trends in these filters as bandwidth increases. In general, the wider band coupled-line BP filters will be more difficult to build. Can you see why? You will probably need to put the electrical parameters of the most difficult elements into LINECALC and see if the separation and overall filter length dimensions can be fabricated. After making these observations, select one of the four filters for complete design, fabrication, and testing. If you find that you do not like any of the filter designs, you can start over with a new bandwidth and center frequency to eliminate the problems you find. Use LINECALC to complete the dimensional design of your selected filter.

2. Use ADS to simulate the design of your selected coupler with open-circuit capacitor elements on all open ports of the coupled-line elements. Use the ADS optimization process to refine the pass band performance of this filter. Since it is based on disconnected resonant elements, the out-of-band performance will probably be quite good without further optimization (nothing gets thrown away from resonance). Save copies of your starting design and be prepared to try several different types of optimization and to optimize over different sets of variables like coupler lengths, line separations, and line widths. If your initial calculations are correct, you shouldn't need to move very far from the initial design to find a good optimum. Therefore, if the optimization process takes you too far away from the starting element values, you probably need to start over.

In your optimization, you may find that the loss in the pass band is higher than expected -- possibly up to 1 dB or more. This is due to the fact that resonant elements with high-standing waves have higher loss than a simple transmission line. Just use the optimization to make the pass band transmission as uniform as possible.

Be sure to collect the printouts needed to compare the performance of your starting design and your optimized design for your report.

3. When the circuit simulation shows the desired result, reduce the simulation schematic to a layout drawing and transport the results to AutoCAD.

4. When your microstrip circuit is returned, you should make careful dimensional measurements using a microscope on the circuits and see how they compare to your original mask dimensions. Small errors in the resonant lengths and the line separations can make a big difference in the filter performance. If you do see differences, you will probably want to make adjustments in the simulation model to make the model as close as possible to the fabricated circuit. Remember that the goal is to see how well ADS predicts the performance of the actual circuit. Be sure to make plots that compare theory and experiment for your report.

5. Expand the frequency range on the NA to 20 GHz and observe the higher frequency pass band of this circuit. This will automatically turn Cal "off", but that's okay because we are only interested in the frequency at which this occurs. Pozar says that the next pass band for this circuit occurs **at three times the center frequency**. Do you observe this? Can you explain it on the basis of coupled-line coupler performance?

WRITE-UP

The write-up for Lab 5 should be written according to the format for lab reports. Hole-punch your report and put it in a three-ring binder. After it is organized and documented so that it reads like a report, staple it together in the upper left-hand comer and turn it in to your TA for grading. Use a three-ring binder to store your lab reports so that they can be reviewed together if necessary at the end of the semester.