# Integrated Radio Electronics

# Laboratory 3: Down-conversion Mixer

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# 1-Introduction

This lab introduces the simulation methods and software capabilities of Cadence SpectreRF commonly used for designing and verifying RF mixers. It is assumed that the students have already learned how to set up a simulation in Cadence, run it, and report the results, therefore it is strongly suggested that they do the first lab prior to this one.

Mixers are used in RF transceivers to shift the frequency content of signals. They are essentially multipliers and frequency translation is realized based on the fact that multiplication in the time domain equals convolution in the frequency domain. In receivers, RF signal is mixed with LO to get down-converted to an intermediate or zero frequency, depending on the architecture. In transmitters, mixer up-converts an IF signal to RF signal. There are two general categories of mixers: active and passive. Active mixers are biased and supplied with DC power. In this lab, a Gilbert down-conversion mixer is implemented and simulated.

Basically, we can characterize a mixer by measuring the following metrics:

- 1- Power consumption
- 2- Conversion gain
- 3- Compression point and IIP3
- 4- Noise figure
- 5- Port-to-port isolation

To evaluate the mixer performance, in this lab the following simulation are introduced:

- 1- PSS+PAC+PXF simulation for conversion gain and isolation
- 2- Transient simulation for investigating the effect of LO transitions on conversion gain
- 3- PSS+Pnoise simulation for noise evaluation
- 4- QPSS+QPAC simulation for compression point and IIP3

#### 2- Schematic View

First a schematic view must be created:

- Create a schematic cellview in the RFIC\_Labs library, call it 'Mixer'.
- Draw the schematic according to Fig. 1. Use minimum length *nlvtlp* tranistors. Set the widths to variables called 'W\_LO' and 'W\_RF'.

- Place DC voltage and current sources to bias the circuit. (ISS =1 mA, VDD = 1.2V)
- To feed in RF and LO signals we use ports terminated to 50 Ω. Then, they are split into out-ofphase components as illustrated in Fig. 2.









## **3- Setting Analog Environment Options**

To reach satisfactorily reliable and precise results the default parameters of ADE should be changed. In this way the residual errors used by the equation solver to converge to the final result become smaller.

Of course, nothing good comes free, we pay it back by larger memory usage and longer simulation time. Therefore, the values shown in Fig. 3 are chosen for a moderate but satisfactory precision.

• Under Simulation>Options>Analog (Fig. 3), set the values in TOLERANCE OPTIONS according to Fig. 4.



Fig. 3

Simulator Options ×						
Main	Algorithm	Component	Check	Annotation	Miscellaneous	
TOL	ERANCE OPTI	ONS	k			
reltol		1e-5				
residu	ualtol					
vabst	DI	3e-8				
iabsto	il	1e-13				
TEMPERATURE OPTI		PTIONS				
temp		27				
tnom		27				
tempeffects		🗌 vt 🔲 to	📃 all			I
MULTITHREADING OPTIONS						
					ancel <u>D</u> efaults <u>Apply</u> <u>H</u> elp	$\sum_{i=1}^{n}$

Fig. 4

#### 4- Port Setup

Since in this lab a multiport circuit is simulated by different tools, it is important to carefully set the parameters of all ports.

Configure the RF, LO, and IF ports as shown in Fig. 5 to 7 respectively. •



off Period of waveform 1/flo s -Zero value -VP\_LO V off One value off -VP\_LO V -Display small signal params off Display temperature params off \* . off Port resistance • Rport temperature coeff. 1 off Rport temperature coeff. 2 off \* -Zport file name off Port number off --Port capacitor off • Port inductor off Suppress noise off ---Mode off off • Noise temperatu • off Temperature Source -Other Eldo parameters off -Frequency name 1 off -Display noise parameter off • Resistance 50 Ohms off -Port number off 2 -Multiplier off Port mode Normal Q HarmonicPort off OK Cancel Apply Defaults Previous Next Help

Edit Object Properties (on subaida.fransg.eit.lth.se)

pulse 🔽

Tr s

Tr s

1/2/flo s

Value

TRUE

off 🔽

Display

off 🔽

off

off --

off

off

off -

off

off 🔽

-

-

lvsignore

CDF Parameter

DC voltage

Source type

Voltage 1

Voltage 2

Delay time

Rise time

Fall time

Pulse width

Fig. 5. RF port setup

Fig.6. LO port setup

Edit Object Pr	Peret Instance Labels Display	t.ith.se)
Property	Value	Display
Library Name	analogLib	off
Cell Name	port	off
Maar Nama	sumbal	off
View Name	Symbol	off
Instance Marne	PORTU	<u>en</u>
Change	Add Delete Modify	$\supset$
All User Property	Master Value Local Value	Display
lvslgnore	TRUE	off
CDF Parameter	Value	Display
DC voltage		off
Source type	dc	off
Display small signal params		off
Display temperature params		off
Port resistance		off
Rport temperature coeff. 1		off
Rport temperature coeff. 2		off
Zport file name		off
Port number		off
Port capacitor		off
Port inductor		off
Suppress noise		off
Mode		off
Noise temperature		off
Temperature Source		off
Other Eldo parameters		off
Display noise parameters		off
Resistance	50 Ohms	off
Port number	3	off
Multiplier		off 🔽
Port mode	🖲 Normal 🔾 HarmonicPort	off
Reactance		off
1		

Fig. 7. IF port setup

# 5- DC Simulation

DC simulation helps to make sure that all transistors are biased properly in the active region.

- Set up the Design Variables according to Fig. 8.
- Carry out DC simulation and report the overdrive voltage of the transistors. What is the voltage across the current source? What portion of mixer's headroom is dropped on RL? What trade-offs do you see in this mixer?

	Name	Value
1	Tr	10p
2	VP_LO	100m
3	frf	2.4G
4	prf	-50
5	RF_pacmag	1
6	flo	2.4G
7	RL	1K
8	Vg_LO	1
9	Vg_RF	700m
10	W_LO	40
11	W_RF	20

Fig. 8

#### 6- Transient Simulation

Next step is to monitor the signals before moving on to frequency domain simulations. It provides important insights into the switching mechanism.

- In ADE, select Outputs → To Be Saved → Select On Design and select the four drain <u>pins</u> of the LO transistors.
- Run transient simulation with "moderate" accuracy and "stop time" = 50/VAR("flo").
- Plot the drain currents of the LO transistors. Is the current completely steered to one side by the LO?
- Do a parametric sweep of VP\_LO from 50 mV to 500 mV in 10 steps and plot the currents again. What is the lowest LO amplitude that gives complete steering of the current?

#### 7- Conversion Gain

The conversion gain is defined as the ratio of the RMS value of the IF voltage to the RF input. In this section we trace the conversion gain variations versus RF and LO power. If the input and output of the mixer are matched to the same resistance, the voltage conversion gain equals the power conversion gain in dB.

To calculate the conversion gain, in this lab we use PSS+PAC simulation as follows.

#### 7-1-LO Power Sweep

- In the RF port, set the source type to DC.
- In ADE, choose PSS simulation and set its parameters according to Fig. 9.

Choosing Analyses ADE Explorer	×			
Periodic Steady State Analysis Engine O Shooting C Harmonic Balance				
Fundamental Tones           # Name         Expr         Value         Signal         SrcId           1         410         2         45         Lasse         20210				
Flo     Flo     2.46     Large     PORTO       flo     flo     2.46     Large     PORTO       Glear/Add     Delete     Update From Hierarchy       Beat Frequency     2.46     Auto Calculate       Beat Period     2.46     Auto Calculate				
Output harmonics Number of harmonics 10				
Conservative V moderate Iliberal Transient-Aided Options Run transient? Ves No Decide automatically Detect Steady State Stop Time (tstab)				
Save Initial Transient Results (saveinit)     no     yes       Dynamic Parameter				



• Check "sweep" option in PSS form and set it up as shown in Fig. 10.

Accuracy Defaults (errpreset) conservative				
Dynamic Parameter				
Oscillator				
Sweep 1 V Frequency Variable? • no ves Variable Variable Name V2_L0 Select Design Variable				
Sweep Range Start-Stop Start 50m Stop 500m Center-Span				
Sweep Type          ● Linear           ● Logarithmic           ● Number of Steps				
Add Specific Points				
New Initial Value For Each Point (restart) 🗌 no 🗌 yes				
Loadpull 🗌				
Enabled 🕑 Options				



• Choose PAC analysis and set its parameters as illustrated in Fig. 11.

	Choosing	J Analyse	s ADE	Explorer	×
	<ul> <li>stb</li> <li>envlp</li> <li>pnoise</li> <li>qpac</li> <li>hb</li> <li>hbsp</li> </ul>	<ul> <li>pz</li> <li>pss</li> <li>pxf</li> <li>qpnoise</li> <li>hbac</li> <li>hbxf</li> </ul>	<ul> <li>If</li> <li>pac</li> <li>psp</li> <li>qpxf</li> <li>hbstb</li> </ul>	<ul> <li>sp</li> <li>pstb</li> <li>qpss</li> <li>qpsp</li> <li>hbnoise</li> </ul>	
	F	Periodic AC A	nalysis		
PSS Beat Freq	uency (Hz)	2.4G			
Sweeptype Input Frequ Single-Poin	default Jency Sweep t	So Range (Hz) Freq 2.46	weep is curr	ently absolute	
Add Points B	y File				
Sidebands Maximum sideband 2 When using shooting engine, default value is 7.					
None			-		
Enabled ⊻	<u>o</u> k	Cance	l Defau	Options	-

Fig. 11

To plot the conversion gain, open Results/Direct Plot/Main form and select PAC and set the parameters as shown in Fig. 12. Then, click on the output net (positive terminal of the IF port).

Direct Plot Form ×				
Plotting Mode Append				
🔾 pss 🖲 pac				
Function				
Voltage      Voltage Gain     Current      IPN Curves				
Select Net				
Sweep				
Spectrum 🖲 variable				
Modifier				
Magnitude      Phase      dB20     Real      Imaginary				
Output Harmonic				
-2 2.4G				
0 2.46 1 4.86 2 7.26				
Loadpull Contours				
Add To Outputs				
freqaxis = absout				
> Select Net on schematic				
<u>C</u> lose <u>H</u> elp				

Fig. 12

Note that the Voltage in dB is equal to the voltage conversion gain because we set the input RF voltage to 1.

- Measure the LO voltage at which the conversion gain reaches its maximum. We call this value VP\_LO\_max from this point of the manual.
- Is the conversion gain in agreement with the theory? What do you expect to happen to it if we double the bias current and transistor's width and halve the load resistance? What happens if we keep the load resistance constant?

#### 7-2- RF Frequency Sweep

- Set VP\_LO to VP\_LO\_max and uncheck the sweep box in PSS setup form.
- Change PAC setup according to Fig. 13. This way the simulation tool sweeps RF frequency from 2.3 to 2.5 GHz.
- Plot the conversion gain from Results/Direct Plot/Main form/PAC/Voltage as illustrated in Fig. 14.

Analysis tran dc ac noise xf sens dcmatch acmatch stb pz If sp envip pss pac pstb pnoise pxf psp qpss qpac qpnoise qpxf qpsp bb bbac bbac bbstb bbnoise	
xf       sens       dcmatch       acmatch         stb       pz       lf       sp         envlp       pss       pac       pstb         pnoise       pxf       psp       qpsp         qpac       qpnoise       qpxf       qpsp         bb       bbstb       bbnoise       pxb	
stb       pz       If       sp         envlp       pss       pac       pstb         pnoise       pxf       psp       qpsp         qpac       qpnoise       qxf       qpsp         bb       bbsc       bbsc       bbsc	
<pre>     envlp ○ pss ● pac ○ pstb     ○ pnoise ○ pxf ○ psp ○ qpss     ○ qpac ○ qpnoise ○ qpxf ○ qpsp     ○ hb ○ hbac ○ hbstb ○ hbnoise     ○ host □ ∩ host □ ○ host □ ○ host □ ∩ host □ ○ host □ ∩ host</pre>	
pnoise     pxf     psp     qpss       qpac     qpnoise     qpxf     qpsp       hb     hbsth     hbnoise	
qpac	
hb hbar hbst hbnoise	
Voltage Veltage Caip	
hbsp hbxf	
Periodic AC Analysis	
PSS Beat Frequency (Hz) 2.46	
Select Net	
Sweeptype default Sweep is currently absolute	
Input Frequency Sweep Range (Hz)	
Start-Stop Start 2.3G Stop 2.5G	
Sweep Type 🔘 Magnitude 🔾 Phase 🖲 dB20	
Automatic 🔽 🔘 Real 🔾 Imaginary	
Output Sideband	
Add Specific Points	
Add Points By File1 0 - 100M	
0 2.3G - 2.5G	
Sidebands 2 7.1G - 7.3G	
Maximum sideband 🔽 2	
Add To Outputs Replot	
Specialized Analyses freqaxis = absout	
None > Select Net on schematic	
OK Cancel Defaults Apply Help	<u>H</u> elp

Fig. 13

Fig. 14

- Can you justify the result?
- Add 3 pF in parallel with each RL and repeat the simulation. Give the reason why the conversion gain behavior has changed.

#### 8- Gain Compression and Intermodulation Intercept Point

The non-linear elements of the mixer lead to conversion gain degradation for large input signals. Also, the intermodulation signals get more pronounced as the input power increases because the high order components of the polynomial expansion of the gain conversion grows much faster than the fundamental tone.

To evaluate the non-linearity effects, we should run QPSS and QPAC simulations instead of PSS and PAC. It can handle multi-tonal inputs.

- Change the RF port to Sine and move the PAC small signal parameter "RF\_pacmag" from "magnitude (Vpk)" to "magnitude (dBm)".
- Assign these values to the variables: flo = 2.4 GHz, frf = 2.401 GHz, prf = -10 dBm, RF\_pacmag = prf
- Choose QPSS simulation and enter the simulation parameters as shown in Fig. 15.
- Activate QPAC simulation and set it up like Fig. 16.





Fig.16

- Run the simulation. This simulation will take quite a bit of time.
- Plot 1dB compression point from Results/Direct Plot/Main Form/QPSS, select the options as shown in Fig. 17 and click on the output port.
- Plot IIP3 from Results/Direct Plot/Main Form/QPAC, select the options as shown in Fig. 18 and click on the output port.
- Can you explain what QPAC is doing and why its frequency is set to 2.4011 GHz?



#### 9- Port-to-Port Leakage

Capacitive couplings between RF, LO, and IF ports of a mixer make feedthrough between these three terminals possible.

LO-RF leakage causes a phenomenon called LO self-mixing which deteriorates the quality of signal capturing, particularly in direct conversion receivers. In the presence of a strong blocker, RF-LO leakage is likely to adversely affect LO and generate unwanted IF signal after getting mixed with the desired RF signal.

In this section, we will use both PAC and PXF (periodic transfer function) to simulate these feedthroughs. Both are small-signal simulations that use the results from a PSS simulation.

#### 9-1- Port and Simulation Setup

- Set RF port to DC and remove RF\_pacmag.
- In the LO port, set the "PAC Magnitude" to LO\_pacmag.

- In Design Variable box assign the following values to the variables.
  - frf = flo = 2.4 GHz, prf = -60 dBm, VP\_LO = VP\_LO\_max dBm, LO\_pacmag = 1
- Deactivate QPSS and QPAC.
- Enable PSS analysis and configure it as shown in Fig. 19.
- Enable PAC analysis and configure it as shown in Fig. 20.
- Activate PXF analysis and set its parameters according to Fig. 21. Select the IF port as your output probe. Note that this is the <u>output</u> frequency we specify, while in the PAC simulation we specify the <u>input</u> frequency.

Choosing Analyses ADE Explorer ×	Choosing Analyses ADE Explorer ×
Fundamental Tones	
# Name Expr Value Signal SrcId	
	C envip C pss C pac C pstb
1 flo flo 2.4G Large PORTO	O phoise O pxf O psp O qpss
2 TFT TFT 2.46 Large PORT	🔾 qpac 🔾 qpnoise 🔾 qpxf 🛛 qpsp
J	🔾 hb 🔍 hbac 🔾 hbstb 🔾 hbnoise
flo flo 2.4G Large PORTO	O hbsp O hbxf
Clear/Add Delete Undate From Hierarchy	Periodic AC Analysis
	PSS Beat Frequency (Hz) 2.4G
Beat Prequency     2.4G     Auto Calculate	
	Sweeptype default Sweep is currently absolute
	Input Frequency Sweep Range (Hz)
Output harmonics	Start-Stop Start 2.4G Stop 2.41G
Number of harmonics 10	
	Sweep Type
Accuracy Defaults (errorecet)	Automatic 🔽
	Add Specific Deinte
Transient-Aided Options	Add specific Points
Run transient? 💿 Yes 🔾 No 🔾 Decide automatically	Add Points By File
Detect Steady State	
	Sidebands
Save Initial Transient Results (saveinit) no yes	Maximum sideband 2
Dynamic Parameter	When using shooting engine, default value is 7.
	Enciplined Applying
Oscillator	specialized Analyses
	None
Sweep	
New Initial Value For Each Point (restart)	Enabled 🗹 Options
OK Cancel Defaults Apply Help	OK Cancel Defaults Apply Help
	Fi- 20
Fig. 19	Fig.20

	⊖ xf	🔾 sens	🔾 dcmatch	🔾 acmatch	<u>^</u>
	🔾 stb	🔾 pz	🔾 sp	🔾 envip	
	🔾 pss	🔾 pac	🔾 pstb	🔾 pnoise	
	🖲 pxf	🔾 psp	🔾 qpss	🔾 qpac	
	🔾 qpnoise	🔾 qpxf	🔾 qpsp	🔾 hb	
	🔾 hbac	🔾 hbnoise	🔾 hbsp		
	Pe	eriodic XF A	nalysis		
DCC Deet Eve		0.40	·		
Poo Beat Fre	quericy (Hz)	2.46			
Sweeptype	default	Sw	eep is curren	tly absolute	
Output Fre	quency Swe	en Range (H	7)		
Culput ric	quency owe	op nange (n	2)		
Start-Stop	<b></b> s	itart 0	Stop	20M	
Sweep Tvp	)e				
Automatic					
Hatomatic					
Add Specifi	c Points 📃				
Sidebands					
Maximum s	ideband 🔤	2			
When usin	g shooting er	ngine, defaul	t value is 7.		
Contract					
Output					
<ul> <li>voltage</li> </ul>	Output F	Probe Instanc	e /PORT2	Select	
• probe					
Snecializer	d Analycac				
None					
TADLE					
Enabled V				Ontions	U
	OK	Cancel	Defaults	Anniv Hein	
		E. 0	4		

Fig. 21

• Run the simulation and follow the steps below for plotting feedthrough characteristics.

#### 9-2- LO-to-IF Feedthrough

- From Results/Direct Plot/Main Form select PXF and configure the form as shown in Fig. 22.
- Click on the LO port.

#### 9-3- LO-to-RF Feedthrough

 Note that this analysis will not give you any usable results, since in a small-signal analysis the RF+ and RF- nets are effectively shorted to ground through the vcvs components. For this analysis to make sense you would need to know the output resistance of the previous stage (typically the LNA) and create a better model of it. Alternatively, you could simulate the whole chain, i.e. simulate the LNA and mixer simultaneously, for the highest accuracy.

- From Results/Direct Plot/Main Form select PSS and configure the form as shown in Fig. 23 (note "Differential Nets").
- Click on "RF+" and then "RF-".

# 9-4- RF-to-IF Feedthrough

- From Results/Direct Plot/Main Form select PXF and configure the form as shown in Fig. 22.
- Click on the RF port (this should give you the same result as when using PAC in section 7).

Direct Plot Form ×	Direct Plot Form ×
Plotting Mode Append	Plotting Mode Append  Analysis
⊖ pss ⊖ pac ● pxf	🔾 pss 🖲 pac 🔾 pxf
Function	Function
● Voltage Gain ⊖ Transimpedance	Voltage Voltage Gain     Current IPN Curves
Sweep	Select Differential Nets
Spectrum Sideband	Sweep
Modifier	Spectrum Sideband
🔾 Magnitude 🔾 Phase 💿 dB20	Modifier
C Real C Imaginary	🔾 Magnitude 🔾 Phase 💿 dB20
Input Sideband	C Real C Imaginary
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	Output Sideband $-2$ $2.396$ $-2.46$ $-1$ $\theta$ $-10M$ $\theta$ $2.46$ $-2.416$ $1$ $4.86$ $-4.816$ $2$ $7.26$ $-7.216$
Add To Outputs	Add To Outputs
freqaxis = a bsin	freqaxis = a bsout
> Select Port or Voltage Source on schematic	> Select Positive Net on schematic
OK Cancel Help	OK Cancel Help
Fig. 22	Fig. 23

• The simulation results in this section are much less than the typical measured values. What do you think is the reason? If you were to manufacture this circuit, would the leakage be this low?

# 10- Noise Figure

The noise performance of a mixer is measured by the degradation of the signal to noise power ratio (SNR) after mixing. The input SNR is measured at RF frequency while the output SNR is calculated at IF frequency. Mixing translates down both signal and noise at both the desired channel and its image channel. In the cases where the image frequency does not contain a useful signal, the noise power is doubled after mixing while the signal power remains constant (both referred to the input). Therefore, even a noiseless mixer

has 3 dB NF. Direct conversion mixer, where IF is zero, is an exception because the image of the desired signal is itself. Therefore, in this special case the signal power and the noise power go through the same process and SNR remain unchanged, i.e. NF=0. In practice, transistors and resistors of the mixer add noise and increase NF, however we can still say that double side-band NF (NF<sub>DSB</sub>) is 3 dB lower than single side-band NF (NF<sub>SSB</sub>).

To simulate the noise performance of a mixer, PSS and Pnoise analysis are used together.

- Configure the PSS simulation form as depicted in Fig. 24.
- Configure the Phoise setup form as Fig. 25 illustrates. Select IF port as "output port" and RF port as "input port".
- Run the simulation.
- From Results/Direct Plot/Main Form choose Pnoise and plot NF, NF<sub>DSB</sub>, and NF<sub>SSB</sub>. Check the box to calculate "integrated noise over bandwidth" (Fig. 26) .

Choosing Analyses ADE Explorer ×	Accuracy Defaults (erroreset)
Periodic Steady State Analysis	□ conservative ☑ moderate □ liberal
Engine 💿 Shooting 🔾 Harmonic Balance	Transient-Aided Options
	Run transient? 💿 Yes 🔾 No 🥥 Decide automatically
# Name Expr Value Signal SrcId	Detect Steady State 📃 Stop Time (tstab)
	Save Initial Transient Results (saveinit) 🛛 🗖 no 🗔 yes
1 flo flo 2.4G Large PORTO	
	Dynamic Parameter 📃
flo flo 2.46 Large PORTO	Oscillator 🔲
Clear/Add Delete Update From Hierarchy	Sweep 1 🔽 🗹
Beat Frequency     2.4G     Auto Calculate	Variable
O Beat Period	Variable Name VP_LU
k la	Select Design Variable
	Sweep Range
Number of harmonics	● Start-Stop Start 50m Stop 500m
	🔾 Center-Span
Accuracy Defaults (errpreset)	Sweep Type
🗌 conservative 🗹 moderate 🔲 liberal	● Linear ● Step Size 50m
Transient-Aided Options	Logarithmic Number of Steps
Run transient? 💿 Yes 🔾 No 📿 Decide automatically	
Detect Steady State 📃 Stop Time (tstab)	Add Specific Points
Save Initial Transient Results (saveinit) 🛛 no 🗌 yes	New Initial Value For Each Point (restart) 🗌 no 🗋 yes
Dynamic Parameter	Loadpull
OK <u>C</u> ancel Defaults Apply <u>H</u> elp	Enabled 🕑 Options

Fig. 24

Choosing Analyses ADE L (1) ×
Periodic Noise Analysis
iS Beat Frequency (Hz) 2 . 4G
Multiple pnoise
weeptype default Sweep is currently absolute
Output Frequency Sweep Range (Hz)
Start-Stop Start 1k Stop 100M
Sweep Type
Automatic 🔽
Add Specific Points
Sidebands
Method efault fullspectrum
when using shooting engine, default value is 7.
Noise Figure 💆
Output
probe Output Probe Instance /PORT3 Select
Input Source
port VI Input Port Source /PORT1 Select
Select from list
From (Hz) 0 To (Hz) 1e12 Max. Order 1
side Frequencies 2.46
1K 100M 0 2.3G 2.4G -1
2.4G 2.5G 1
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

Fig. 25

Fig. 26

- Compare the result when using NFdsb.
- You can investigate the dominant noise sources by turning on the "noise separation" option in Pnoise analysis.