**Texas A&M University**
**Electrical Engineering Department**

**ECEN 665**

# Laboratory #6: RF Front-End Integration

**Objectives:** To learn the main design considerations related to the interconnection of the different building blocks of an RF Front-End (LNA, Mixer and VCO). To simulate the operation of a complete Front-End at 1.9GHz in Cadence. To learn how to transfer Cadence generated circuit data to MATLAB and simulate the front end with imported circuit parameters, in MATLAB Simulink.

## PART 1 : CADENCE INTEGRATION

**Procedure:**

1. **LNA re-design:** Starting from your single-ended LNA from Lab 4, remove the output buffer and create a fully differential version. The ground of the single-ended LNA now becomes a virtual ground at the drain of a NMOS transistor which serves a current source. The tail current should be twice the current of the single ended LNA. Notice that you will have to adjust the bias voltage of the input and cascode transistors to make sure that the transistor at the current source is in saturation. The LNA will now be matched to 100 ohms differential. You can choose to continue with this new impedance or adjust the matching network to make the differential input of the LNA match 50ohm (extra credit).

2. **LNA and Mixer connection:** Connect the differential output of the LNA to the RF port of the mixer designed in Lab 5 through an RC coupling network. Choose R in the order of Kohms and C in the order of pF. Notice that the RF transistors of the mixer will be biased through the resistors. How would they affect the NF? In this configuration, obtain the AC gain of the LNA. The peak of the AC response might have shifted from the simulation of the single-ended LNA due to the difference between the input parasitics of the buffer and the mixer. If this is the case, make appropriate adjustments to the load inductors of the LNA. Obtain the NF, Gain and IIP3 of your re-designed LNA. During this simulations, the LNA should remain connected to the mixer but the LO signal will be off.

3. **LNA and mixer simulation:** Using the data of the performance of the mixer designed in Lab 5, calculate the expected cascaded (LNA+mixer) NF, gain and IIP3. Turn-on the LO signal (with the amplitude you used for the characterization of the mixer) and run a pss and/or transient simulation to verify the operation of the cascaded blocks. Measure the overall conversion gain.

4. **VCO and mixer connection and buffer design:** On a separate schematic, place the VCO from Lab 6 and the mixer. The buffer to couple them will be a differential pair with an inductive/resistive load. Connect the VCO to the buffer (remove the 200fF capacitors that were employed to emulate parasitics), and the buffer to the LO port of the mixer. The RF port of the mixer should be biased but no signal should be applied. Design the buffer such that, for a 1.9GHz signal, the amplitude at the LO port is approximately the same that you used for the simulations in step 4.

5. **Complete front-end simulation**: Add the re-designed LNA to the schematic in step 4. Using transient simulations verify the conversion gain of the entire front-end. Show the transient waveforms at the connections between the building blocks. *Extra-credit*: Using PSS simulations obtain the overall NF, IIP3 and gain of the complete assembled circuit.

## Part 2. MATLAB Integration

**Procedure:**

**1.** For your LNA and Mixer, you will first need to export your
S parameters vs. Frequency,
NF vs. Frequency,
Output Power vs. Input Power
Simulation results to a file in Cadence. You can use the Print command from the Results Menu in Analog Environment to view the desired outputs. Figure 1. shows the 2 port S parameter results window. You should change the data format to Engineering (Exponent) from the Display Options Menu in the Results Display Window under Expressions->Display Options.

Results Display Window

Window Expressions Info Help 30

| freq (Hz) | mag(sp(1 1)) | phase(sp(1 1)) | mag(sp(1 2)) | phase(sp(1 2)) | mag(sp(2 1)) | phase(sp(2 1)) | mag(sp(2 2)) | phase(sp(2 2)) |
|---|---|---|---|---|---|---|---|---|
| 1e9 | 914.2e-3 | -24.29 | 13.64e-6 | -103.5 | 751.6e-3 | -115.9 | 112.7e-3 | -29.06 |
| 1.011e9 | 911e-3 | -24.75 | 14.3e-6 | -104.4 | 770.9e-3 | -116.9 | 114.3e-3 | -27.32 |
| 1.022e9 | 907.7e-3 | -25.21 | 15e-6 | -105.3 | 791e-3 | -117.9 | 115.9e-3 | -25.69 |
| 1.034e9 | 904.2e-3 | -25.69 | 15.74e-6 | -106.2 | 811.9e-3 | -119 | 117.7e-3 | -24.17 |
| 1.045e9 | 900.5e-3 | -26.19 | 16.52e-6 | -107.2 | 833.7e-3 | -120.1 | 119.5e-3 | -22.75 |
| 1.056e9 | 896.7e-3 | -26.7 | 17.35e-6 | -108.1 | 856.5e-3 | -121.1 | 121.4e-3 | -21.44 |
| 1.068e9 | 892.7e-3 | -27.23 | 18.22e-6 | -109.1 | 880.2e-3 | -122.3 | 123.4e-3 | -20.22 |
| 1.08e9 | 888.4e-3 | -27.77 | 19.15e-6 | -110 | 905e-3 | -123.4 | 125.4e-3 | -19.1 |
| 1.092e9 | 884e-3 | -28.34 | 20.13e-6 | -111 | 930.8e-3 | -124.5 | 127.5e-3 | -18.06 |
| 1.104e9 | 879.3e-3 | -28.92 | 21.18e-6 | -112 | 957.9e-3 | -125.7 | 129.5e-3 | -17.11 |
| 1.116e9 | 874.3e-3 | -29.52 | 22.29e-6 | -113.1 | 986.2e-3 | -126.9 | 131.6e-3 | -16.24 |
| 1.128e9 | 869.2e-3 | -30.14 | 23.46e-6 | -114.1 | 1.016 | -128.1 | 133.7e-3 | -15.44 |
| 1.141e9 | 863.7e-3 | -30.78 | 24.72e-6 | -115.2 | 1.047 | -129.3 | 135.8e-3 | -14.71 |
| 1.154e9 | 857.9e-3 | -31.44 | 26.05e-6 | -116.3 | 1.079 | -130.6 | 137.8e-3 | -14.05 |
| 1.166e9 | 851.8e-3 | -32.12 | 27.47e-6 | -117.4 | 1.114 | -131.8 | 139.8e-3 | -13.45 |
| 1.179e9 | 845.4e-3 | -32.83 | 28.98e-6 | -118.6 | 1.15 | -133.1 | 141.8e-3 | -12.9 |
| 1.192e9 | 838.6e-3 | -33.57 | 30.6e-6 | -119.7 | 1.187 | -134.5 | 143.8e-3 | -12.41 |
| 1.205e9 | 831.5e-3 | -34.33 | 32.32e-6 | -121 | 1.227 | -135.9 | 145.7e-3 | -11.98 |
| 1.219e9 | 823.9e-3 | -35.12 | 34.16e-6 | -122.2 | 1.269 | -137.3 | 147.5e-3 | -11.59 |
| 1.232e9 | 815.9e-3 | -35.94 | 36.13e-6 | -123.5 | 1.313 | -138.7 | 149.3e-3 | -11.24 |
| 1.246e9 | 807.5e-3 | -36.79 | 38.23e-6 | -124.8 | 1.359 | -140.2 | 151e-3 | -10.94 |
| 1.259e9 | 798.5e-3 | -37.67 | 40.49e-6 | -126.1 | 1.408 | -141.7 | 152.7e-3 | -10.68 |
| 1.273e9 | 789e-3 | -38.58 | 42.91e-6 | -127.5 | 1.46 | -143.3 | 154.3e-3 | -10.45 |
| 1.287e9 | 779e-3 | -39.53 | 45.5e-6 | -128.9 | 1.515 | -144.9 | 155.8e-3 | -10.26 |
| 1.302e9 | 768.3e-3 | -40.52 | 48.29e-6 | -130.4 | 1.573 | -146.5 | 157.2e-3 | -10.1 |
| 1.316e9 | 757e-3 | -41.55 | 51.28e-6 | -131.9 | 1.635 | -148.2 | 158.6e-3 | -9.98 |
| 1.331e9 | 745.1e-3 | -42.61 | 54.51e-6 | -133.5 | 1.7 | -150 | 159.8e-3 | -9.886 |
| 1.345e9 | 732.4e-3 | -43.72 | 57.98e-6 | -135.1 | 1.769 | -151.8 | 160.9e-3 | -9.82 |
| 1.36e9 | 718.9e-3 | -44.87 | 61.72e-6 | -136.8 | 1.842 | -153.7 | 161.9e-3 | -9.782 |
| 1.375e9 | 704.6e-3 | -46.07 | 65.76e-6 | -138.5 | 1.92 | -155.6 | 162.8e-3 | -9.769 |
| 1.39e9 | 689.5e-3 | -47.32 | 70.13e-6 | -140.3 | 2.004 | -157.6 | 163.6e-3 | -9.782 |
| 1.406e9 | 673.4e-3 | -48.62 | 74.85e-6 | -142.2 | 2.092 | -159.7 | 164.2e-3 | -9.818 |

Fig.1. 2 Port S Parameter Results Display in Cadence

Export this file to a .txt file from the Window → Print Menu.

**2.** In MATLAB Simulink RF Blockset, you will use General Amplifier instead of S-Parameters Amplifier that you used in Lab2. Read the “Amp File Format” section from MATLAB Help to understand the .amp file format.
You can read the results files generated by Cadence, in MATLAB by using the “dlmread” command.
Note that you will need to convert the polar format that Cadence uses into rectangular format that MATLAB uses for complex parameters.

After reading the circuit parameters from Cadence generated file, you will need to create a valid .amp format. You can use the .amp file you generated in the "General Amplifier" block and use it in your Simulink simulation.

**3.** By using the Visualization tab of the Physical blocks, plot the S parameters, NF and Nonlinearity of your LNA and Mixer in MATLAB Simulink. Figure 2. shows the S parameter plots for the LNA design given in Lab 3, obtained from General Amplifier block in MATLAB.

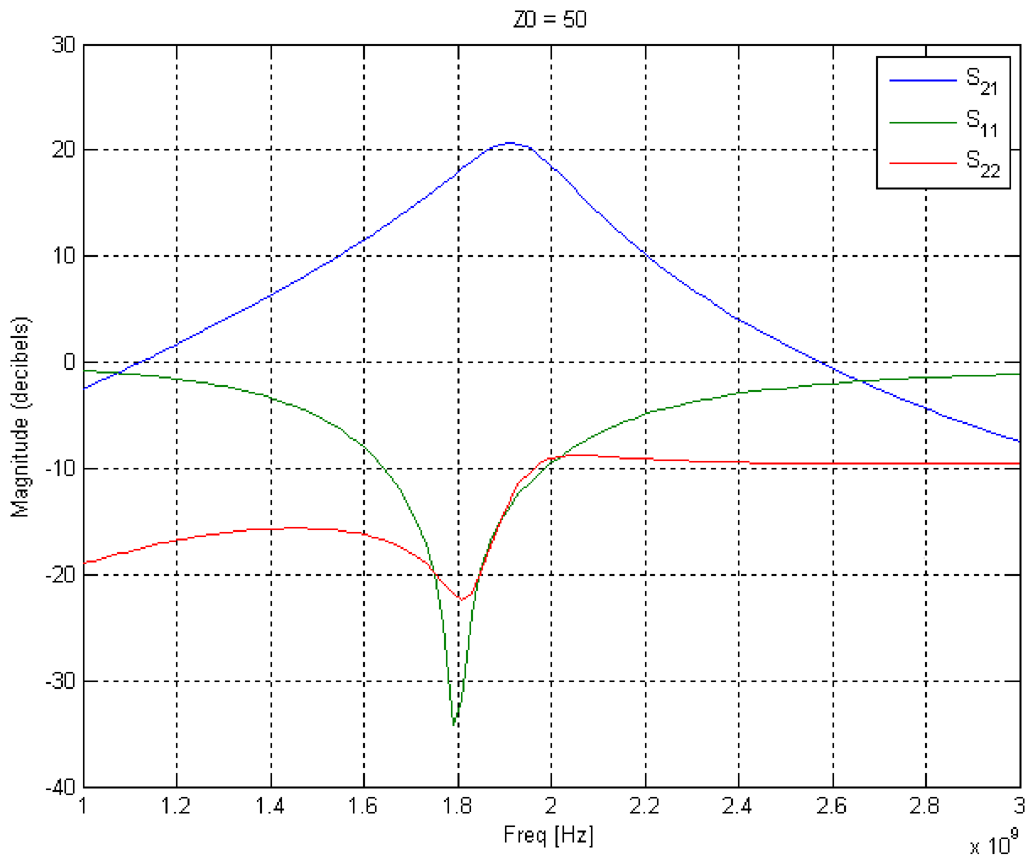


Fig.2 LNA S parameters in Cadence, exported from Cadence into a General Amplifier Block

**4.** Combine your LNA and Mixer, you can use an ideal LO to represent the oscillator and disregard the phase noise of the oscillator. Perform the complete RF Front End Simulation, provide plots of this simulation. How do the results compare with Cadence results, are they similar? Discuss.

**Final Remarks:**
You have two weeks to complete this lab. Please include Cadence and MATLAB schematics and plots, attach your MATLAB codes to your report.