Texas A&M University
Electrical Engineering Department

ECEN 665

Laboratory #4: Analysis and Simulation of a CMOS Mixer

Objectives: To learn the use of periodic steady state (pss) simulation tools in spectre (cadence) in the characterization of the major figures of merit of a down-conversion mixer: noise figure, conversion gain and IIP3. To understand the basic operation of a Gilbert-cell-based CMOS Mixer and analyze its performance trade-offs.

1. Schematic setup

Using a library for CMOS 0.5um technology in cadence, create the schematic shown in figure 1. This is a Gilbert cell which will be employed as a down-conversion mixer for an RF input signal of 1.9GHz. The component values are shown in tables 1-3.

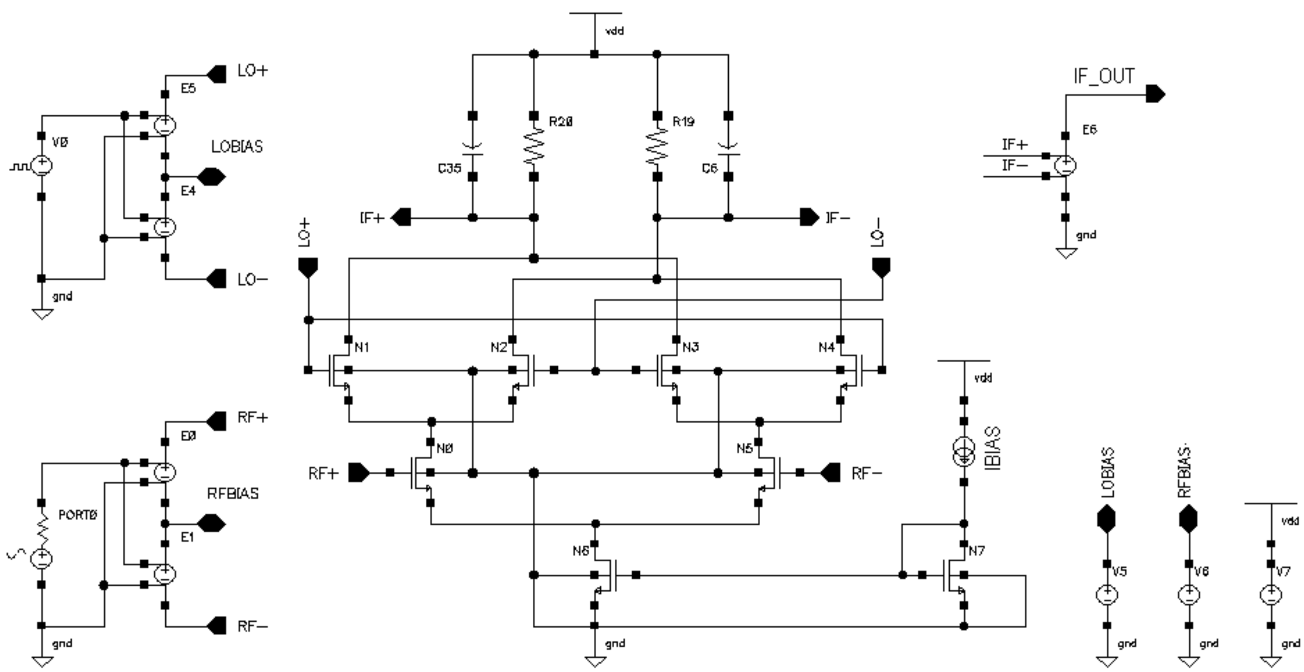

Figure 1. CMOS mixer schematic

Table 1. Transistor parameters

Transistor	W [um]	L [um]	Multiplicity
N7	36	0.6	2
N6	36	0.6	12
N0, N5	30	0.6	10
N1, N2, N3, N4	22	0.6	10

Table 2. Component values

Component	Value
R19, R20	500ohm
C6, C35	200fF
E0, E1, E4, E5	Gain = 0.5 V/V
IBIAS	1mA
LOBIAS	2.5V
RFBIAS	1.5V
VDD	5V
E6	GAIN = 0.5 V/V

Table 3. RF port (left) and LO (right) parameters

Instance	PORT0	**Instance**	V0
Cell name	psin	**Cell Name**	vpulse
Frequency name	F1	**Voltage 1**	300mV
Resistance	50ohms	**Voltage 2**	-300mV
Port number	1	**Rise time**	10ps
Source type	Sine	**Fall time**	10ps
Amplitude (dBm)	PRF	**Pulse width**	230ps
Frequency	1.9GHz	**Period**	500ps

1.1 Describe the operation of the Gilbert cell as a down-conversion mixer.

1.2 In a typical receiver, the output of the LNA is connected to the lower transistors of the Gilbert cell while the output of the frequency synthesizer is connected to the upper transistors. Explain why this configuration is preferred for a down-conversion mixer. Describe the phenomena of LO self-mixing and its impact for direct-conversion and low-IF receivers.

1.3 Describe the main design variables affecting each of the following performance parameters: Conversion gain, Noise Figure, IIP3. Using the information from the DC analysis, and fundamental equations calculate a bound for the expected values of the mentioned parameters.

2. PSS simulation

PSS analysis will be employed to characterize the conversion gain and noise figure of the mixer.

2.1 Simulation setup for the basic operation of the mixer.

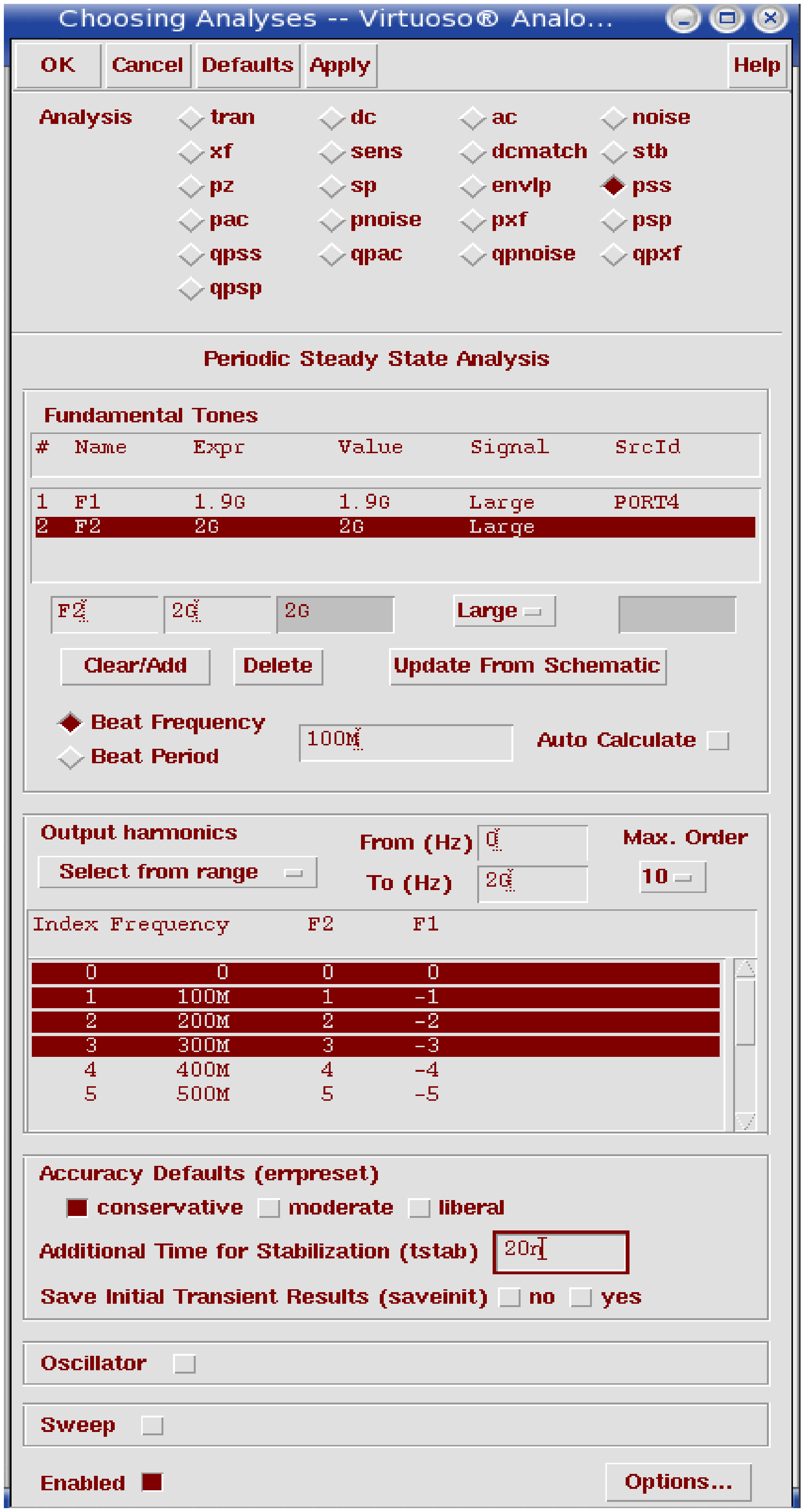

Figure 2. PSS simulation setup

NOTE: In the selection of the output harmonics make sure to select also the harmonics 19 and 20 (tones at 1.9GHz and 2GHz)

When the simulation is finished, configure the results window as shown in figure 3.

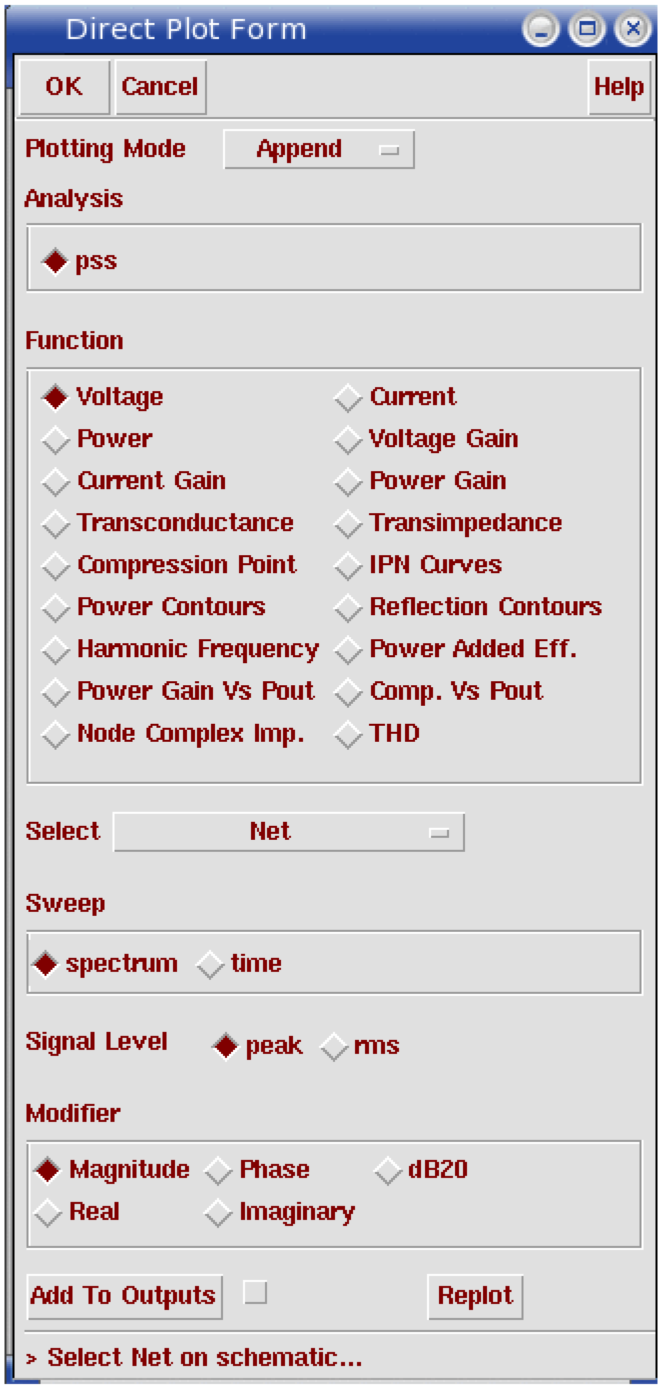

Figure 3. PSS results setup

Select the net at the top of PORT0 and IF_OUT.

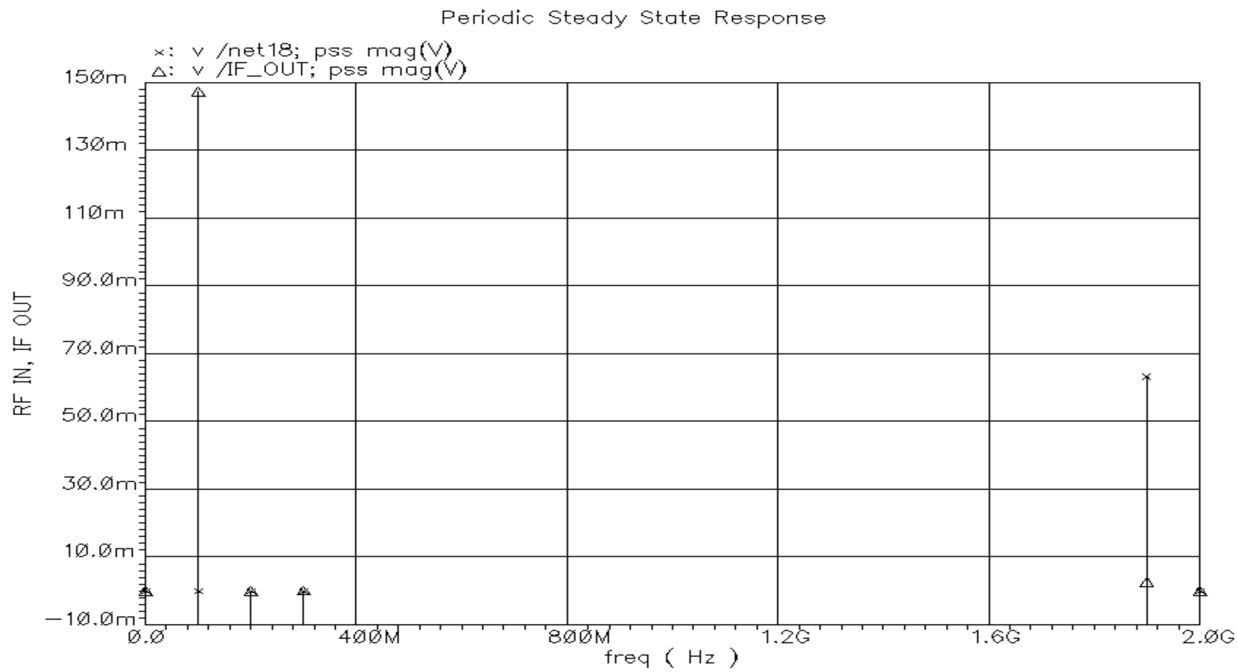

Figure 4. PSS simulation results

2.2 Plot the voltage at the same nets with the modifier dB20. What is the conversion gain of the mixer in dB? Explain the origin of all the tones you see at the IF output. What is the RF isolation? What is the LO isolation? Is there any LO self-mixing happening? How do these characteristics change if the RF frequency is change to 1GHz and 2.5GHz? (adjusting the LO frequency so that the IF is always 100MHz).

2.3 Noise Figure Simulation

Change the settings of PORT0 according to table 4. For noise analysis you will need to run pss and pnoise analyses together. Configure pss and pnoise analyses as shown in figure 5.

Table 4. RF Port parameters for NF simulation

Instance	PORT0
Cell name	psin
Frequency name	
Resistance	50ohms
Port number	1
Source type	dc
Amplitude (dBm)	
Frequency	

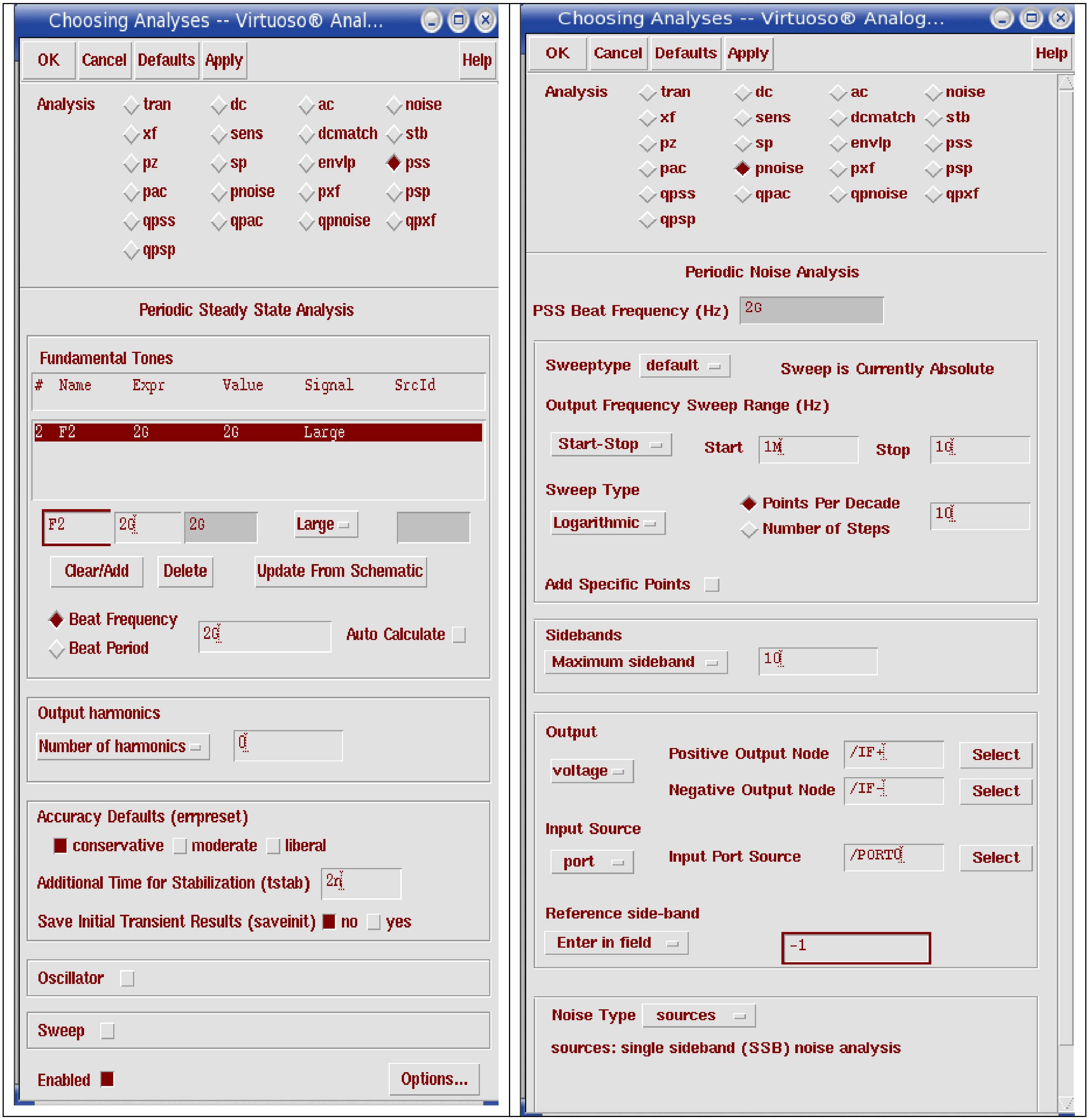

Figure 5. PSS (left) and Pnoise(right) simulation setups

The noise figure of the mixer can be plotted as follows:

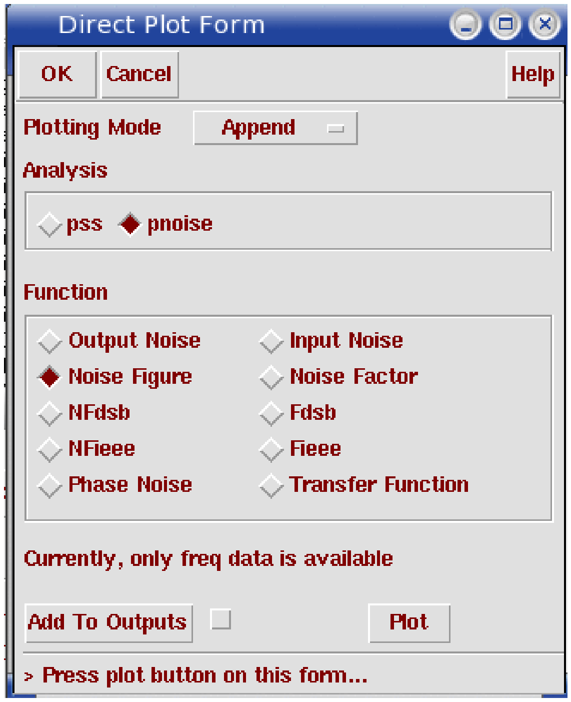

Figure 6. NF results setup

Notice that, for a down-conversion mixer, the noise figure is related to the output noise at the IF port referred back to the RF port.

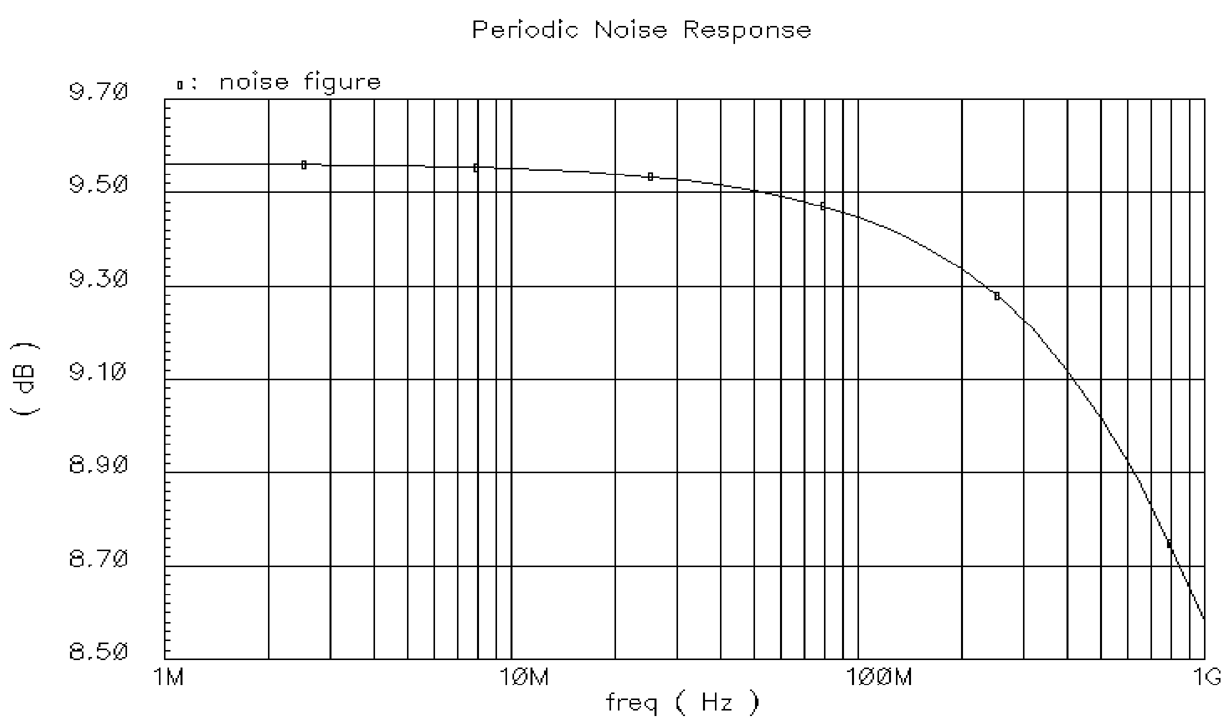

Figure 7. Noise figure of the mixer

2.3 Is the shape of the NF Vs. frequency plot what you expect? What is missing in the noise analysis?
2.4. Using the simulation techniques shown above, create plots of Conversion Gain Vs. LO amplitude and NF Vs. LO amplitude for a range between 50mV to 300mV. Consider both, a square (as in the examples above) and a sinusoidal LO signal.

3. SPSS simulation

SPSS Analysis will be employed to characterize the compression and non-linearities of the mixer.
3.1 Set the parameters of PORT0 back to the original values shown in Table 3 and the SPSS simulation as shown in figure 8.

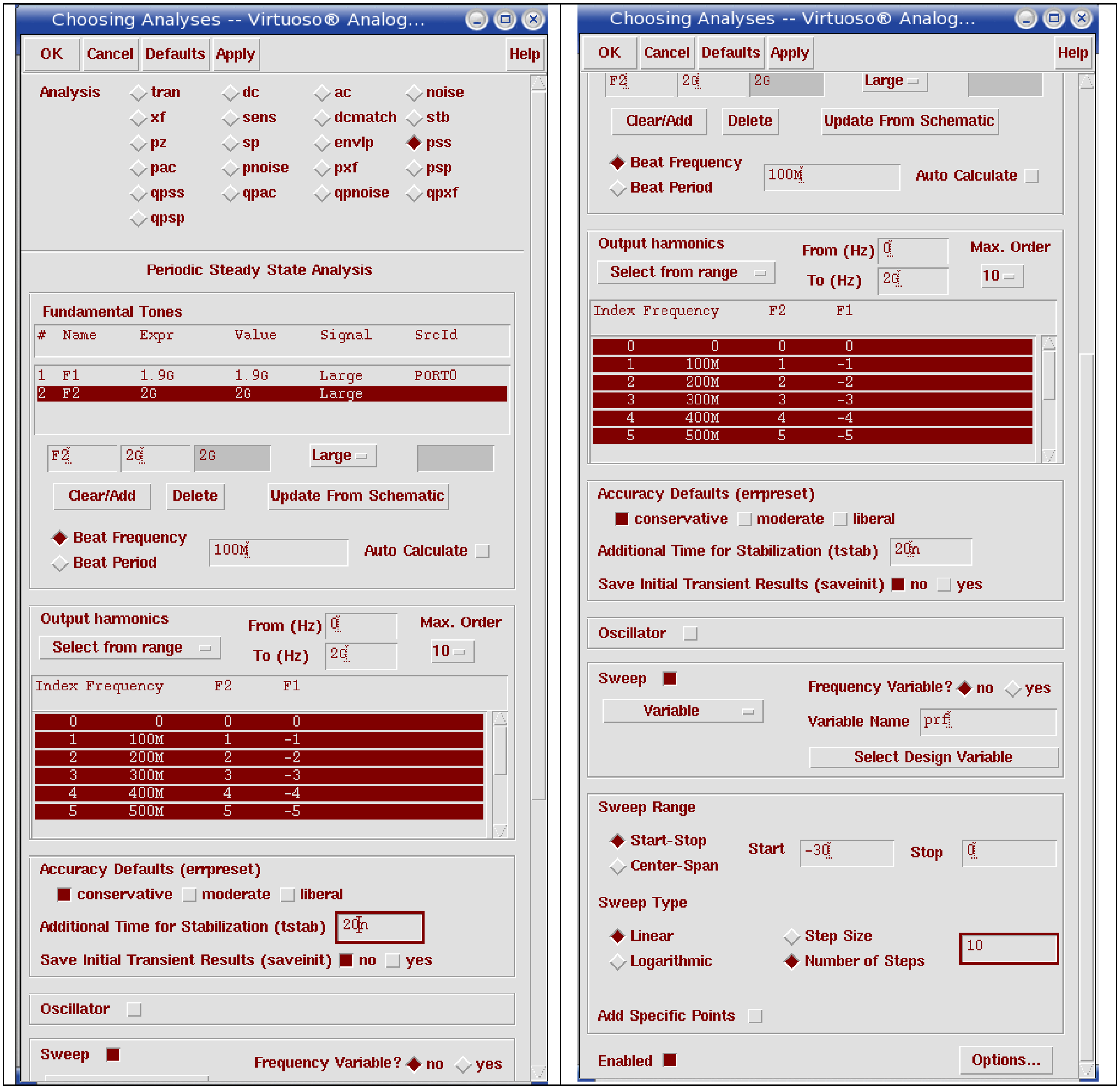

Figure 8. SPSS single tone simulation setup

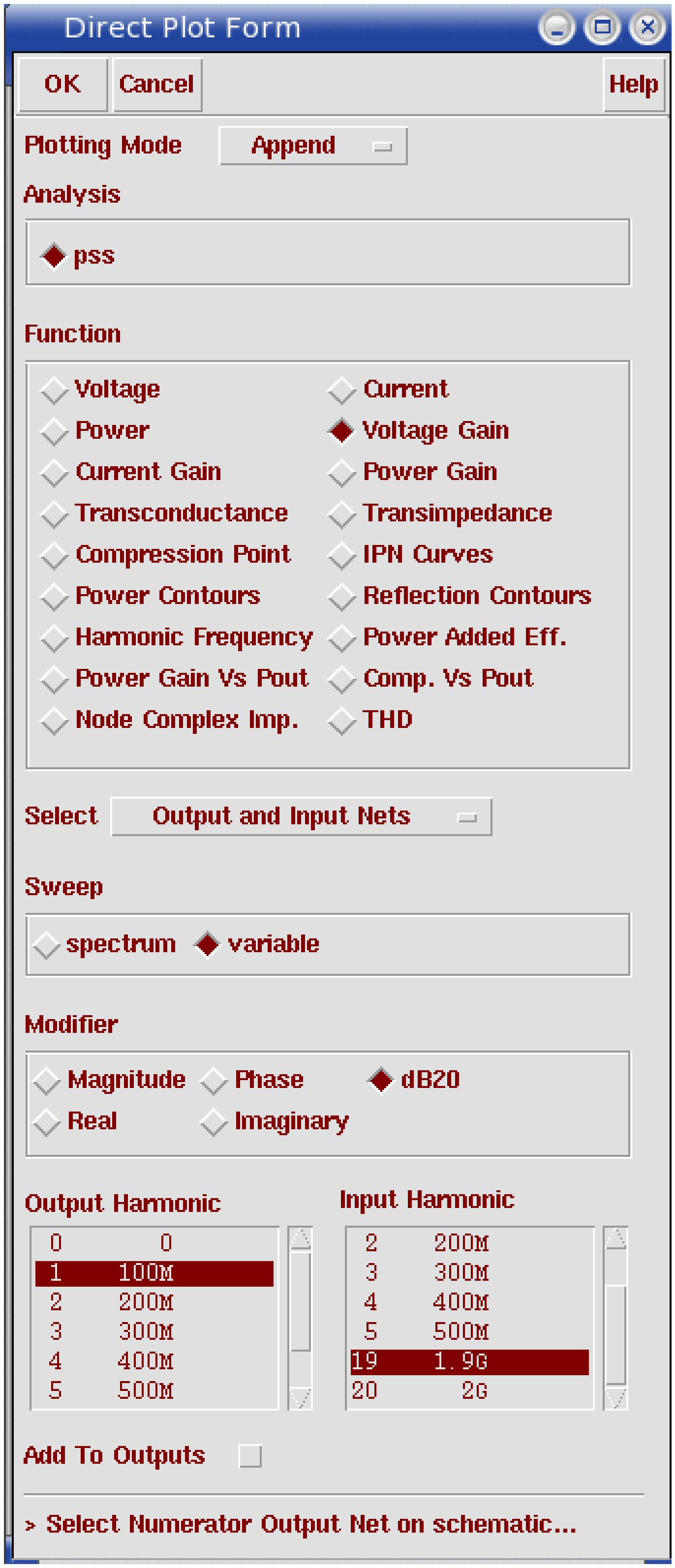

Figure 9. SPSS single tone simulation results setup

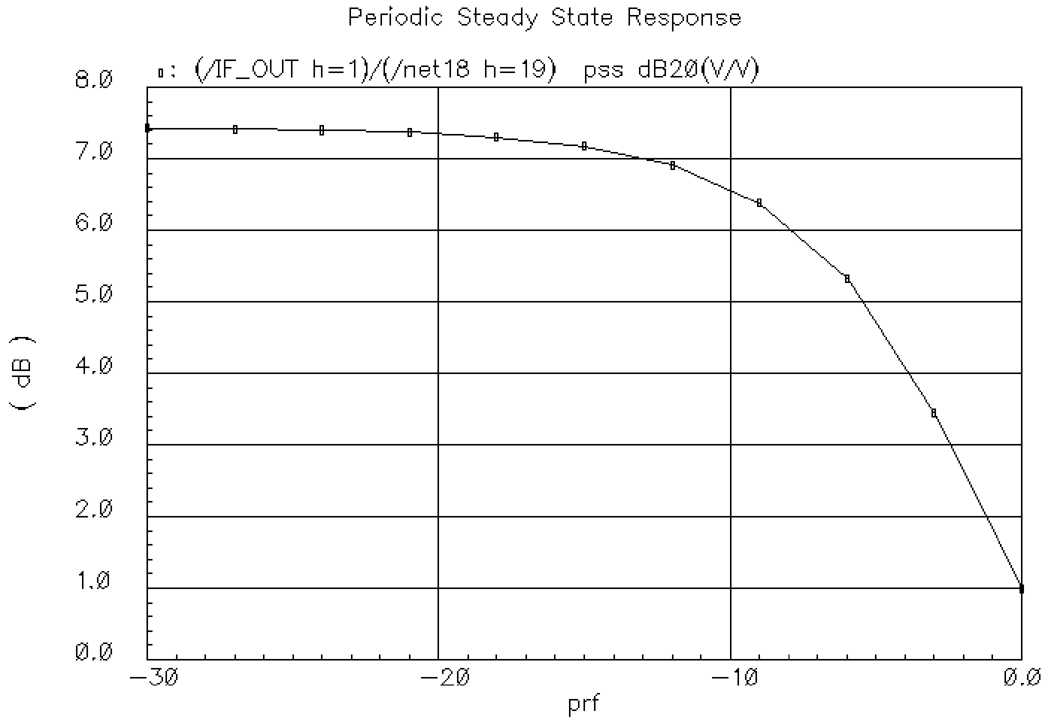

Figure 10. Conversion gain Vs. Input power

3.2 In a similar way as it was done for the LNA, set a two-tone SPSS simulation setup and obtain the IIP3 of the mixer.

3.3 Obtain plots of IIP3 Vs. LO amplitude as in step 2.4

3.4 Provide your conclusions on the impact that the LO amplitude and shape has on the overall performance of the mixer (considering both noise and linearity). Based on your results, what is a convenient amplitude range for the LO signal?

4. Mixer Design Trade-Offs

4.1 Starting from your simulation results for a square 150mVp LO signal, modify the design of the mixer to reduce the NF by 2.5dB, improve the IIP3 by 11dB (use of source degeneration is recommended) while attaining a conversion gain of 7dB. Explain the decisions taken in your re-design process. Hint: The size of the LO switching transistors plays an important role in the overall performance.