

Analysis and Simulation of a CMOS LNA

Objectives: To learn the use of s-parameter and periodic steady state (pss) simulation tools in spectre (cadence) in the characterization of the major figures of merit of an LNA: input and output match, noise figure, gain and IIP3. To understand the basic operation of a cascode CMOS LNA and analyze its performance trade-offs.

Cadence Simulator : In this and all the following lab exercises, we will use **Spectre** simulator of Cadence.

1. Schematic setup

Using a library gpdk045 technology in cadence, create the schematic shown in figure 1. This is a well known cascode LNA topology with an output buffer to provide output impedance match. The component values are shown in tables 1-3.

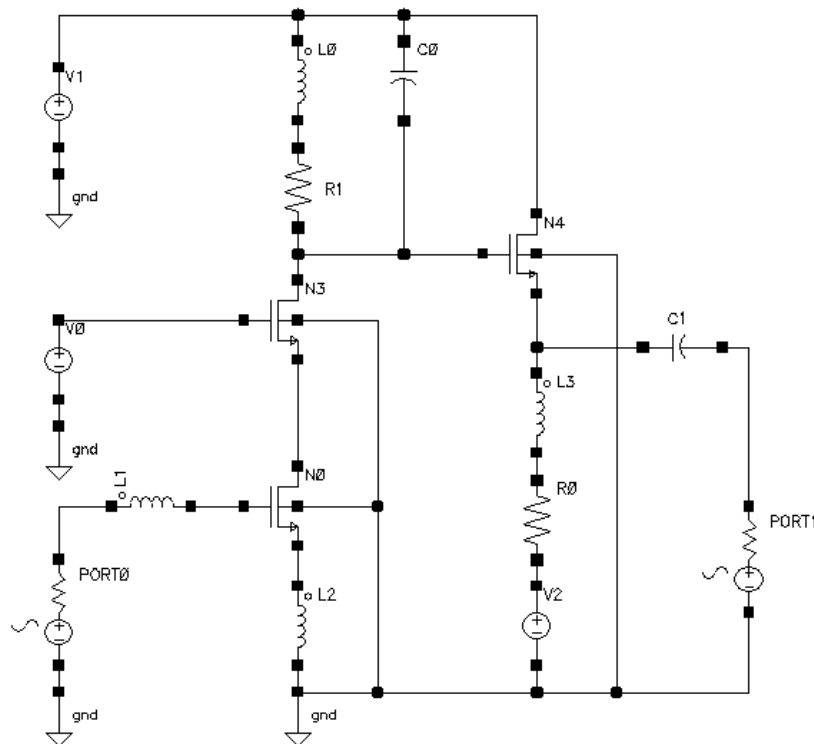


Figure 1. Cascode LNA schematic

Table 1. Transistor parameters

Transistor	W [um]	L [um]	Multiplicity
N0	24	0.6	10
N3	12	0.6	10
N4	9	0.6	10

Table 2. Component values

Component	Value
L0	6 nH
L1	16nH
L2	1nH
L3	20nH
R0	15ohm
R1	8.4 ohm
C0	900fF
C1	4pF
V0	2.8V
V1	3.5V
V2	0.8V

Table 3. Port parameters

Parameter	PORT0	PORT1
Cell name	psin	Psin
Frequency Name	F1	
Resistance	50ohms	50ohms
Port number	1	2
DC voltage	0.5V	
Source type	Sine	
Amplitude (dBm)	PRF	
Frequency	1.9GHz	
AC magnitude	1	

1.1 Briefly describe the role of each transistor and passive component in the LNA.

1.2 Describe in general terms, how is the input and output match implemented in this design.

1.3 Would the output buffer (transistor N4) and/or the output matching network to 50ohm be needed if the load of the LNA was a Mixer on the same chip? Explain.

2. S parameter simulation

S-parameter simulation will be used to measure the input and output match of the LNA as well as its small signal gain.

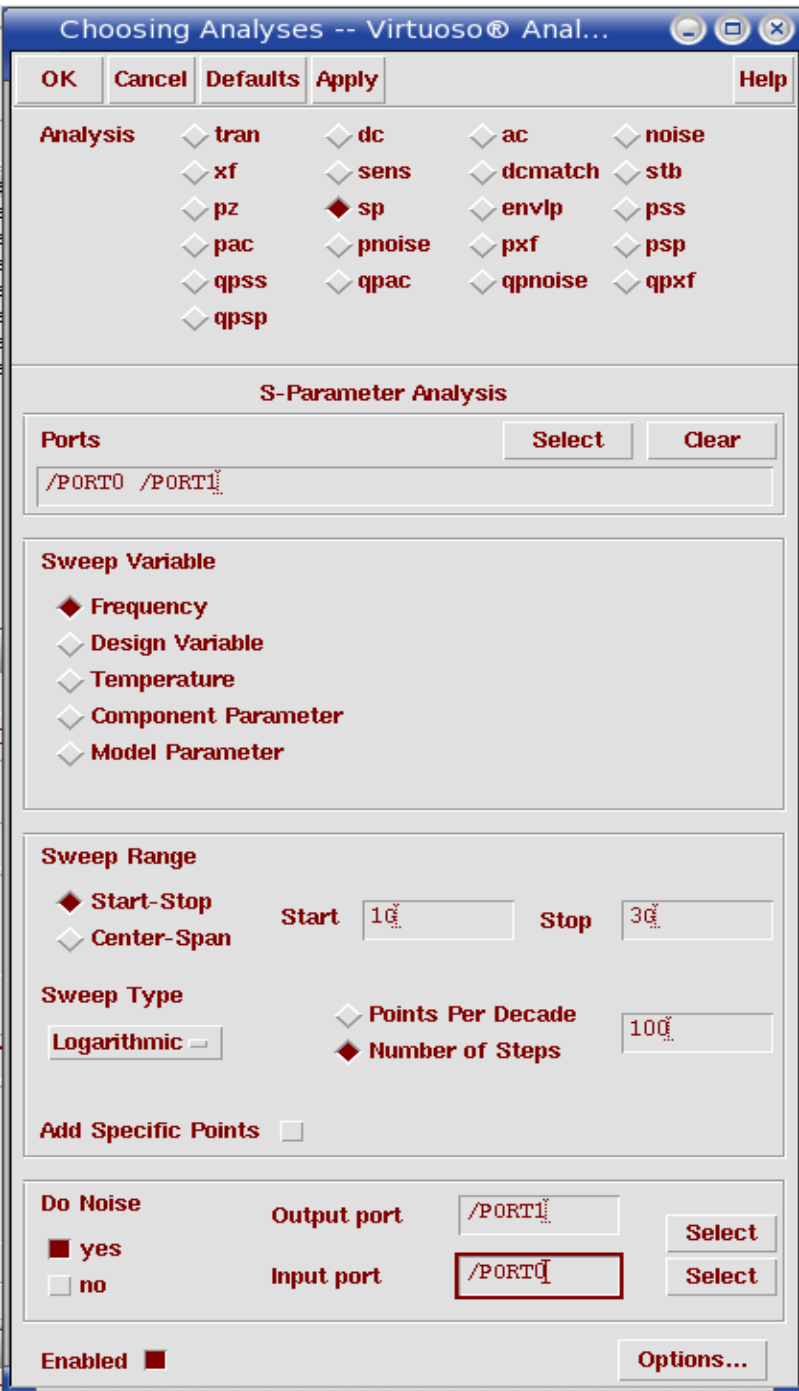


Figure 2. S-parameter simulation setup

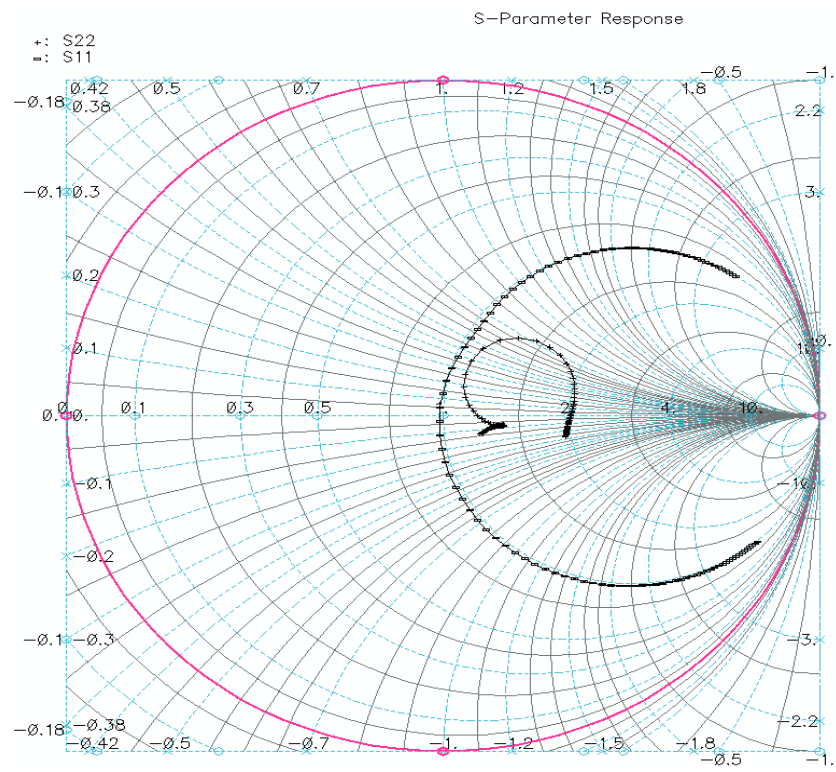


Figure 3. S11 and S22

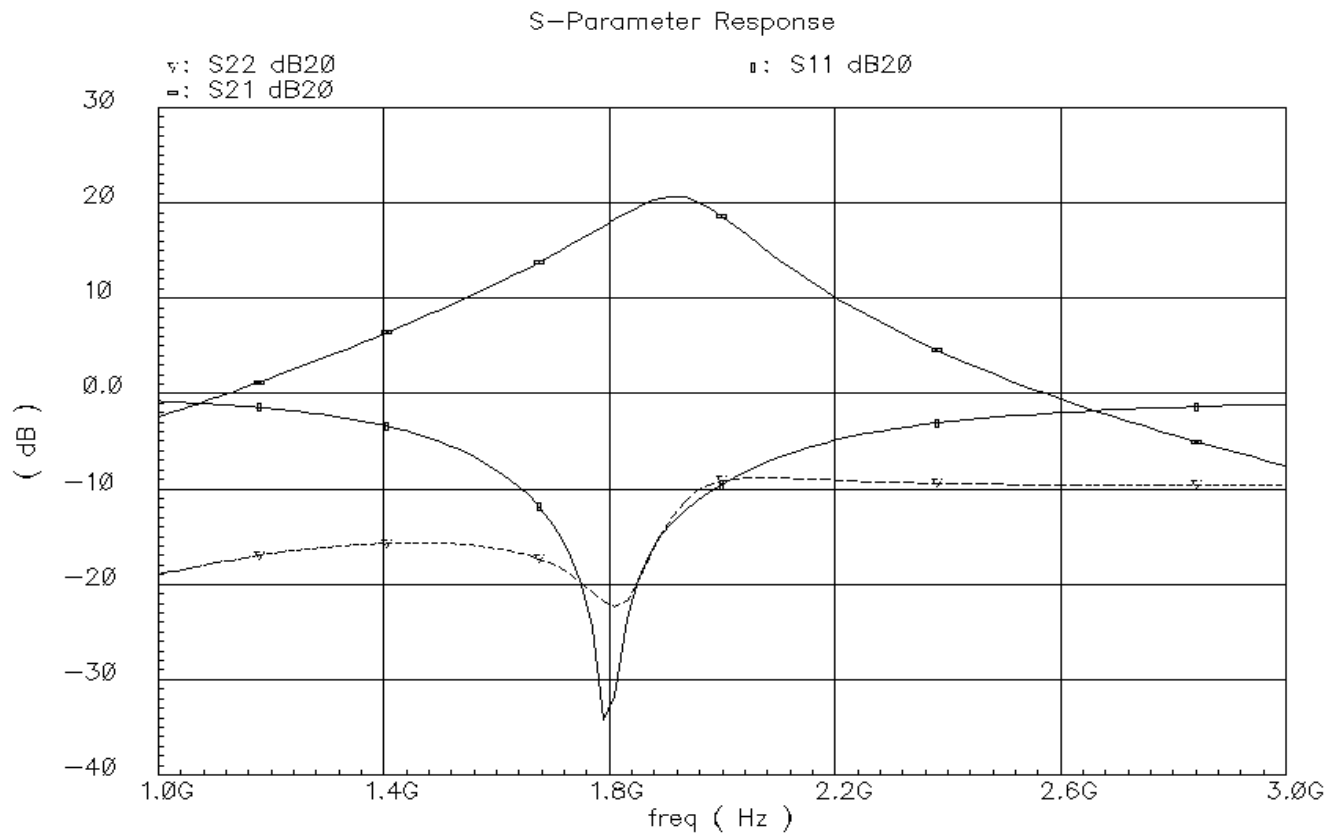


Figure 4. S-parameters for the 1.9GHz LNA

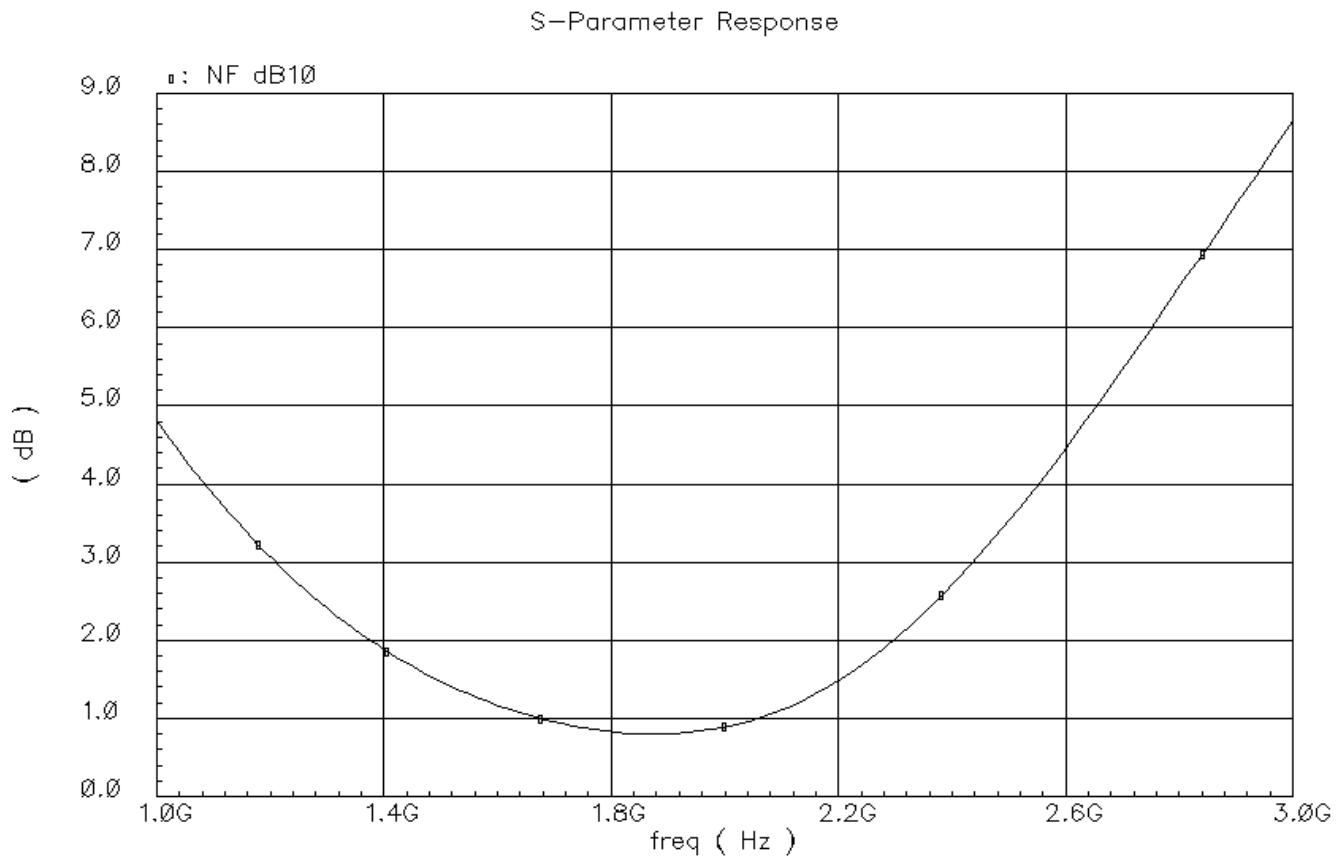


Figure 5. Noise figure (through s-parameter simulation) of the LNA

2.1 Run a DC Analysis and save the operating point. Display the operating point of transistor N0 and take note of its g_m , v_{gs} and c_{gs} . Using these values calculate the theoretical gain, noise figure and input impedance of the LNA. Are the calculated values different from the S-parameter simulation results? Explain the differences. (Set PRF to -20dBm)

3. PSS simulation

A periodic steady-state analysis provides an accurate simulation of the transient behavior of a circuit. For the non-linear characterization of the LNA this is a preferred simulation method over the conventional transient analysis.

3.1 Single tone simulation

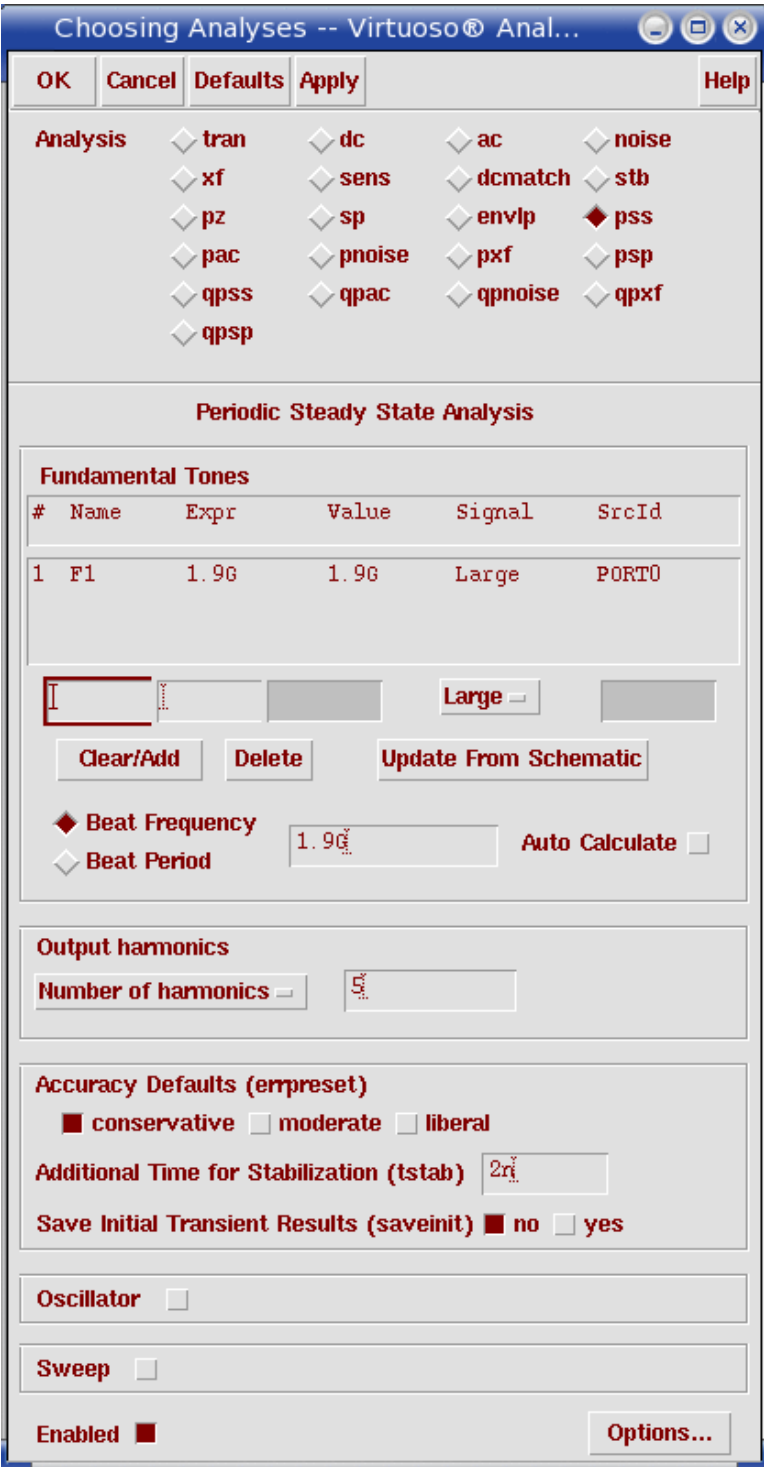


Figure 6. PSS simulation setup

Direct Plot Form

OK Cancel Help

Plotting Mode Append

Analysis

◆ pss

Function

◇ Voltage	◇ Current
◆ Power	◇ Voltage Gain
◇ Current Gain	◇ Power Gain
◇ Transconductance	◇ Transimpedance
◇ Compression Point	◇ IPN Curves
◇ Power Contours	◇ Reflection Contours
◇ Harmonic Frequency	◇ Power Added Eff.
◇ Power Gain Vs Pout	◇ Comp. Vs Pout
◇ Node Complex Imp.	◇ THD

Select Port (fixed R(port))

Currently, only spectrum data is available

Modifier

◇ Magnitude ◇ dB10 ◆ dBm

Add To Outputs ☐

> Select Port on schematic...

Figure 7. PSS results setup

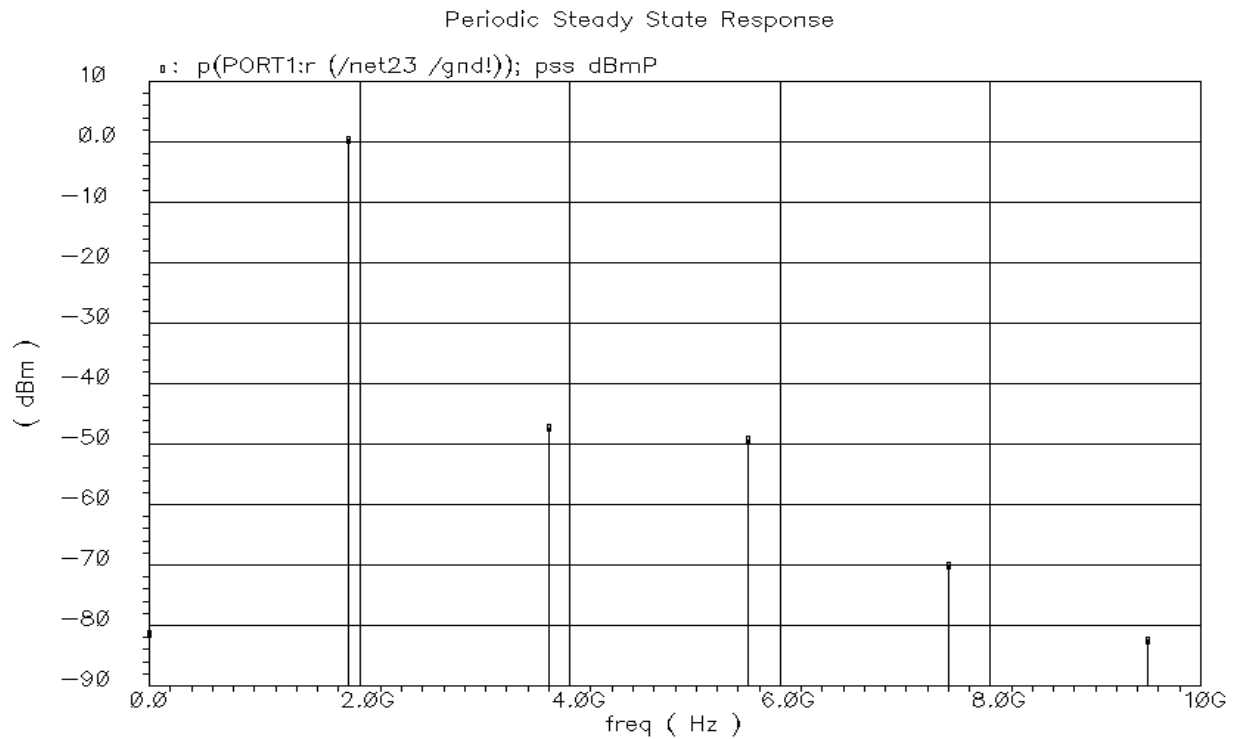


Figure 8. Output spectrum for a -20dBm 1.9GHz input

3.11 What is the power gain of the LNA for the fundamental tone? What is the HD2 and HD3? How do these 3 parameters change for an input of -40dBm and -5dBm?

3.2 Two tone simulation

PSS can also be employed for a two-tone test of the LNA. For this purpose, change the setting of the input port according table 4 and the pss setup according to figure 9. Notice that the input tones and the expected intermodulation products are the selected harmonics for the simulation.

Table 4. Port 1 parameters

Parameter	PORT0
Cell name	psin
Frequency name	F1
Second frequency name	F2
Resistance	50ohms
Port number	1
DC voltage	0.5V
Source type	Sine
Amplitude (dBm)	PRF
Frequency	1.85GHz
Amplitude 2 (dBm)	PRF
Frequency 2	1.95GHz
AC magnitude	1

Choosing Analyses -- Virtuoso® Analo...

OK Cancel Defaults Apply Help

Analysis

☐ tran
 ☐ dc
 ☐ ac
 ☐ noise

☐ xf
 ☐ sens
 ☐ dcmatch
 ☐ stb

☐ pz
 ☐ sp
 ☐ envlp
 ☒ pss

☐ pac
 ☐ pnoise
 ☐ pxf
 ☐ psp

☐ qpss
 ☐ qpac
 ☐ qpnoise
 ☐ qpxf

☐ qpsp

Periodic Steady State Analysis

Fundamental Tones

#	Name	Expr	Value	Signal	SrcId
1	F1	1.85G	1.85G	Large	PORT0
2	F2	1.95G	1.95G	Large	PORT0

Large

☒ Beat Frequency
 ☐ Beat Period

☐ Auto Calculate

Output harmonics

From (Hz)
 To (Hz)
 Max. Order

Index	Frequency	F1	F2
35	1.75G	2	-1
37	1.85G	1	0
39	1.95G	0	1
41	2.05G	-1	2

Accuracy Defaults (empreset)

☒ conservative
 ☐ moderate
 ☐ liberal

Additional Time for Stabilization (tstab)

Save Initial Transient Results (saveinit) ☐ no ☐ yes

Oscillator ☐

Sweep ☐

Enabled ☒

Figure 9. PSS simulation setup for a two tone test

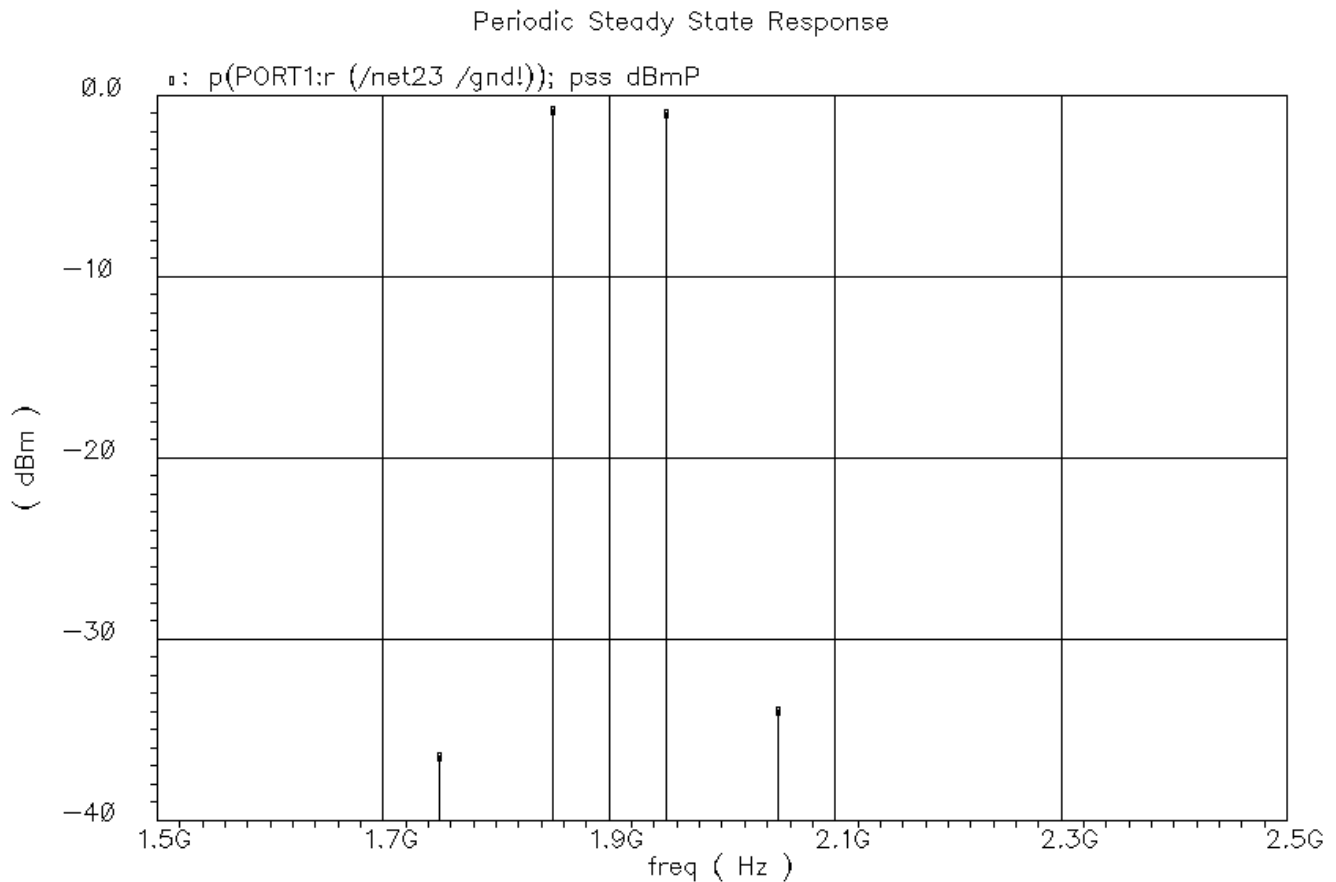


Figure 10. Two tone test output using PSS

3.21 From the PSS simulation results, what is the IIP3 of this LNA?

4. SPSS simulation

The swept periodic steady state (SPSS) is used to analyze the steady state transient behavior of the LNA while sweeping a certain design variable, for example the input power. In Spectre, SPSS is performed through PSS where Sweep option is enabled.

4.1 Single tone simulation

Choosing Analyses -- Virtuoso® Analo...

OK Cancel Defaults Apply Help

Analysis ☐ tran ☐ dc ☐ ac ☐ noise
☐ xf ☐ sens ☐ dcmatch ☐ stb
☐ pz ☐ sp ☐ envlp ☒ pss
☐ pac ☐ pnoise ☐ pxf ☐ psp
☐ qpss ☐ qpac ☐ qpnoise ☐ qpxf
☐ qpssp

Periodic Steady State Analysis

Fundamental Tones

#	Name	Expr	Value	Signal	SrcId
1	F1	1.9G	1.9G	Large	PORT0

Large

Clear/Add Delete Update From Schematic

☒ Beat Frequency 1.9G ☐ Auto Calculate

☐ Beat Period

Output harmonics

Number of harmonics 10

Accuracy Defaults (emmpreset)

☒ conservative ☐ moderate ☐ liberal

Additional Time for Stabilization (tstab) 20

Save Initial Transient Results (saveinit) ☐ no ☐ yes

Oscillator ☐

Sweep ☒ Frequency Variable? ☒ no ☐ yes

Choosing Analyses -- Virtuoso® Analog...

OK Cancel Defaults Apply Help

Save Initial Transient Results (saveinit) ☒ no ☐ yes

Oscillator ☐

Sweep ☒ Frequency Variable? ☒ no ☐ yes

Variable

Variable Name prf

Select Design Variable

Sweep Range

☒ Start-Stop Start -40 Stop 10

☐ Center-Span

Sweep Type

☒ Linear ☒ Step Size 5

☐ Logarithmic ☐ Number of Steps

Add Specific Points ☐

Enabled ☒ Options...

Figure 11. SPSS single tone simulation setup

Direct Plot Form

OK

Cancel

Help

Plotting Mode

Append

Analysis

pss

Function

Voltage

Power

Current Gain

Transconductance

Compression Point

Power Contours

Harmonic Frequency

Power Gain Vs Pout

Node Complex Imp.

Current

Voltage Gain

Power Gain

Transimpedance

IPN Curves

Reflection Contours

Power Added Eff.

Comp. Vs Pout

THD

Select

Port (fixed R(port))

Format

Output Power

Gain Compression (dB)

1

"prf" ranges from -40 to 10

Input Power Extrapolation Point (dBm)

-20

Input Referred 1dB Compression

1st Order Harmonic

0	0
1	1.9G
2	3.8G
3	5.7G
4	7.6G
5	9.5G

Add To Outputs

Replot

> Select Port on schematic...

Direct Plot Form

OK

Cancel

Plotting Mode

Append

Analysis

pss

Function

Voltage

Power

Current Gain

Transconductance

Compression Point

Power Contours

Harmonic Frequency

Power Gain Vs Pout

Node Complex Imp.

Current

Voltage Gain

Power Gain

Transimpedance

IPN Curves

Reflection Contours

Power Added Eff.

Comp. Vs Pout

THD

Select

Output and Input Nets

Sweep

spectrum

variable

Modifier

Magnitude

Real

Phase

Imaginary

dB20

Output Harmonic

0	0
1	1.9G
2	3.8G
3	5.7G
4	7.6G
5	9.5G

Input Harmonic

0	0
1	1.9G
2	3.8G
3	5.7G
4	7.6G
5	9.5G

Add To Outputs

Replot

> Select Numerator Output Net on schematic...

Figure 12. SPSS single tone results setup for 1dB compression point (left) and voltage gain (right)

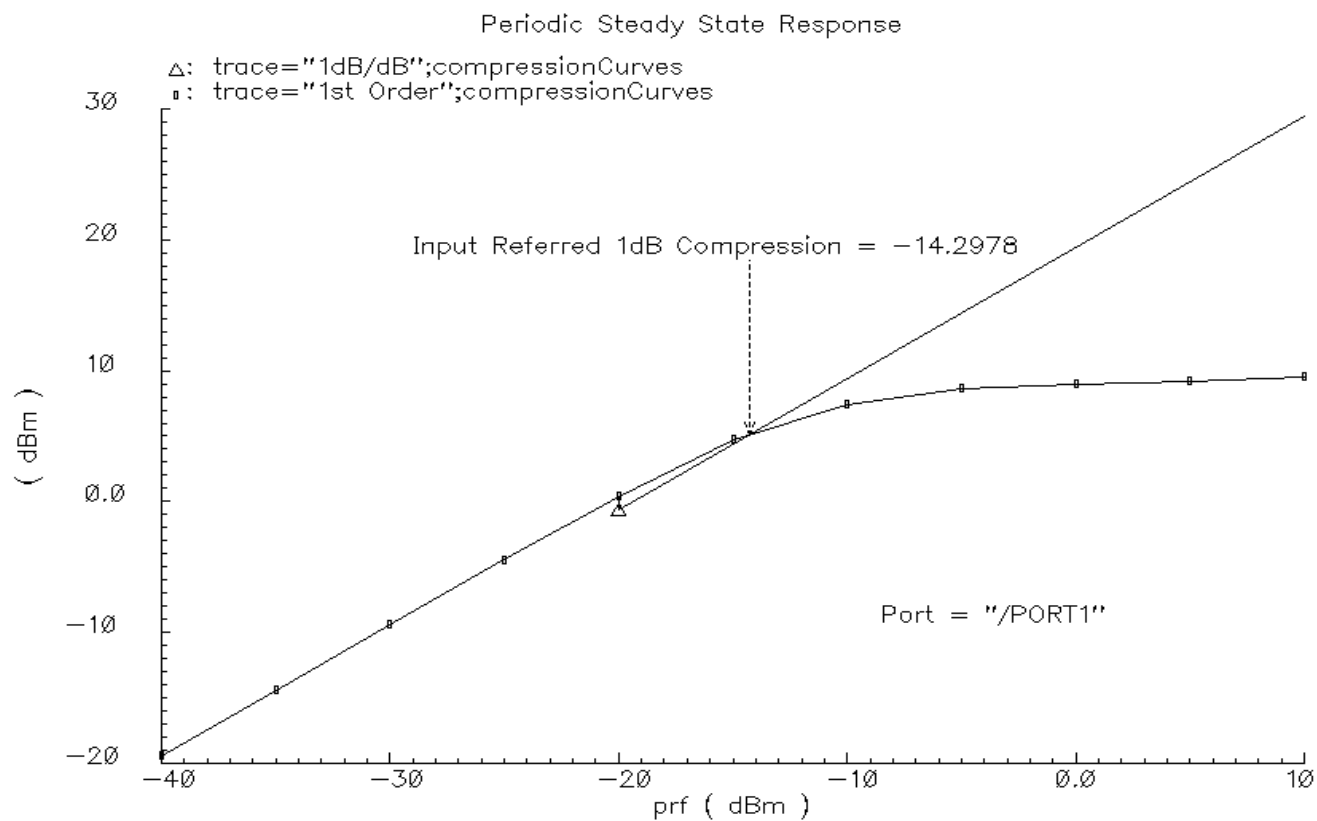


Figure 13. Input 1dB compression point

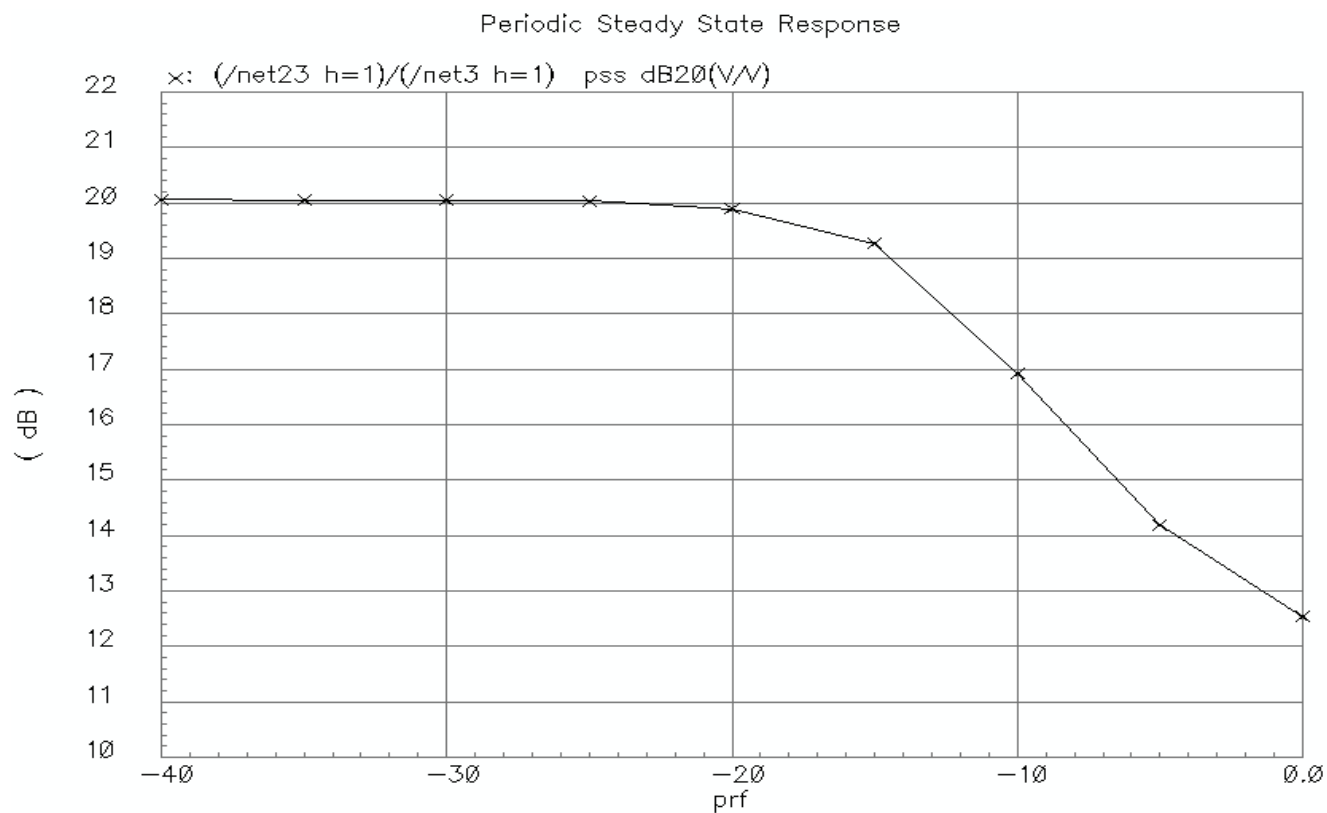


Figure 14. Gain Vs. Input power

4.2 Two tone simulation

This simulation setup allows you to observe how the intermodulation products grow with the input power level.

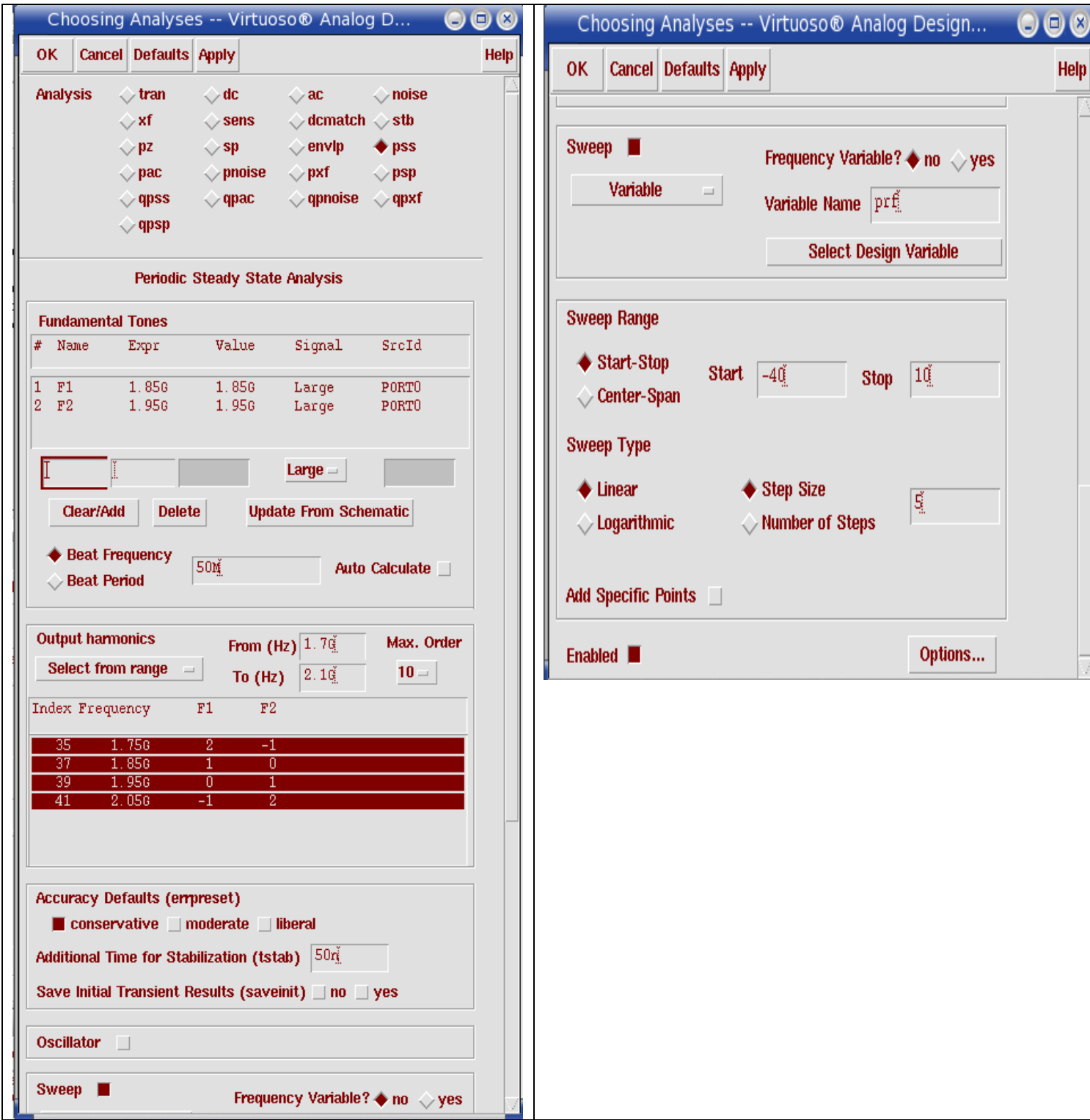


Figure 15. Two tone SPSS simulation setup

Direct Plot Form

OK Cancel Help

Plotting Mode Append

Analysis

pss

Function

☐ Voltage ☐ Current
☐ Power ☐ Voltage Gain
☐ Current Gain ☐ Power Gain
☐ Transconductance ☐ Transimpedance
☐ Compression Point ☒ IPN Curves
☐ Power Contours ☐ Reflection Contours
☐ Harmonic Frequency ☐ Power Added Eff.
☐ Power Gain Vs Pout ☐ Comp. Vs Pout
☐ Node Complex Imp. ☐ THD

Select Port (fixed R(port))

Circuit Input Power ☐ Single Point
☒ Variable Sweep ("prf")

"prf" ranges from -40 to 10

Input Power Extrapolation Point (dBm) -20

Input Referred IP3 Order 3rd

3rd Order Harmonic

0	0
35	1.75G
37	1.85G
39	1.95G
41	2.05G

1st Order Harmonic

0	0
35	1.75G
37	1.85G
39	1.95G
41	2.05G

Add To Outputs Replot

> Select Port on schematic...

Figure 16. SPSS two tone results setup for output power and IIP3

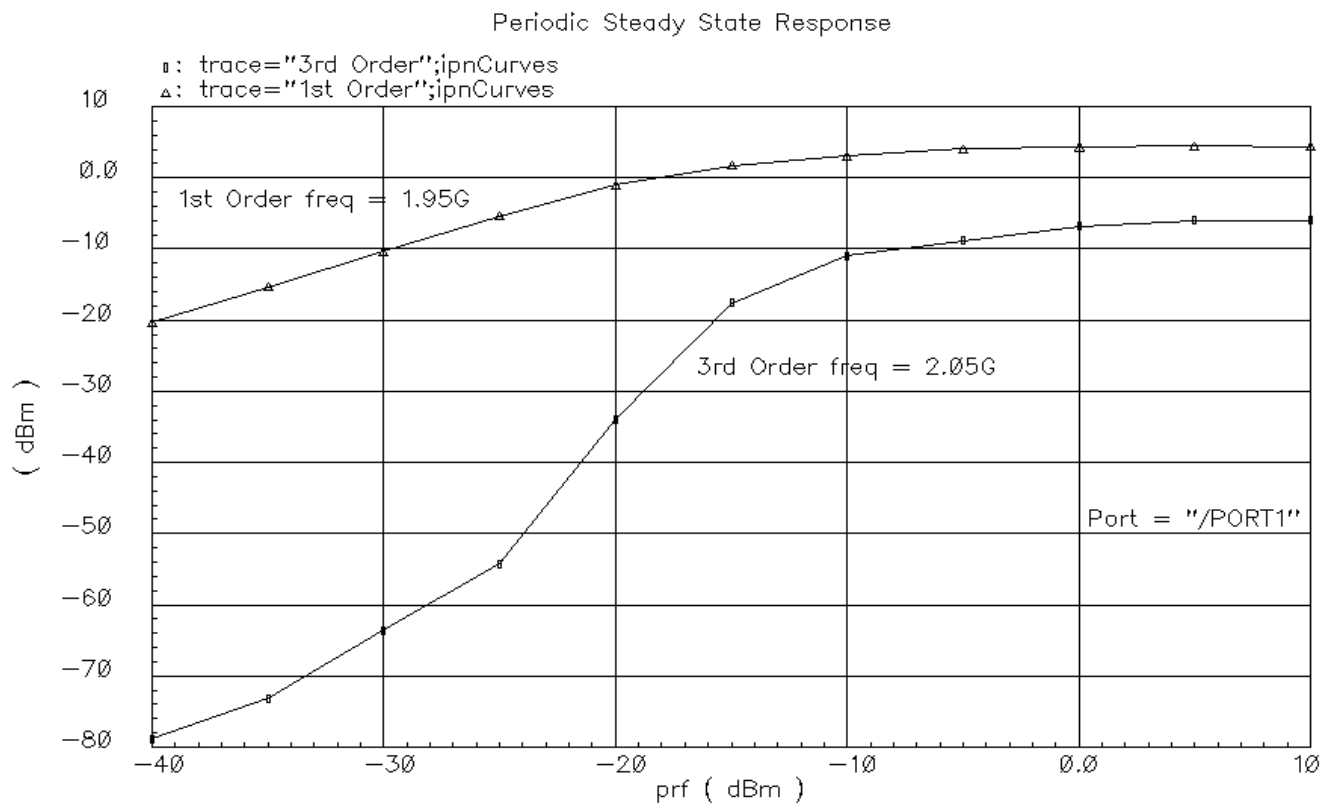


Figure 17. Main tones and intermodulation products

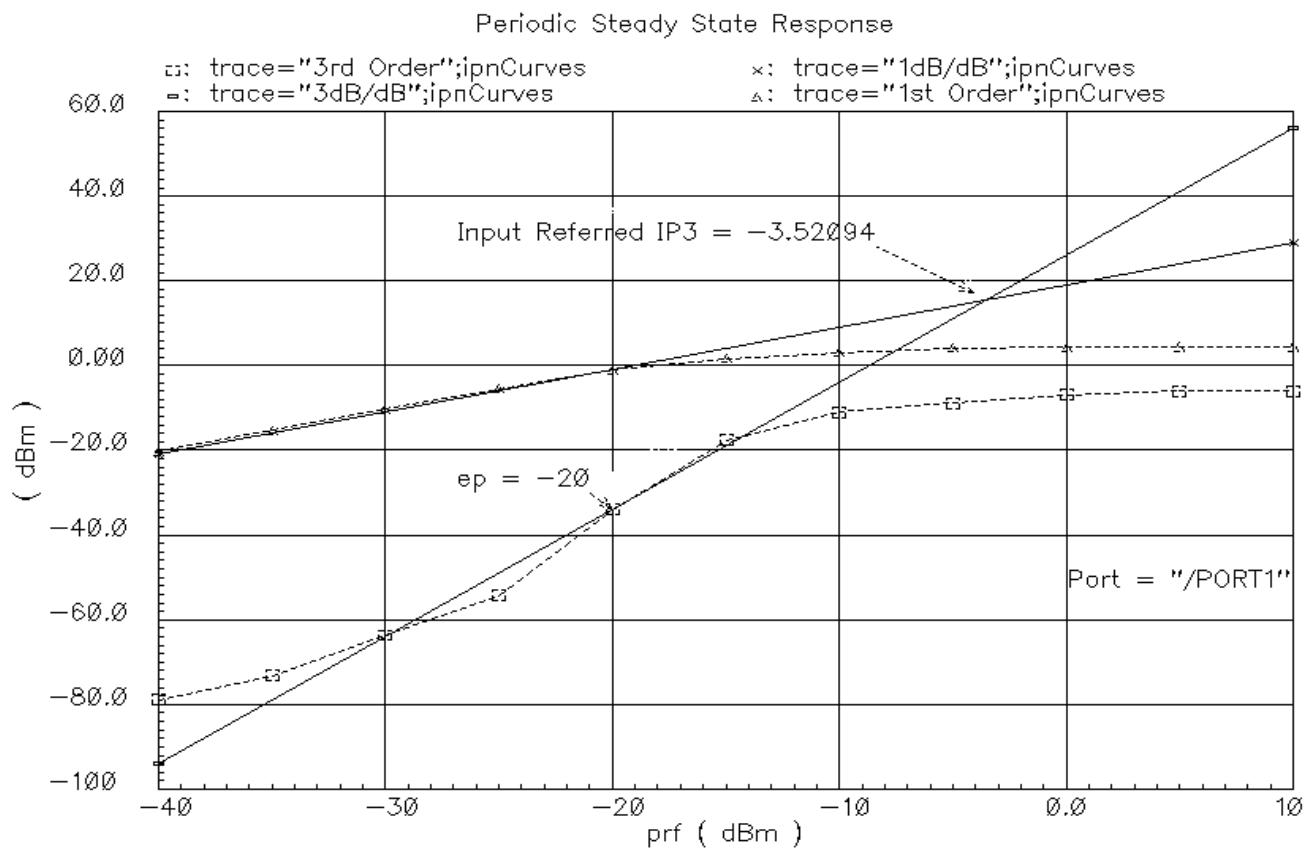


Figure 18. Extrapolated IIP3

4.21 How does the extrapolated IIP3 compare with your calculation from 3.21? Is the difference between the 1dB compression point and the IIP3 what you would expect?

4.22 The IIP3 of a cascode LNA can be estimated from the V_{dsat} of the input transistor and other parameters. Calculate the IIP3 and compare it with your simulation results.