Chapter 4

Lab 4 - Double Conversion Superheterodyne Receiver

4.1 Background Information

The goal of this lab is to build and characterize a double-conversion superheterodyne FM receiver. The block diagram of the receiver you will construct is shown in Figure 4.1.

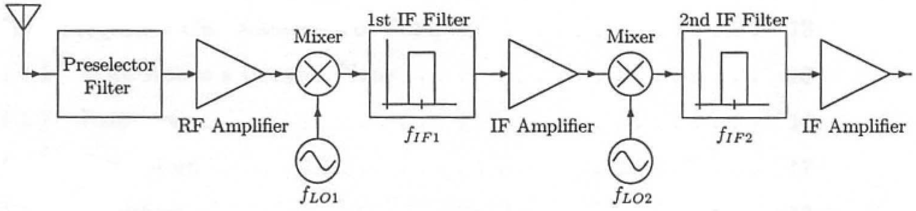

Figure 4.1: Block diagram of a double-conversion superheterodyne receiver.

The antenna receives an incoming signal which is passed through an optional preselector and RF amplifier stage. Then the signal is mixed with LO1 in a mixer provided for you, which will be characterized in the first session of this lab. LO1 is implemented using your voltage controlled oscillator (from Lab 2) and should be tuned to mix the desired signal to a 10.7 MHz IF. The signal after the first mixer stage will then be filtered by a ceramic filter that has been characterized and matched to 50Ω by you. The amplifier you built in Lab 3 will serve as the first IF amplifier. The second conversion stage and demodulator will be provided for you. It is a software FM receiver written in LabVIEW. The sampling rate of the software is adjusted to implement the second stage downconversion by aliasing the channel onto the target band centered around 460 kHz (recall the 10.24 MHz oscillator from Lab 2 which could accomplish this downconversion).

4.1.1 The Doubly-Balanced Mixer

The mixers used in this lab are doubly-balanced mixers like the one shown in Figure 4.2. This

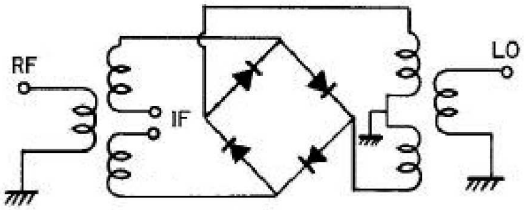

Figure 4.2: Circuit diagram of doubly balanced mixer.

type of mixer uses diode switches to approximate ideal multiplication. These mixers have a wide dynamic range and large bandwidth, but because they are switching devices, they generate more spectral components than the desired sum and difference terms. A lot of information about the operation of these mixers can be found in section 11.2 of the course notes.

Characterizing the non-ideal behavior of the mixers is important in the design of your FM receiver. The characterization is done using the test setup as shown in Figure 4.3.

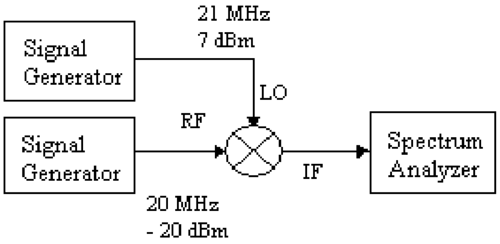

Figure 4.3: Test setup for mixer characterization.

4.1.2 Ceramic Filter

The first IF filter will be implemented with a 10.7 MHz ceramic filter. This type of filter is a resonating element, much like a quartz crystal. The ceramic filters are three terminal devices, one terminal each for the input, output, and a reference. These filters have a narrow bandwidth that is ideal for your first IF filter stage. The ceramic filters will have a flat passband, and excellent shape factor, when terminated in the proper source and load impedances. Because the filter is going to be used in a 50 ohm system, it is necessary to find the optimum termination impedances and to design impedance transformation networks to transform the 50 Ohm terminations into the required termination impedance. We can simplify this task by first measuring the 2 port S-parameters for the ceramic filter (see figure 4.4), reading data into ADS, and then simulating the transducer gain of the filter with varying input and output terminations. We shall assume that the ceramic filter is symmetric, so that the optimum input and output terminations will be identical. We shall also restrict attention to resistive terminations, to simplify the design of the impedance transformation networks.

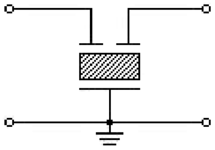

Figure 4.4: Two-port setup for ceramic filter.

4.1.3 Receiver Performance - SINAD

Receiver performance is most commonly evaluated by making a SINAD measurement. SINAD (Signal In Noise And Distortion measurement) is a parameter that provides a quantitative measurement of the quality of an audio signal. It is the ratio of total power (signal + noise + distortion) to the unwanted signal power (noise + distortion) and is easily calculated from two measurements - one measurement of the total signal+noise+distortion power, and a second measurement with the signal component notched out with a very narrow filter. SINAD is usually expressed in dB, since it is a ratio of powers.

$$\text{SINAD (dB)} = 10\log[(\text{signal+noise+distortion})/(\text{noise+distortion})]$$

A higher SINAD value corresponds to a better quality audio signal. For measurement purposes, the signal is a tone, usually at 1 kHz. The frequency deviation of the test signal is 75 kHz for broadcast FM receivers, and 2.5 kHz for narrowband receivers. If we applied a strong RF signal to our receiver that was frequency modulated by a 1 kHz sine wave with a known frequency deviation, we expect the receiver output to be a clean sinusoid at 1 kHz and the SINAD measurement to be very high. However, if we lower the incoming signal power, the output waveform becomes noisier and, possibly, more distorted. If we adjust the incoming power to produce a reference level SINAD (typically 12 dB), then input power becomes a useful measure of sensitivity that can be used to compare the sensitivity of different receivers. The SINAD calculation you need to make will be simplified by using Digital Signal Processing. An analog to digital converter card will capture the audio signal from your receiver. Then a LabVIEW program will compute the total waveform power, perform a notch filter at 1 kHz, and compute the power of the remaining waveform (1 kHz tone removed). The ratio of these powers will produce your required SINAD measurement.

4.2 Lab 4 Step-by-step guide

4.2.1 Mixer Characterization

1. Assemble the test setup as shown in Figure 4.3.
2. Measure and record the power of the RF and LO inputs with the spectrum analyzer (better yet, set the signal generators to measure the required powers on the VSA, compensating for cable and connector loss).
3. Identify and record the spectral components of the IF output of the mixer. Make a table showing the frequency, magnitude, and origin (i.e. 61 MHz tone = 2*RF + LO) of each spectral component from 0-70 MHz. You should be able to identify 20 or more. This is best accomplished in 2 separate ranges: one from 0-10 MHz and another from 10-70 MHz. For the 0-10 MHz range, on the spectrum analyzer press: instrument mode > receiver > RF section

0-10 MHz. Connect the input as usual. For the 10-70 MHz range, change the receiver back to the larger RF range.

4. Make measurements to estimate the RF to IF isolation, the LO to IF isolation, and the conversion loss for the sum and difference terms.

4.2.2 Ceramic Filter

5. Attach the ceramic filter to the provided PCB board with the center pin grounded.
6. Bridge the gaps to input and output by coupling capacitors.
7. Calibrate the network analyzer from 9.7 to 11.7 MHz with 801 points for a full 2-port measurement. Calibrate using the ECE453 Test Board standards to place your measurement reference plane on the board.
8. Read all S-parameters of the ceramic filter into ADS.
9. Construct a simulation in ADS using the collected data (see procedures)
10. Simulate the filter for various termination, observing the S-parameters
11. Select the best termination (flat gain, low and flat reflection are best)
12. Design a lossless two-element matching network to transform 50Ω to optimal termination impedance at 10.7 MHz (you may be able to use inductors from lab 1)
13. Construct the required inductors (if not using the ones from lab 1)
14. Remove the coupling capacitors and place the L-nets on the board
15. Verify filter S-parameters. Measure 3 dB and 20 dB full-width bandwidth.

4.2.3 Receiver Performance

16. Construct the double-conversion superheterodyne FM receiver from Figure 4.1. It is probably all right to ignore the preselector and RF amplifier at this time, although you should keep this in mind during the lab. So what remains is to connect the output of your VCO to LO port of the mixer, take the mixer output to the filter and then amplifier, completing the first stage.
17. In order to listen to FM radio, connect the output of the wall antenna to the RF input of the filter. Here, an RF amplifier may be used (refer to your TA). The output of the first stage is connected to te input of a specialized PC card, and the further processing is done in LabVIEW. Run the LabVIEW program to implement the secon stage of the receiver and demodulation. You should be able to tune your VCO and listen to a radio station. Comment on sound quality. Ask TA to help you improve tuning and sound.
18. We will characterize receiver performance using the tone modulated output of a signal generator. Set the signal generator to 99.9 MHz, -20 dBm output, 1 kHz deviation, 440 Hz modulating signal. Connect the output to RF input of the mixer. Can you hear the tone? Note and record what happens as you increase the deviation to 5 kHz, 20 kHz, 75 kHz. Note and record what happens when you increase the modulation to 880 Hz, 1760 Hz, 3520 Hz.

19. Make a table with the three deviation (1, 5, 20, 75 kHz) for columns and the four modulation frequencies for rows (440, 880, 1760, 3520 Hz). Ask TA how to measure SINAD. Record SINAD values in the table. Record the receiver software settings (gain, filter parameters).
20. Try to improve the quality of the tone (VCO tuning, software settings). Record the new SINAD table. Does your observation correspond to SINAD improvement?
21. Find the power required to achieve 12 dB SINAD for 1 kHz tone, 75 kHz frequency deviation. Label this as receiver sensitivity.
22. Take the amplifier output to the VSA. Adjust resolution settings to observe tone modulation sidebands. What are the amplitude values for the central five peaks?
23. Account for power of the 10.7 MHz IF output. Consider conversion loss and amplifier gain. Turn off modulation. Does that make the accounting easier?
24. Calculate the image frequency for the LO tuned as it is. Change the carrier (Signal Generator) to that frequency. Record the power at IF (modulation OFF).
25. Repeat the above for the 1/2 IF and 2/3 IF spurrious responses. Compare the resulting power at IF. How does it correspond to results of mixer characterization.
26. Play around, have fun.

4.3 Lab 4 Procedures

4.3.1 ADS Simulation for Ceramic Filter

Refer to Figure 4.5. From the pulldown list, select “Data Items.” Place a “VAR” box. Double click this box and change the name to the name you will use for your input and output terminations (Res). Also place an S2P box from the Data Items menu. Double click this box and under the file name browse for your measured S-parameter data. Be sure to change the type to “dataset” under the “select parameter” menu. Place the S-parameter simulation block and the terminations. Set the termination value to your sweep variable. Change the S-parameter simulation to 9.7 MHz to 11.7 MHz with 801 points. Finally, place a Parameter Sweep box from the “Simulations S-Param” pull down menu. Change the sweep variable, SimInstance, start, stop, and step to appropriate values.

Plot S21 for the various values of Res. Find the curves of S21, S11 that has the most desirable shape. Desirable attributes include smoothness in the passband, minimal attenuation in the passband, and symmetry about the intermediate frequency. This will occur when the input and output terminations are closely matched to the filter’s input and output impedances. If you wish, you can use the ADS functions “sm_gamma1(S)” and “sm_gamma2(S)” to compute the input and output reflection coefficients for a simultaneous conjugate match. From this, you can calculate the input and output terminations required for a match and compare these to the optimum terminations determined from your ADS simulation.

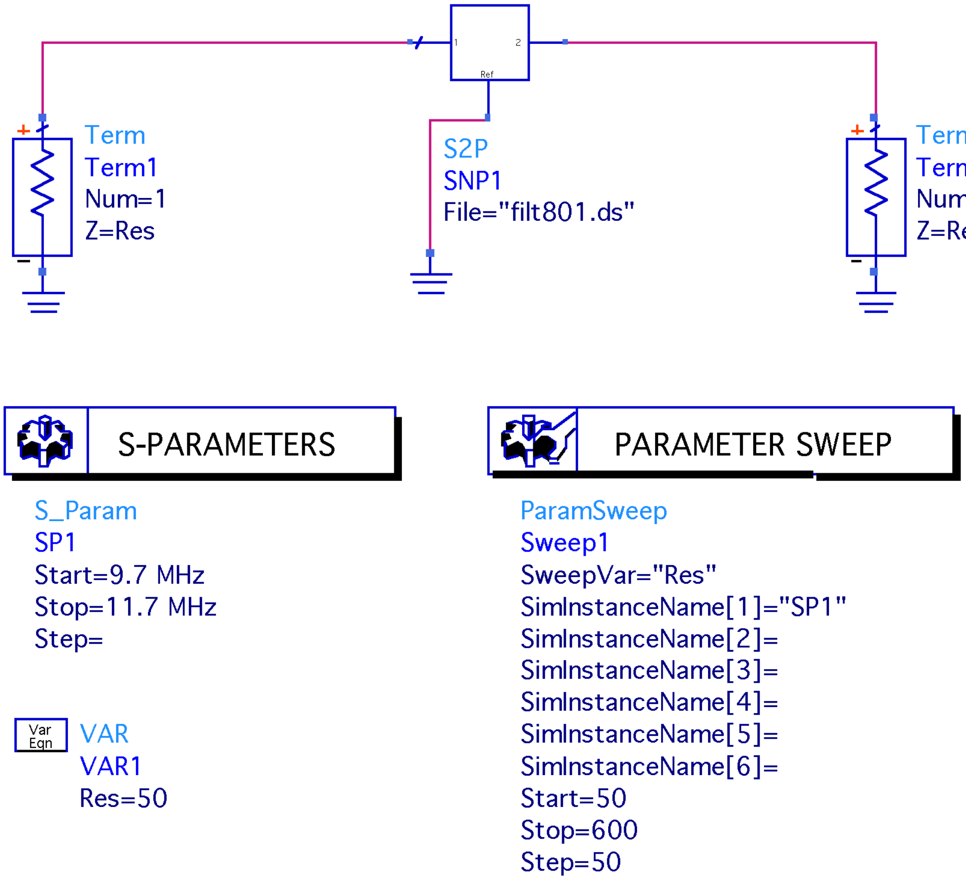

Figure 4.5: ADS simulation for determining optimum terminations for ceramic filter.