

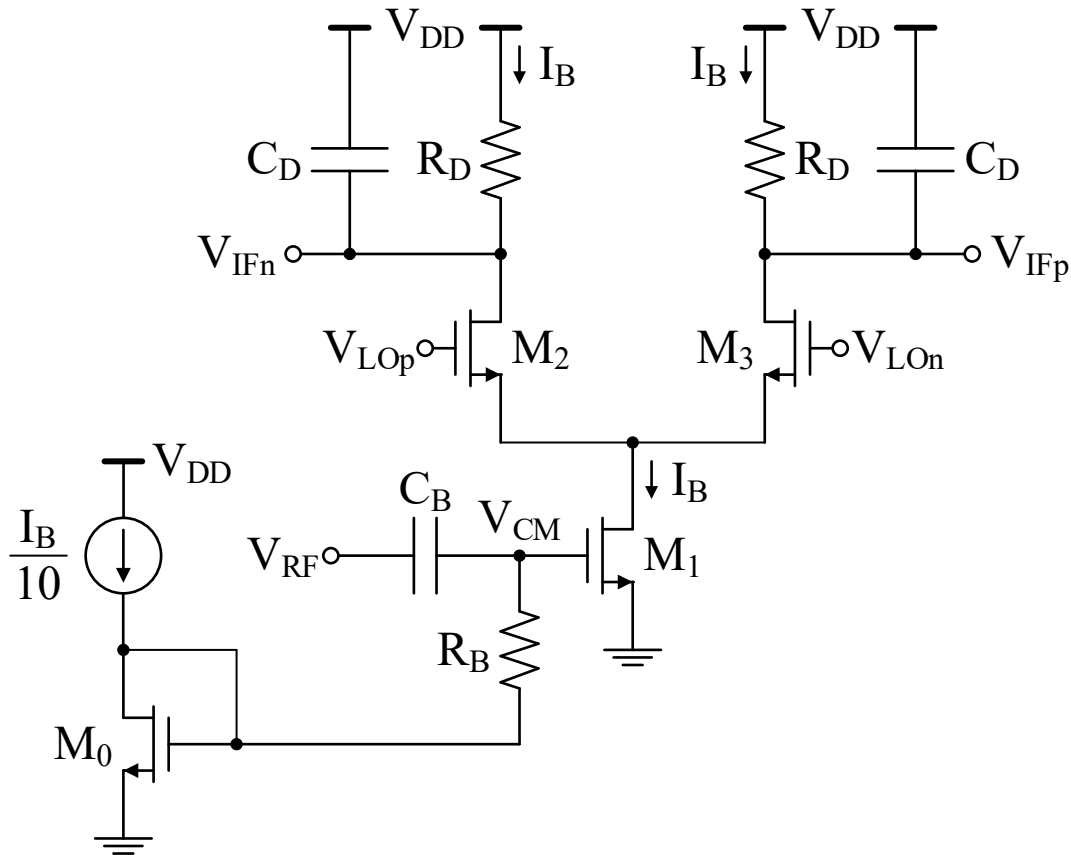
# **Circuits and Systems for Radio Frequency**

## **Single Balanced Mixer Simulation**

**2025/2026**

# Single balanced mixer – Design example and testbench

- Only one branch is active at any given time
- Simulate circuit without and with capacitor  $C_D$



## Design:

- $nch\_lvt$
- $V_{DD} = 1.2\text{ V}$  and  $V_{CM} = 0.475\text{ V}$
- $W_F$  = Width per finger and  $W_T$  = Total width

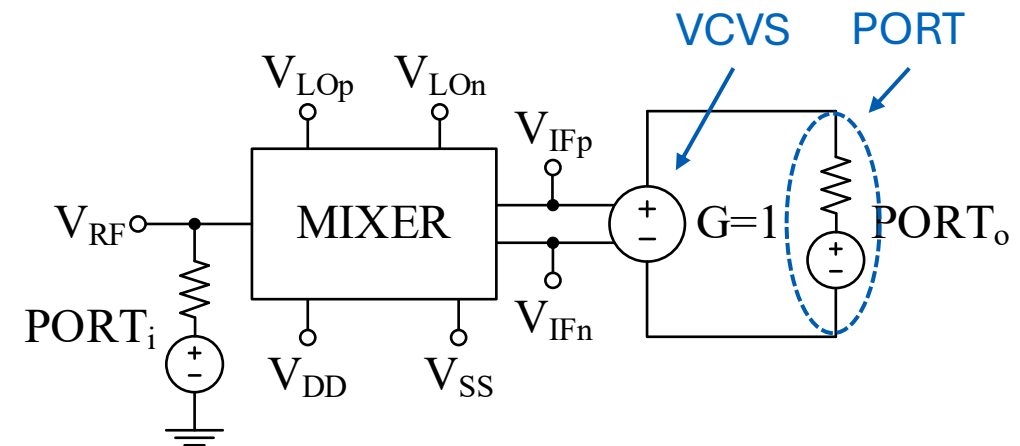
	$W_F$ [ $\mu\text{m}$ ]	$W_T$ [ $\mu\text{m}$ ]	Fingers	$L$ [ $\mu\text{m}$ ]
$M_0$	0.44	3.52	8	0.06
$M_1$	3.88	31.04	8	0.06
$M_{2,3}$	2.10	4.20	2	0.06

$I_B$ [mA]	$R_D$ [k $\Omega$ ]	$R_B$ [k $\Omega$ ]	$C_B$ [pF]	$C_D$ [pF]
1.0	0.5	10.0	1.0	50.0

$f_{RF}$ [MHz]	$f_{LO}$ [MHz]	$V_{amp}$ [dBm]
90.0~99.0	100.0	-30

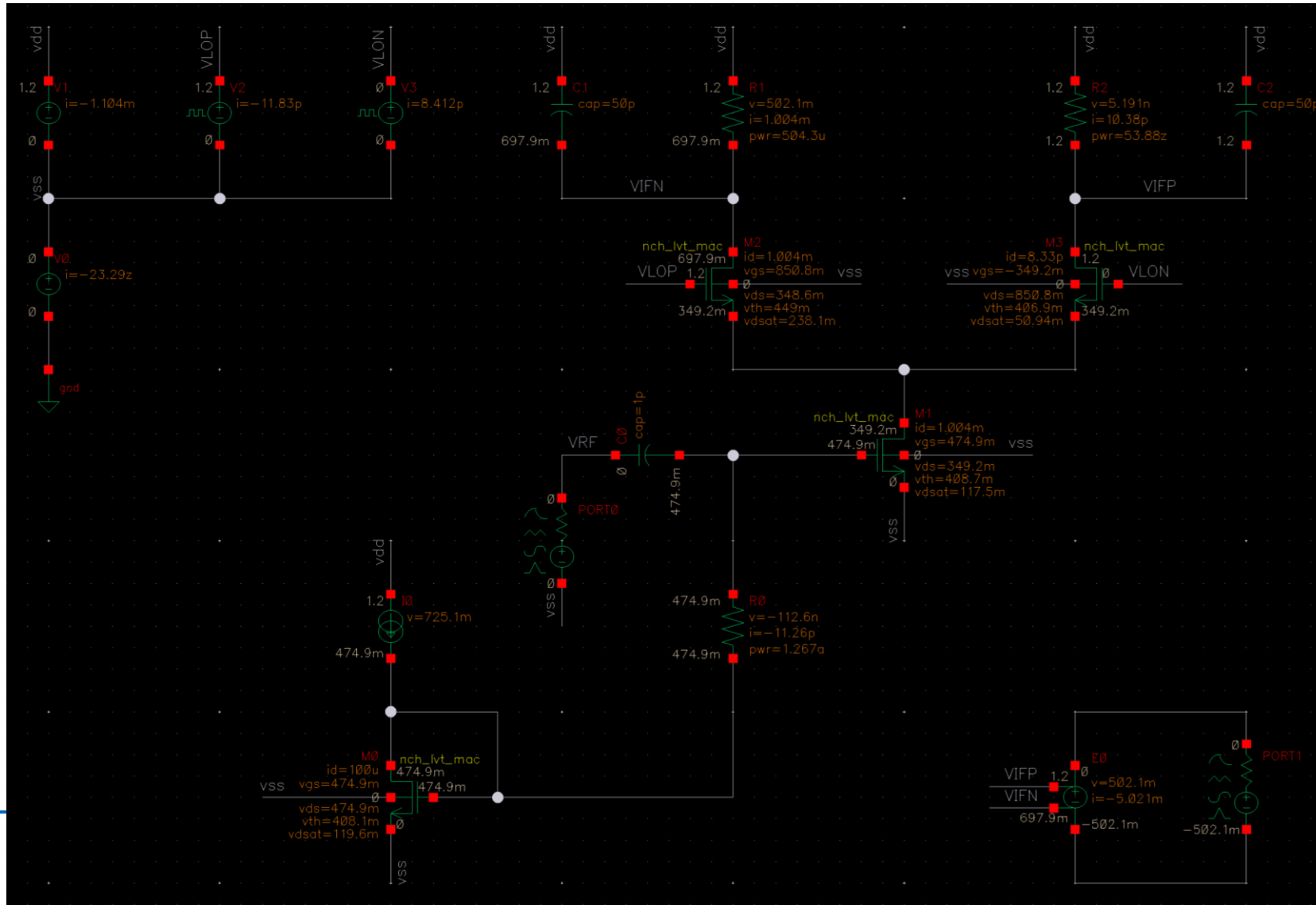
## Procedure for PSS only simulations:

- Input port ( $\text{PORT}_i$ ) – Simulate circuit for different port resistances (50 and 1000  $\Omega$ )
  - Define port as a sine signal with a given frequency and amplitude
- Output port ( $\text{PORT}_o$ ) with 100  $\Omega$
- **PSS simulation:**
  - Beat frequency =  $f_{\text{LO}} - f_{\text{RF}}$
  - Number of harmonics = 100



# Single balanced mixer – Flat schematic example

- Check PFR to make sure design is correct



# Simulation window/result plotting for PSS only simulation

Choosing Analyses -- ADE Explorer

Analysis

☐ tran ☐ dc ☐ ac ☐ noise  
☐ xf ☐ sens ☐ dcmatch ☐ acmatch  
☐ stb ☐ pz ☐ lf ☐ sp  
☐ envlp ☒ pss ☐ pac ☐ pstb  
☐ pnoise ☐ pxf ☐ psp ☐ qpss  
☐ qpac ☐ qpnoise ☐ qpxf ☐ qpss  
☐ hb ☐ hbac ☐ hbstb ☐ hbnoise  
☐ hbzp ☐ hbzf

Periodic Steady State Analysis

Engine ☒ Shooting ☐ Harmonic Balance

Fundamental Tones

#	Name	Expr	Value	Signal	SrcId
2		$1/(1/f_{lo}-0)$	100M	Large	V3
3		frf	90M	Large	PORT0
1		$1/(1/f_{lo}-0)$	100M	Large	V2

Clear/Add Delete Update From Hierarchy

☒ Beat Frequency ☐ Beat Period

10M Auto Calculate ☒

Output harmonics

Number of harmonics 100

Accuracy Defaults (errpreset)

☒ conservative ☐ moderate ☐ liberal

Transient-Aided Options

Run transient? ☒ Yes ☐ No ☐ Decide automatically

Detect Steady State ☐ Stop Time (tstab)

Run Envelope tstab ☐ yes ☒ no

Detect Envlp Steady State ☐ Stop Time (tstabenvlpstop)

Save Initial Transient Results (saveinit) ☐ no ☐ yes

Dynamic Parameter ☐

Oscillator ☐

☐ Sweep

New Initial Value For Each Point (restart) ☐ no ☐ yes

Loadpull ☐

Enabled ☒

Options...

OK Cancel Defaults Apply Help

Direct Plot Form

Plotting Mode Append

Analysis

☐ dc ☒ 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 Net

Sweep

☒ spectrum ☐ time

Signal Level ☒ peak ☐ rms

Modifier

☐ Magnitude ☐ Phase ☒ dB20  
☐ Real ☐ Imaginary

Scalar Expression

Value At (harms)

Power Spectral Density Parameters

Time Interval

From To Get From Data

Nyquist half-bandwidth

Frequency bin width

Max. plotting frequency

Min. plotting frequency 0

Windowing Hanning

Detrending None

Add To Outputs ☐

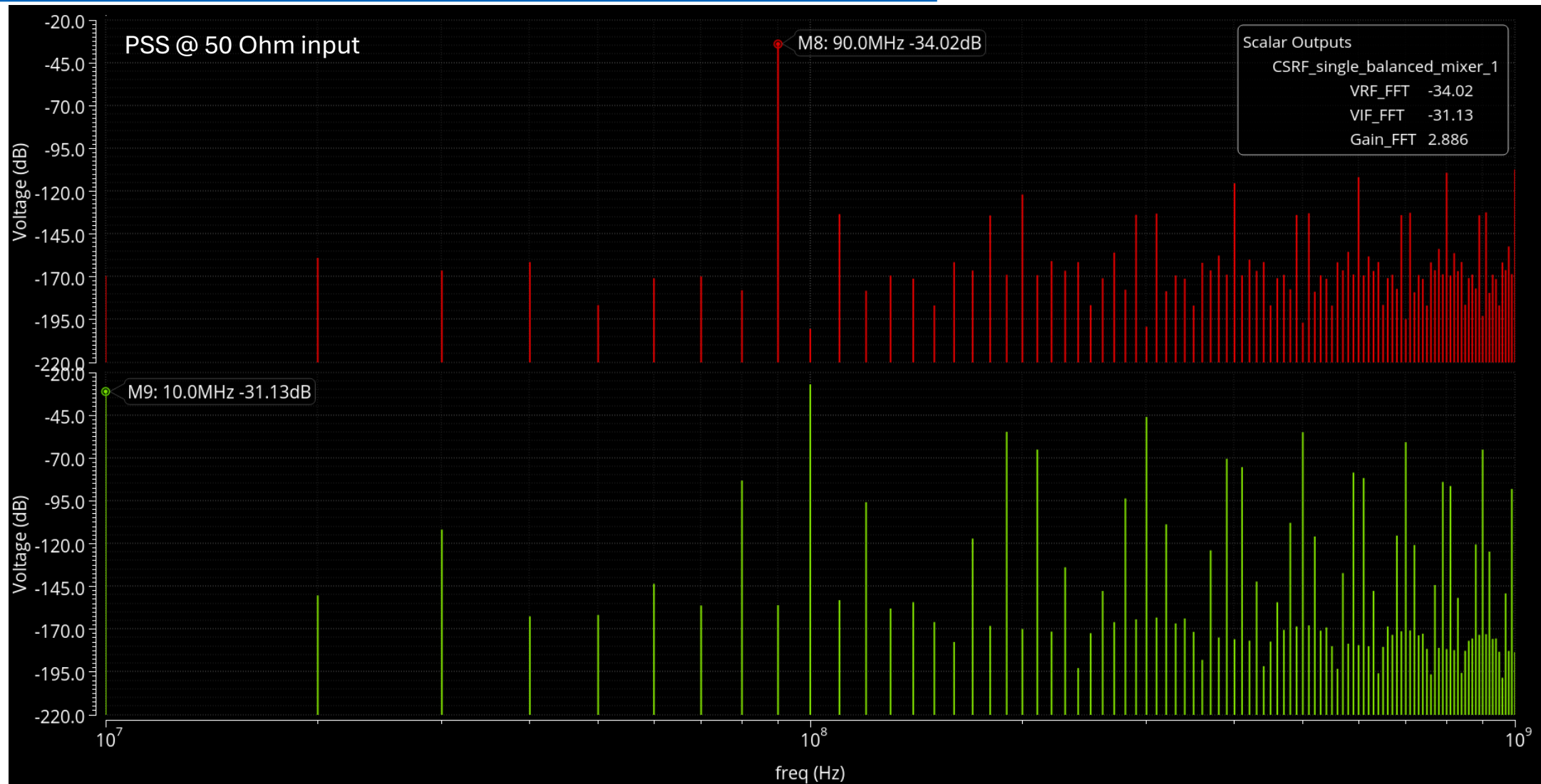
> Select Net on schematic...

Close Help

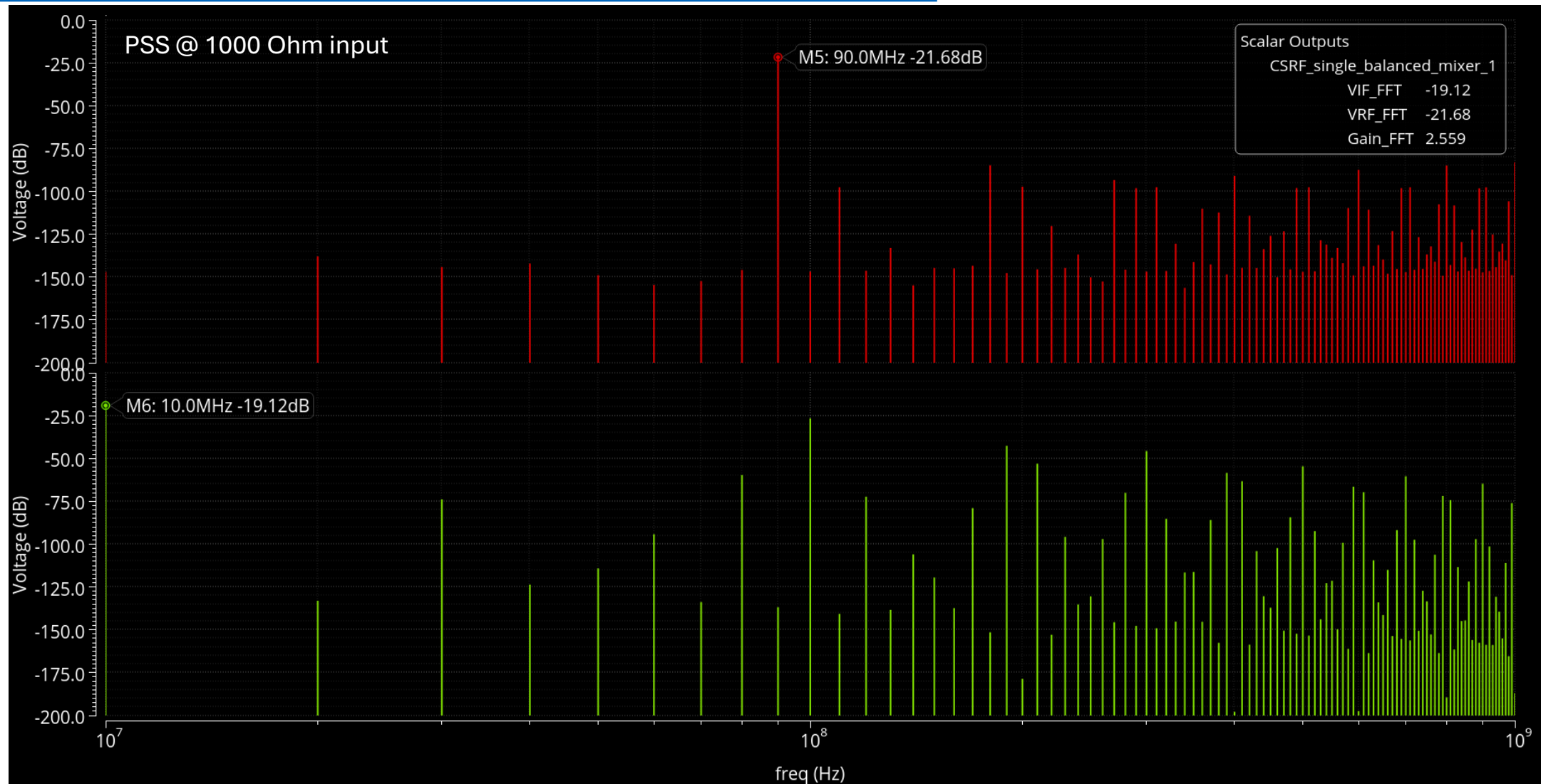
## PSS simulation configurations

## Direct plot configurations

# Single balanced mixer – Simulation results (PSS)

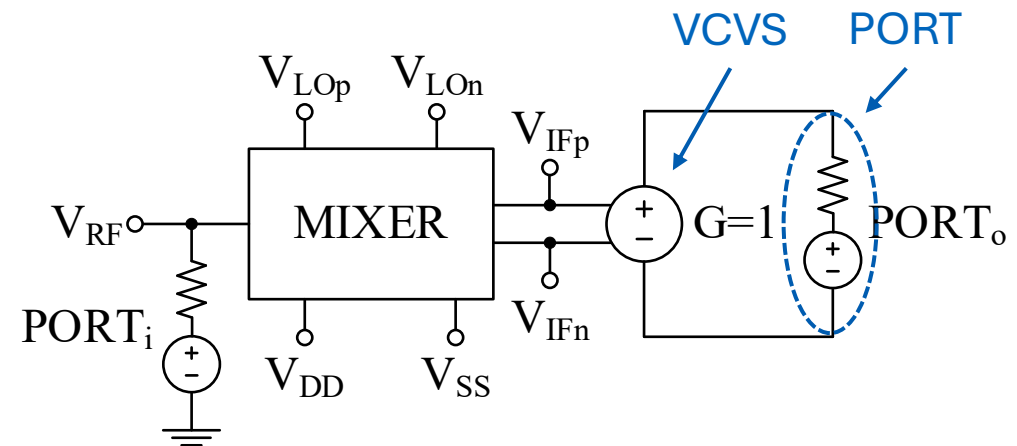


# Single balanced mixer – Simulation results (PSS)



## Procedure for PSS+(PAC/PNOISE) simulations:

- Input port ( $PORT_i$ ) – Simulate circuit for different port resistances (50 and 1000  $\Omega$ ) and PAC magnitude = 1
  - For frequency simulations input port must be configured to a DC source
- Output port ( $PORT_o$ ) with 100  $\Omega$
- **PSS simulation:**
  - Beat frequency =  $f_{LO}$
  - Number of harmonics = 100
- **PAC simulation for conversion gain simulation:**
  - Start Frequency =  $f_{LO}$
  - Stop Frequency =  $2 \times f_{LO}$
  - Maximum sidebands = 1
  - Use a high number of points ( $>1000$ )
  - To plot, select “Voltage Gain”, and the “sideband” sweep option with output sideband = -1 and input = 0



**Important note:** The voltage gain option is necessary because, even with PAC magnitude = 1, the input magnitude is dependent on the circuit's input impedance



# Simulation window/result plotting for PSS+PAC simulation

Choosing Analyses -- ADE Explorer

Analysis

☐ tran ☐ dc ☐ ac ☐ noise  
☐ xf ☐ sens ☐ dcmatch ☐ acmatch  
☐ stb ☐ pz ☐ lf ☐ sp  
☐ envlp ☒ pss ☐ pac ☐ pstb  
☐ pnoise ☐ pxf ☐ psp ☐ qpss  
☐ qpac ☐ qpnoise ☐ qpxf ☐ qpssp  
☐ hb ☐ hbac ☐ hbstb ☐ hbnoise  
☐ hbasp ☐ hbxf

Periodic Steady State Analysis

Engine ☒ Shooting ☐ Harmonic Balance

#	Name	Expr	Value	Signal	SrcId
2		$1/(1/f_{10}-0)$	100M	Large	V2
3		$1/(1/f_{10}-0)$	100M	Large	V3

Clear/Add Delete Update From Hierarchy

☒ Beat Frequency ☐ Beat Period 100M Auto Calculate ☒

Output harmonics  
Number of harmonics 100

Accuracy Defaults (errpreset)  
☒ conservative ☐ moderate ☐ liberal

Transient-Aided Options

Run transient? ☒ Yes ☐ No ☐ Decide automatically

Detect Steady State ☐ Stop Time (tstab)

Run Envelope tstab ☐ yes ☒ no

Detect Envlp Steady State ☐ Stop Time (tstabenvlpstop)

Save Initial Transient Results (saveinit) ☐ no ☐ yes

Dynamic Parameter ☐

Oscillator ☐

☐ Sweep

New Initial Value For Each Point (restart) ☐ no ☐ yes

Loadpull ☐

Enabled ☒ Options...

OK Cancel Defaults Apply Help

Choosing Analyses -- ADE Explorer

Analysis

☐ tran ☐ dc ☐ ac ☐ noise  
☐ xf ☐ sens ☐ dcmatch ☐ acmatch  
☐ stb ☐ pz ☐ lf ☐ sp  
☐ envlp ☐ pss ☒ pac ☐ pstb  
☐ pnoise ☐ pxf ☐ psp ☐ qpss  
☐ qpac ☐ qpnoise ☐ qpxf ☐ qpssp  
☐ hb ☐ hbac ☐ hbstb ☐ hbnoise  
☐ hbasp ☐ hbxf

Periodic AC Analysis

PSS Beat Frequency (Hz) 100M

Sweep type default Sweep is currently absolute

Input Frequency Sweep Range (Hz)

Start-Stop Start VAR("f10") Stop \*VAR("f10")

Sweep Type ☒ Points Per Decade 10000  
☐ Number of Steps

Add Specific Points ☐

Add Points By File ☐

Sidebands  
Maximum sideband 1

When using shooting engine, default value is 7.

Specialized Analyses  
None

Enabled ☒ Options...

OK Cancel Defaults Apply Help

Direct Plot Form

Plotting Mode Append

Analysis  
☐ dc ☐ pss ☒ pac

Function  
☐ Voltage ☒ Voltage Gain  
☐ Current ☐ IPN Curves

Select +- Output and +- Input Nets

Sweep  
☐ spectrum ☒ sideband

Modifier  
☐ Magnitude ☐ Phase ☒ dB20  
☐ Real ☐ Imaginary

Output Sideband			Input Sideband		
-1	0	100M	-1	0	100M
0	100M	200M	0	100M	200M
1	200M	300M	1	200M	300M

Add To Outputs Replot

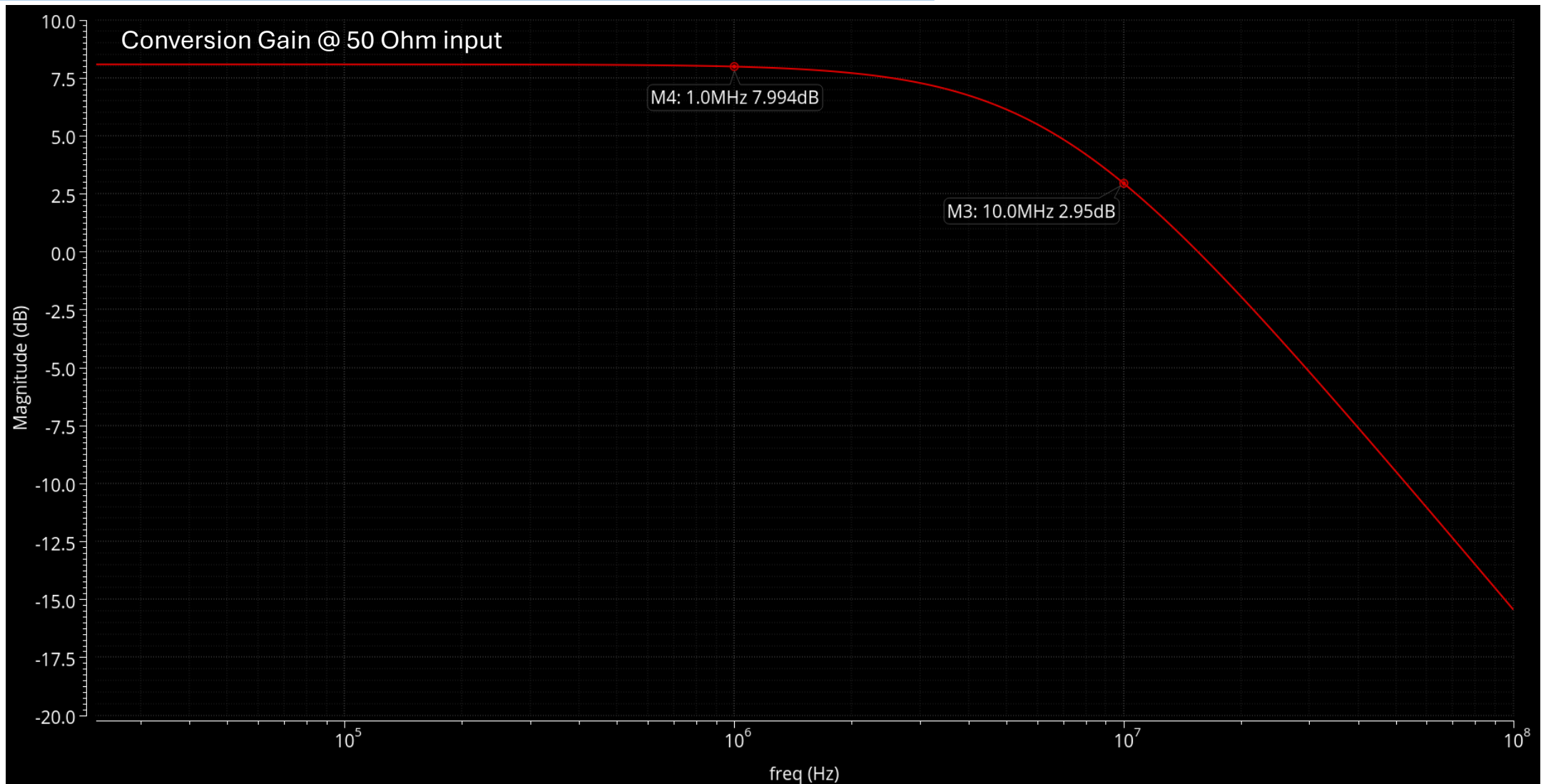
freqaxis = absout  
> Select Numerator Positive Output Net on schematic...

Close Help

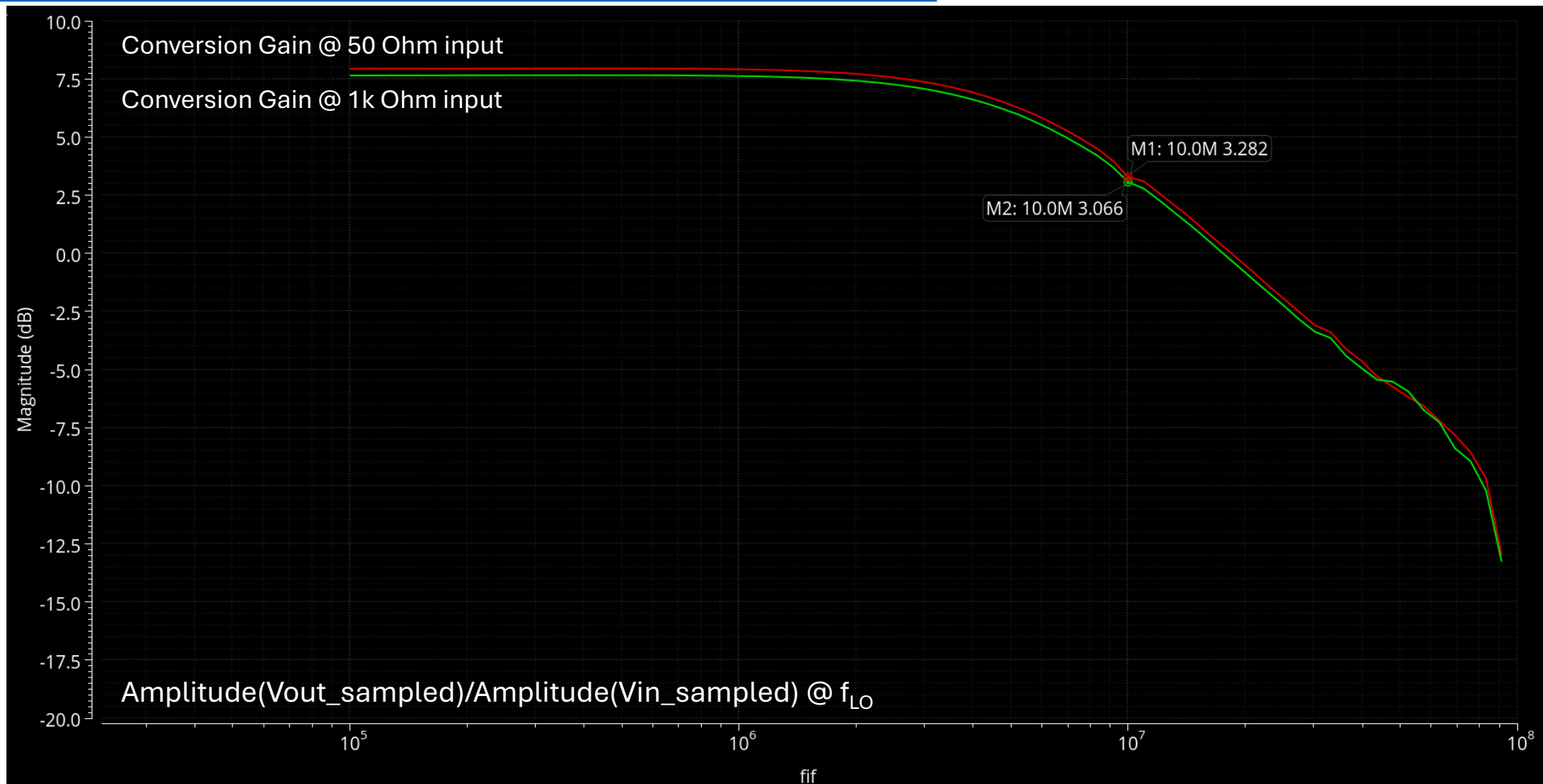
## PSS+PAC simulation configurations

## Direct plot configurations

# Single balanced mixer – Simulation results (PSS+PAC)

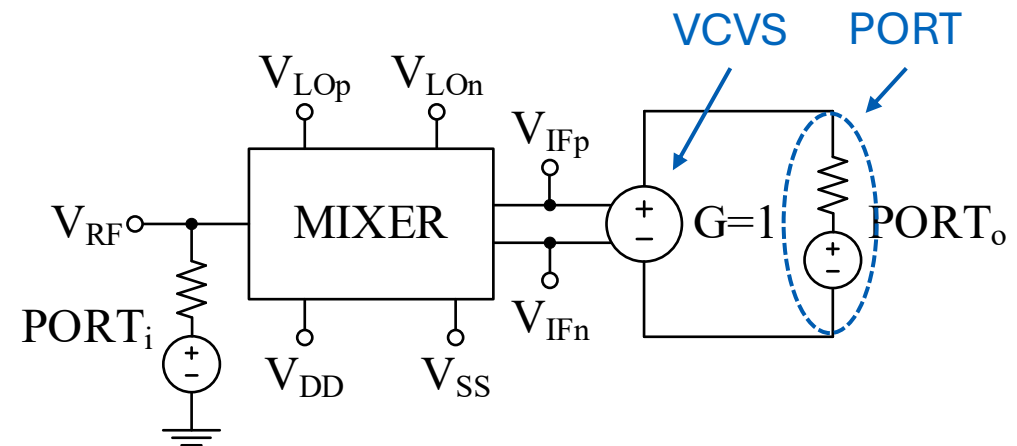


# Single balanced mixer – Simulation results (obtained from a transient simulation)



## Procedure for PSS+(PAC/PNOISE) simulations:

- Input port ( $PORT_i$ ) – Simulate circuit for different port resistances (50 and 1000  $\Omega$ ) and PAC magnitude = 1
  - For frequency simulations input port must be configured to a DC source
- Output port ( $PORT_o$ ) with 100  $\Omega$
- **PSS simulation:**
  - Beat frequency =  $f_{LO}$
  - Number of harmonics = 100
- **PNOISE simulation for noise figure simulation:**
  - Start Frequency = 1
  - Stop Frequency =  $f_{LO}$
  - Maximum sidebands = 10
  - Reference sideband = -1
  - Select output and input ports



**Choosing Analyses -- ADE Explorer**

Analysis

- ☐ tran ☐ dc ☐ ac ☐ noise
- ☐ xf ☐ sens ☐ dcmatch ☐ acmatch
- ☐ stb ☐ pz ☐ lf ☐ sp
- ☐ envlp ☐ pss ☐ pac ☐ pstb
- ☒ pnoise ☐ pxf ☐ psp ☐ qpss
- ☐ qpac ☐ qpnoise ☐ qpxf ☐ qpss
- ☐ hb ☐ hbac ☐ hbstb ☐ hbnoise
- ☐ hbasp ☐ hbxf

Periodic Noise Analysis

PSS Beat Frequency (Hz)

Multiple pnoise ☐

Sweeptype ☐ default ☒ Sweep is currently absolute

Output Frequency Sweep Range (Hz)

Start-Stop ☐ Start  Stop

Sweep Type

☒ Logarithmic ☐ Points Per Decade

☐ Number of Steps

Add Specific Points ☐

Add Points By File ☐

**Sidebands**

Method ☒ default ☐ fullspectrum

Maximum sideband

When using shooting engine, default value is 7.

Noise Figure ☒

Output

☐ probe ☐ Output Probe Instance

Input Source

☐ port ☐ Input Port Source

Reference Side-Band  $|f(in)| = |f(out) + refsideband * fund|$

Enter in field

Noise Type ☒ timeaverage

Timeaverage: single-sided spectrum and harmonic-referred (modulated) noise analysis

Contribution Type:

☒ USB ☐ AM ☐ PM ☐ AM&PM ☐ ALL(AM,PM,USB,LSB)

Noise Separation ☐

Separate noise into source and gain

**Direct Plot Form**

Plotting Mode ☒ Append

**Analysis**

☐ dc ☐ pss ☐ pac ☒ pnoise

**Function**

☐ Output Noise ☐ Input Noise

☒ Noise Figure ☐ Noise Factor

☐ NFdsb ☐ Fdsb

☐ NFieee ☐ Fieee

☐ Transfer Function

Integrated Over Bandwidth ☐

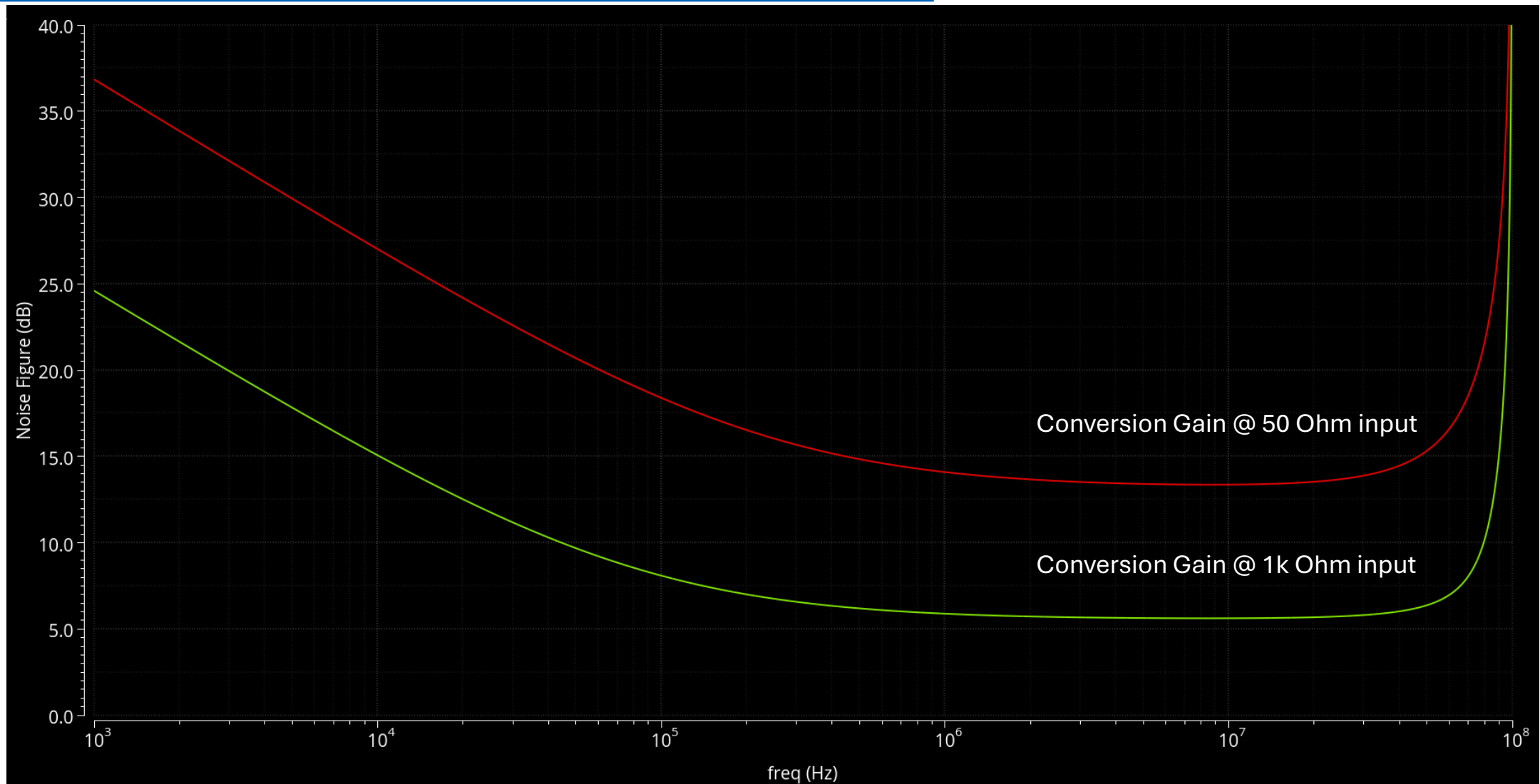
Loadpull Contours ☐

> Press plot button on this form...

## PNOISE simulation configuration (see slide 9 for PSS simulation configuration)

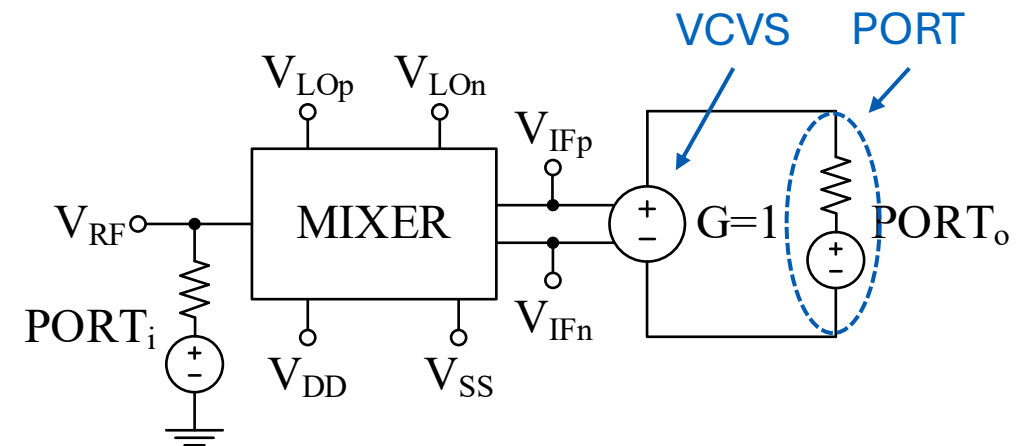
## Direct plot configurations

# Single balanced mixer – Simulation results (PSS+PNOISE)



## Procedure for 1dB compression point simulation using PSS:

- Input port ( $PORT_i$ ) – Simulate circuit for different port resistances (50 and 1000  $\Omega$ )
  - Define port as a sine signal with a given frequency and amplitude
- Output port ( $PORT_o$ ) with 100  $\Omega$
- **PSS simulation:**
  - Beat frequency =  $f_{LO} - f_{RF}$
  - Number of harmonics = 100
  - Activate the sweep box
  - Define design variable that controls input amplitude
  - Define sweep range from -60 to 0 and define step
  - To plot select “Compression Point”, an “Input Power Extrapolation Point” inside the linear region and the  $f_{IF}$  frequency in the “1st Order Harmonic” table



# Simulation window/result plotting for PSS only simulation

The image displays three screenshots of simulation software windows, likely from a circuit simulation tool like Cadence ADE.

**Choosing Analyses -- ADE Explorer**

This window shows the selection of analyses for simulation. The 'Analysis' section includes radio buttons for various simulation types: tran, dc, ac, noise, xf, sens, dcmatch, acmatch, stb, pz, lf, sp, envlp, pss, pac, pstb, pnoise, pxf, psp, qpss, qpac, qpnoise, qpxf, qpss, hb, hbac, hbstb, hbnoise, hbsp, and hbxf. The 'Periodic Steady State Analysis' section has radio buttons for 'Shooting' (selected) and 'Harmonic Balance'. The 'Fundamental Tones' table is shown below:

#	Name	Expr	Value	Signal	SrcId
2		1/(1/f1o-0	100M	Large	V2
1	frf	90M	Large	PORT0	
3		1/(1/f1o-0	100M	Large	V3

Buttons for 'Clear/Add', 'Delete', and 'Update From Hierarchy' are present. The 'Beat Frequency' section has radio buttons for 'Beat Frequency' (selected) and 'Beat Period', with a '10M' value and 'Auto Calculate' checked. The 'Output harmonics' section has a 'Number of harmonics' dropdown set to 100.

**Accuracy Defaults (errpreset)**

This window shows the accuracy defaults and transient-aided options. The 'Accuracy Defaults (errpreset)' section has radio buttons for 'conservative' (selected), 'moderate', and 'liberal'. The 'Transient-Aided Options' section has radio buttons for 'Run transient?' (Yes, selected), 'No', and 'Decide automatically'. The 'Detect Steady State' section has a checkbox and a 'Stop Time (tstab)' field. The 'Run Envelope tstab' section has radio buttons for 'yes' and 'no' (selected). The 'Detect Envlp Steady State' section has a checkbox and a 'Stop Time (tstabenvlstop)' field. The 'Save Initial Transient Results (saveinit)' section has radio buttons for 'no' and 'yes'.

**Dynamic Parameter**

The 'Dynamic Parameter' section has a checkbox.

**Oscillator**

The 'Oscillator' section has a checkbox.

**Sweep**

The 'Sweep' section has a 'Sweep' checkbox (checked) and a 'Frequency Variable?' section with radio buttons for 'no' (selected) and 'yes'. The 'Variable' dropdown is set to 'vdbm'. The 'Sweep Range' section has radio buttons for 'Start-Stop' (selected) and 'Center-Span', with 'Start' set to -60 and 'Stop' set to 0. The 'Sweep Type' section has radio buttons for 'Linear' (selected) and 'Logarithmic', and a 'Step Size' field set to 1. The 'Add Specific Points' section has a checkbox. The 'New Initial Value For Each Point (restart)' section has radio buttons for 'no' and 'yes'. The 'Exchange Order With' section has a dropdown menu.

**Loadpull**

The 'Loadpull' section has a checkbox.

**Enabled**

The 'Enabled' section has a checkbox (checked).

**Direct Plot Form**

This window shows the configuration for the direct plot. The 'Plotting Mode' section has a dropdown menu set to 'Append'. The 'Analysis' section has radio buttons for 'dc' and 'pss' (selected). The 'Function' section has radio buttons for 'Voltage', 'Current', 'Power', 'Voltage Gain', 'Current Gain', 'Power Gain', 'Transconductance', 'Transimpedance', 'Compression Point' (selected), 'IPN Curves', 'Power Contours', 'Reflection Contours', 'Harmonic Frequency', 'Power Added Eff.', 'Power Gain Vs Pout', 'Comp. Vs Pout', 'Node Complex Imp.', and 'THD'. The 'Select' dropdown is set to 'Port ( fixed R(port) )'. The 'Format' dropdown is set to 'Output Power'. The 'Gain Compression (dB)' field is set to 1. The 'Input Power Extrapolation Point (dBm)' field is set to -60. The 'Input Referred 1dB Compression' dropdown is set to 'vdbm'. The '1st Order Harmonic' table is shown below:

0	0
1	10M
2	20M
3	30M
4	40M
5	50M

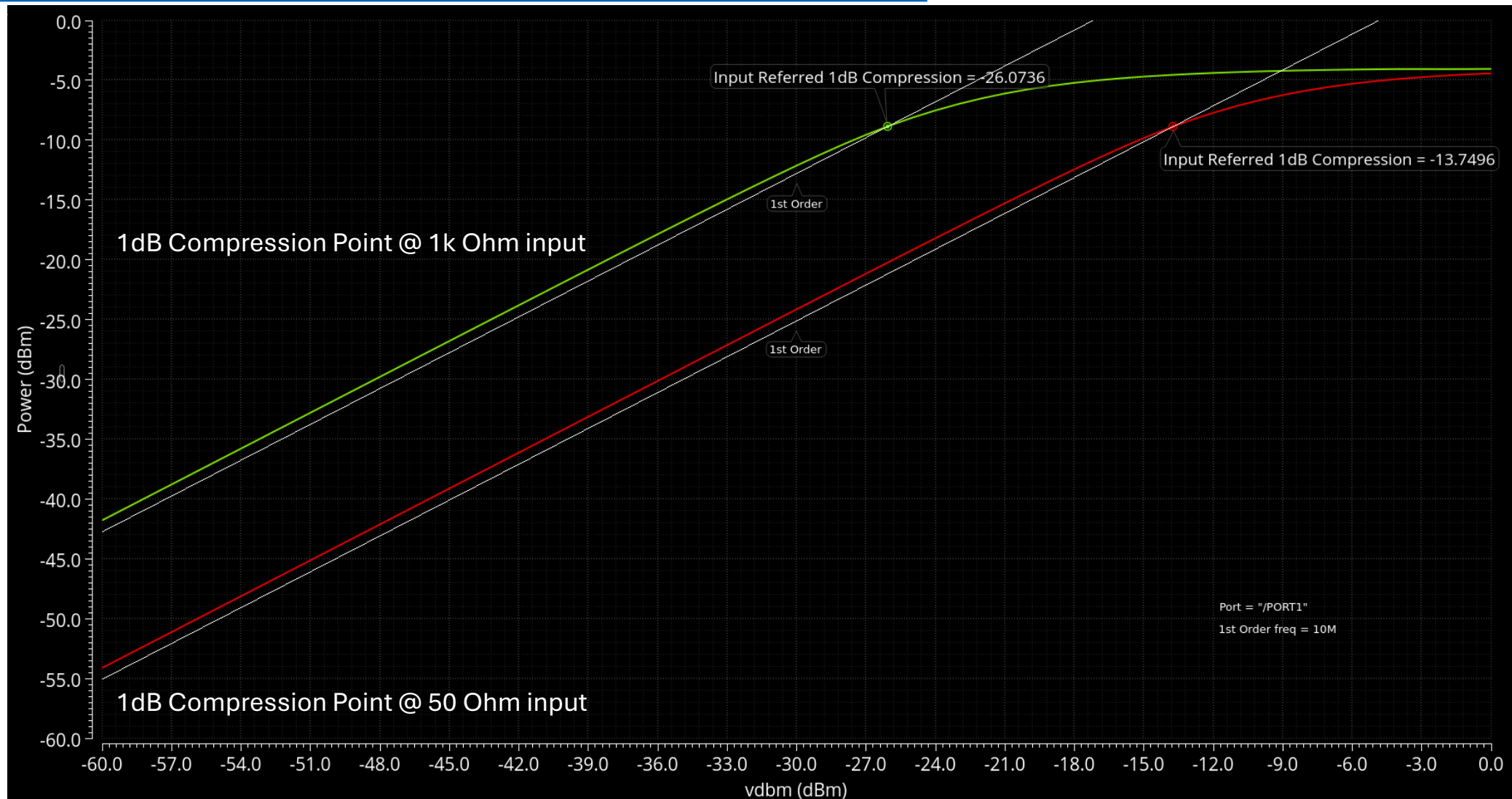
Buttons for 'Add To Outputs' and 'Replot' are present. The 'Loadpull Contours' section has a checkbox. The 'Select Port on schematic...' section has a dropdown menu. The 'Close' and 'Help' buttons are at the bottom.

**PSS simulation configuration for 1dB CP**

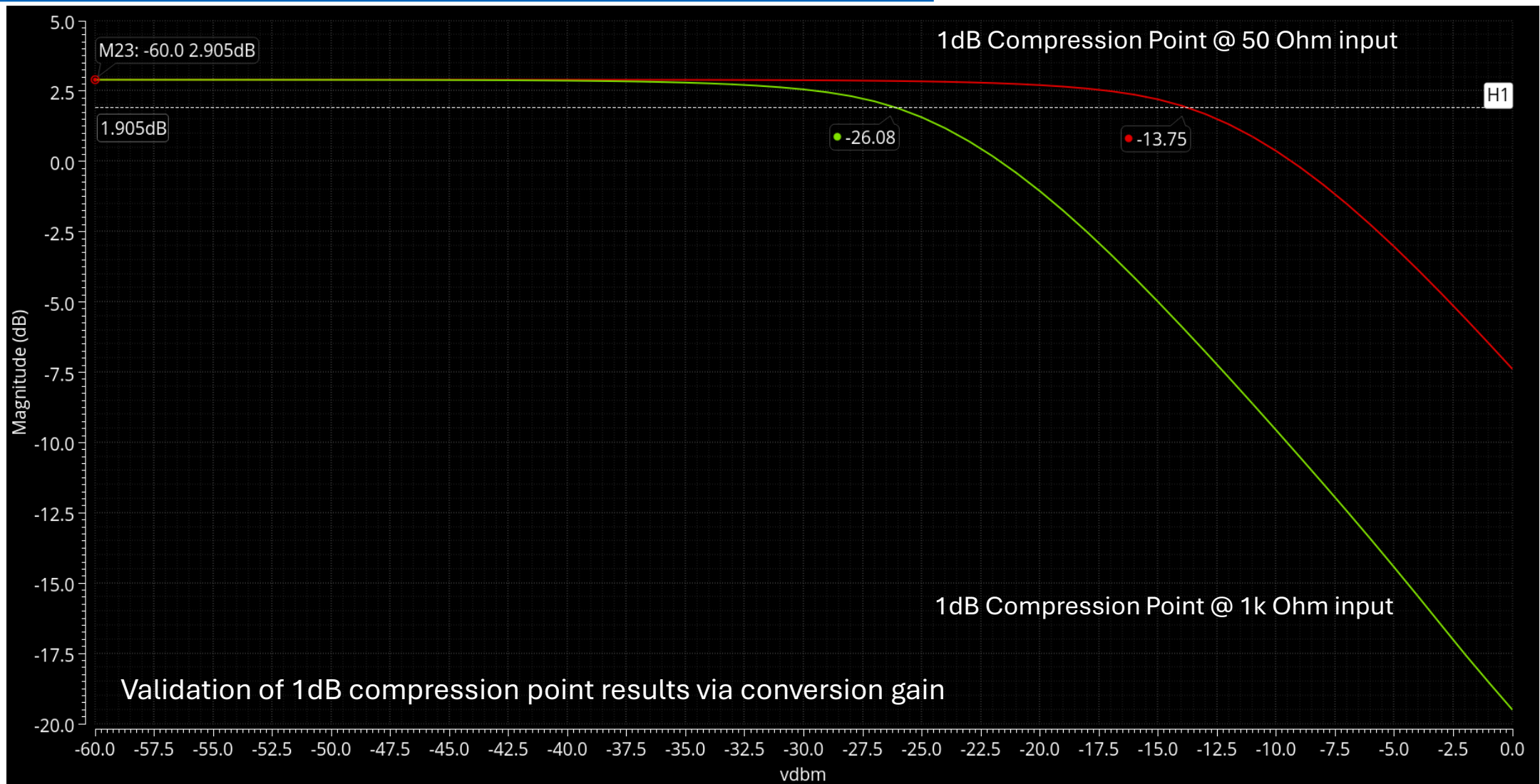
**Direct plot configurations**



# Single balanced mixer – Simulation results (PSS)

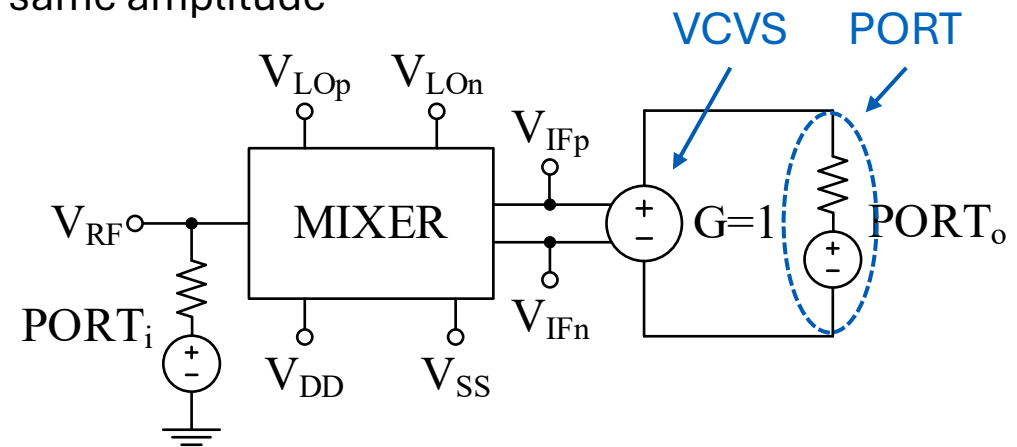


# Single balanced mixer – Simulation results (PSS)



## Procedure for IIP3 simulation using PSS:

- Input port ( $PORT_i$ ) – Simulate circuit for different port resistances (50 and 1000  $\Omega$ )
  - Define port as a sine signal with two tones ( $f_{RF}$  and  $f_{RF2}$ ) and same amplitude
- Output port ( $PORT_o$ ) with 100  $\Omega$
- **PSS simulation:**
  - Beat frequency =  $f_{RF2} - f_{RF}$
  - Number of harmonics = 100
  - Activate the sweep box and
  - Define design variable that controls input amplitude
  - Define sweep range from -60 to 0 and define step
  - To plot select “IPN Curves”, choose “Variable Sweep” in “Circuit Input Power” and an “Input Power Extrapolation Point” inside the linear region. In the “1st Order Harmonic”, choose  $f_{IF}$  (considering there is no second tone). In the “3rd Order Harmonic”, choose  $f_{IFx}$  or  $f_{IFy}$  (see below), whichever is closer to  $f_{IF}$
- **Frequency examples:**
  - $f_{RF} = 90$  MHz and  $f_{RF2} = 91$  MHz
  - Calculate  $f_x = 2 \times f_{RF} - f_{RF2} = 89$  MHz and  $f_y = 2 \times f_{RF2} - f_{RF} = 92$  MHz
  - Perform down-conversion:  $f_{IFx} = f_x - f_{LO} = 11$  MHz and  $f_{IFy} = f_y - f_{LO} = 8$  MHz



# Simulation window/result plotting for PSS only simulation

The image displays three screenshots of simulation software windows:

- Choosing Analyses -- ADE Explorer:** This window shows various analysis options. Under 'Periodic Steady State Analysis', 'Shooting' is selected. The 'Fundamental Tones' table is as follows:

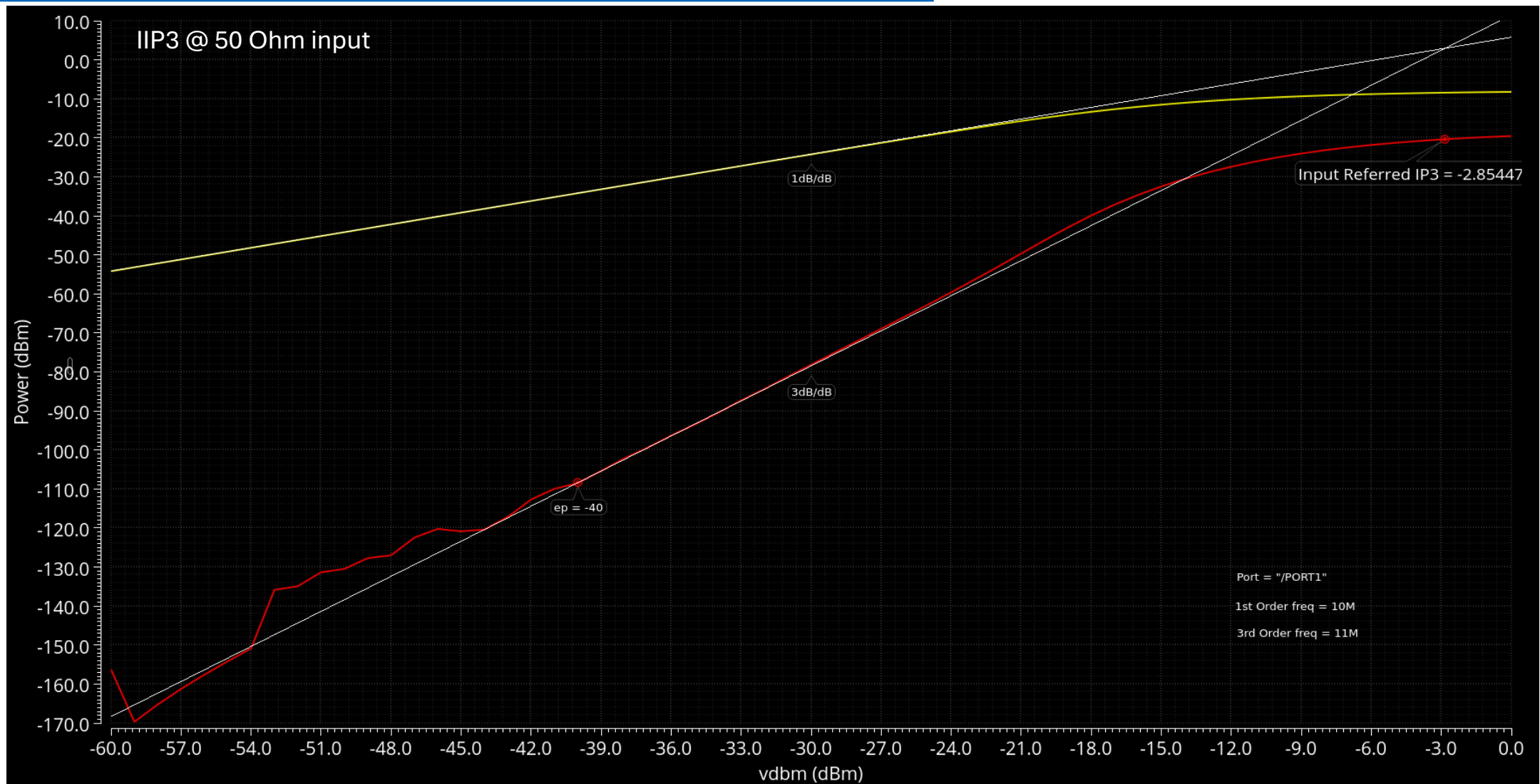
#	Name	Expr	Value	Signal	SrcId
3	f1o_n	1/(1/f1o-0	100M	Large	V3
2	f1o_p	1/(1/f1o-0	100M	Large	V2
1	frf_1	frf	90M	Large	PORT0
4	frf_2	frf2	91M	Large	PORT0

Buttons include 'Clear/Add', 'Delete', 'Update From Hierarchy', 'Beat Frequency', 'Beat Period', and 'Output harmonics' (Number of harmonics: 100).
- Accuracy Defaults (errpreset):** This window shows 'conservative' accuracy and 'Run transient?' set to 'Yes'. It also includes options for 'Detect Steady State', 'Run Envelope tstab', 'Detect Envlp Steady State', and 'Save Initial Transient Results (saveinit)'.
- Direct Plot Form:** This window shows 'Plotting Mode' set to 'Append' and 'Analysis' set to 'pss'. Under 'Function', 'IPN Curves' is selected. It also shows 'Input Referred IP3' and 'Order' set to '3rd'.

## PSS simulation configuration for IIP3

## Direct plot configurations

# Single balanced mixer – Simulation results (PSS)



# Single balanced mixer – Simulation results (PSS)

