1 Laboratory 4

Mixers

Summary: The students will design, fabricate, and test their own balanced mixer.

1.1 Useful resources

`http://www.avagotech.com/docs/AV02-1365EN`

1.2 Mixer Preparation

1. The previous laboratories have introduced you to microstrip and lumped element design using MWO. You now have a decent set of template files to work off of. There is no MWO file template for this week. You will construct your own using those from the previous laboratories.
2. Create a new MWO project, or use an existing file as a starting point. My suggestion would be to start with the file from your Branchline work in week 2, for obvious reasons. Note that if you decide to create a file from scratch, you will need to make adjustments to the frequency sweep range, layout grid, and dxf export options.
3. You will be designing a balanced mixer, using the Branchline coupler as your hybrid circuit, to drive two anti-parallel diodes. The circuit is based on application note AN-1052 from Avago. Use this as a guide only, we will be designing the mixer for 5.9 GHz, where the diode is better matched to 50 Ω.
4. Build up your circuits in stages, creating new schematics and layouts for each step. You can then assemble these subcircuits at the end into the completed mixer (schematic and artwork). This allows you to iterate on individual portions of the design quickly.
5. The datasheet for the mixer diode pair can be found on the moodle site, the part number is HSMS-8202 from Avago technologies.
6. Within the datasheet you will see an equivalent circuit for each diode contained in the package. Create a new schematic within your MWO project and create this circuit, using ideal

lumped components. Note that this is just for one diode within the pair. Remember to put ports on the circuit so you can use it as a sub-circuit in other schematics.

7. The mixer diode outputs need to see a short circuit at 5.9 GHz, while passing the IF frequency of several hundred MHz. Probably the easiest way to do this is with a pair of radial open stubs. The radial stubs appear as a short circuit at their center frequency, their radius helps broadband their response, making them fairly insensitive to fabrication errors. The input and outputs should be short sections of 50 Ω line. Start your design by completing this circuit and manually optimizing it to provide a short at the design frequency. Include at its output a small gap (30 mils wide) for the inclusion of a small 0402 series matching element, that you can use to better match the IF response to 50 Ω if required. You can use the **MGAP2** component within MWO to create the gap and have it appear correctly in your layout. Place your matching element in parallel with the gap, your circuit will simulate correctly and your layout will have the required feature. At the end, your circuit artwork should appear something like that shown in Figure (1).

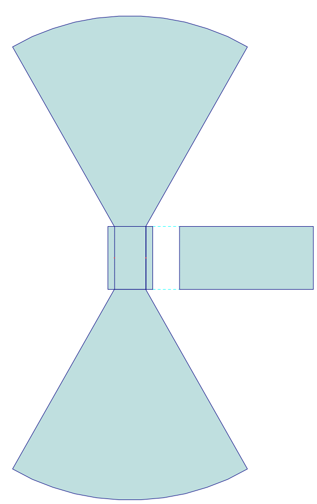

Figure 1: Radial Stub. The mixer diode package will interface to the left of the stub, the IF output will be on the right. Place a small gap in the output to facilitate placement of an IF matching component to improve performance.

8. Now, we need to create the artwork for the diode package. Create a new schematic and use short sections of open circuited transmission lines to form the pads of the diode pair. Set the length and widths of the lines based on the datasheet. Within the schematic, put in two of

the circuits you created for the diode equivalent circuit. You can bring these in by selecting **Elements** ⇒ **Subcircuits**, and selecting the circuit you created for the diode.

9. Now go to the layout window for this part and move the lines around until they correctly match the spacing of the pads of the parts. **Double check these dimensions!** When the layout is completed it should appear similar to that shown in Figure (2).

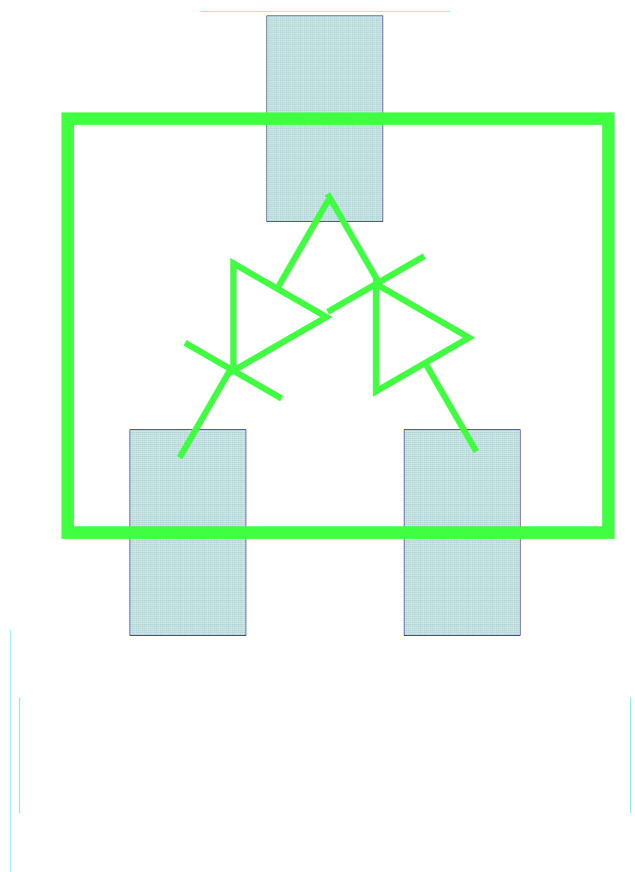

Figure 2: Footprint for Mixer Diode Package. I have placed in the outline of the diode package and symbols for the diodes only for illustration.

10. Now you have two subcircuits, one for the diode pair and one for the radial stub. Open up a new schematic and bring these two sub-circuits into the new circuit. The diode pair will come in as a 3-port, the radial stub as a 2-port. You will have some line width differences between the output of the mixer diode circuit and that of the radial stub. Add a microstrip

step element, **Elements** ⇒ **Microstrip** ⇒ **Junctions** ⇒ **MSTEP** to model this discontinuity. You will need to provide it the widths of the lines of your adjacent circuits.

11. Put three ports into your schematic and simulate the circuit. Look at the input match to each of your diode input lines. You will now need to design a matching circuit that brings the impedance back to 50 Ω and provides the necessary interface to the Branchline coupler. You can either use a single series element, a set of varying width lines, open stubs, or all of the above. If you use a series element, add a gap as discussed earlier to make it appear correctly in your artwork. *Note: you can put in your ideal (lumped) or .s2p file for the series element in parallel with the microstrip gap element. The gap will appear correctly in the artwork, and the circuit will simulate correctly.*

12. To merge your diode lines to the Branchline output arms, it helps to have your measurements snapped to a grid of 0.25 mil and to round off your line widths and lengths to the nearest 0.5 mil. To set the grid go to **Options** ⇒ **Layout Options** and select the Layout tab. Make sure that your entire layout is no larger than 1x1.25 inches, which should include the space you need to mount the 3 SMA connectors.

13. When completed, your artwork should appear similar to that shown in Figure (3)

14. Email your file to drussell@caltech.edu no later than Thursday at noon.

1.3 Required Equipment

Descrition	Model	Quantity	Notes
FFox	N9917A or N9918A	1	-
Cables	TM26-3131-36	4	-
SMA Connectors	J502-ND	3	Cinch
Inductor/Capacitor Design Kit	L/C-402DS	1	Johanson
Anti-parallel Diodes	HSMS-8202	1	Avago
Synthesizer	Quick Syn	1	NI
RF Generator	HMC-T2220	1	Hittite
Step Attenuator	RCDAT-8000-30	Minicircuits	
BPF	VBFZ-5500-S+	Minicircuits	

Table 1: Required Equipment

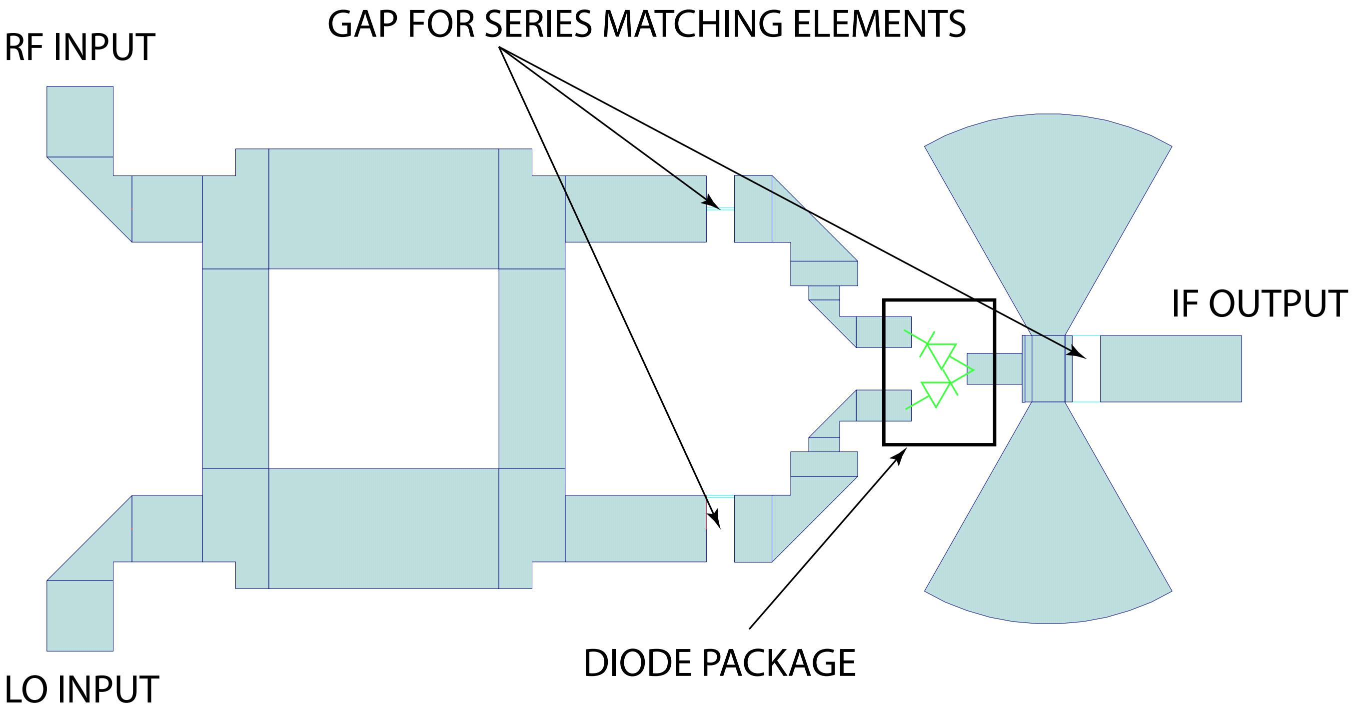

Figure 3: Mixer Layout

1.4 Circuit Assembly

1. Deburr your mixer circuit and solder on its 3 SMA connectors.
2. Locate the necessary matching inductors (should you have implemented a matching network) and solder them into our circuit.
3. **10 Extra Points**. Start out with 0 Ω resistors in these places, get some baseline data, then solder in the matching circuit and see how your results improve.
4. Solder in your mixer diode anti-parallel pair.

1.5 Mixer Measurements

Now that you are familiar with the test equipment from labs 1-3, less instruction is required. You should be comfortable setting the FFox frequency range, resolution bandwidth (RBW) and video bandwidth (VBW). Look back through your previous labs should you have questions. Note that you will be using two RF signal generators in your setup. The new signal generator from National Instruments (NI) uses an external laptop to control its frequency. The signal generator is powered by an external 12 V DC supply, and consumes approximately 0.8 A. The laptop reads out the internal temperature of the signal generator. If you see it climb above 50 C, turn off the 12 V supply immediately and notify the instructor.

1. Perform a power calibration of the NI and Hittite signal generators, similar to the process you went through in laboratory 1. Hook the Hittite to the FFox and determine what the offset is between the generator readout and the power read by the FFox. The offset is repeatible, so you only need to take one reading with the signal generator set at 5.9 GHz.
2. Repeat this process with the NI synthesizer (signal generator). It requires a band-pass filter to be added to its output, to clean up unwanted harmonics, and a digital step attenuator to adjust the power. Both frequency and attenuation are controlled via an external laptop. Its offset is also repeatible, so one reading at 5.89 GHz is sufficient to determine the offset between the instrument settings and delivered power.
3. Hook the RF (Hittite) and LO (NI) outputs to the inputs of your mixer.
4. Hook the output of your mixer to the FFox.

5. When completed, your setup should appear similar to Figure (4).
6. Enable all sources.
7. Set the RF and LO powers so that -20 dBm and +3 dBm respectively are input to your mixer.
8. Look at a wideband sweep of your measurement. You will see several products in the IF spectrum. You will use this sweep to calculate the LO to IF isolation.
9. Look at a narrow band sweep of the FFox, centered around 5.9 GHz, you will see the primary LO tone and the RF leakage through the IF port. You will use these sweep settings to determine the RF to IF isolation.
10. Now look at DC-200 MHz with the FFox. You will see your down-converted IF signal. Save this to .CSV. The conversion loss of your mixer is the difference (in dB) between your RF input power and IF output power.
11. Step the Hittite signal generator in 10 MHz steps from 5.9 GHz to 6.09 GHz and record the amplitude of the IF tone at each frequency. You do not need to save the data for each step, but do need to record the result.
12. Feel free to go beyond 6.09 GHz, you will likely find that your mixer is very broadband.
13. Now set the Hittie signal generator to 6 GHz, resulting in a 100 MHz IF output.
14. Step the input power from the LO in 1 dBm steps from -5 dBm to +7 dBm and record the IF output power at each setting. You will find a LO power at which the IF power is highest. Note this down. Keep the LO at this level for all future tests.
15. Save the data to file. This will provide you the optimal conversion loss of the mixer at -20 dBm input power.
16. Now step the RF input power from -30 dBm to 0 dBm and record the IF output power at each value of RF input power. You will use this data to calculate the linearity of your mixer to RF input power. Remember to adjust your RBW and VBW to reduce measurement uncertainty at lower power levels.
17. Place the RF input power back at -20 dBm, at 6 GHz. Save a wideband sweep of the FFox (DC-18 GHz) so that you can calculate the LO to IF isolation.

18. Now set the FFox to sweep between 5.8 and 6.1 GHz. Set the RBW and VBW appropriately so that you can see the RF leakage. Save this data to file.

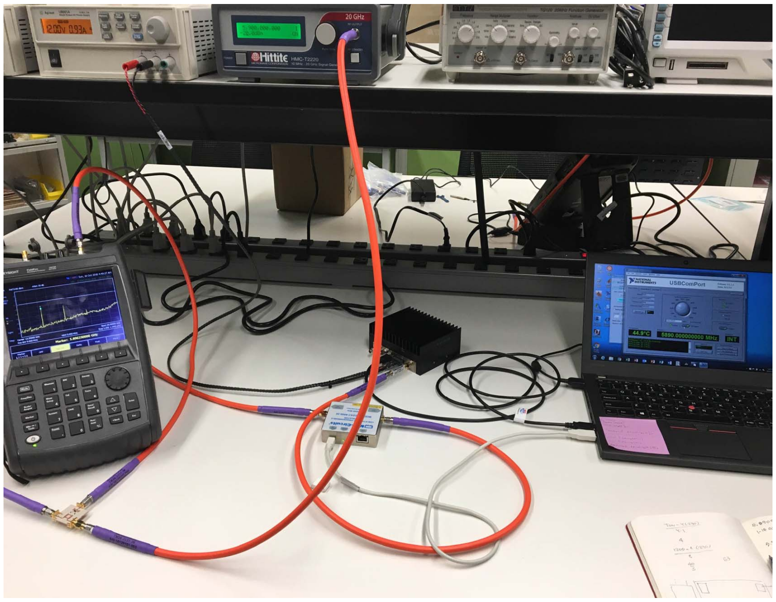

Figure 4: Mixer Test Setup.

1.6 Data Analysis and Report

Reports are due by noon October 24th, emailed to drussell@caltech.edu and to dwinker@caltech.edu

Use the guidelines for the report from Laboratory 1.

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. Do this for individual design steps as well as the overall design.

3. Include simulation results from MWO, for individual design steps as well as for the overall design.

4. Photos of your test setup and your completed mixer.

- Calculate and plot the conversion loss of your mixer vs frequency, from your RF sweep of 5.9 to 6.09 GHz.
- Calculate and plot the conversion loss vs LO power. What is the optimum LO drive for your mixer? How does this agree with what is in the datasheet (remember to take into account the power split provided by the Branchline coupler).
- Calculate and plot the conversion loss vs RF power. Do you see compression similar to that of an amplifier? What is RF input power at which the conversion loss of your mixer increases by 1 dB?
- Plot out the wideband measurement showing LO leakage and associated harmonics. What is the LO isolation at the fundamental LO frequency? What is the value, in dBC, of the first harmonic of the LO?
- Plot out the narrowband measurement showing the RF leakage at the IF port. What is the RF isolation at the IF port?