ZHEJIANG UNIVERSITY

RF circuits and systems
Project Report

实验名称	Receiver Link Design
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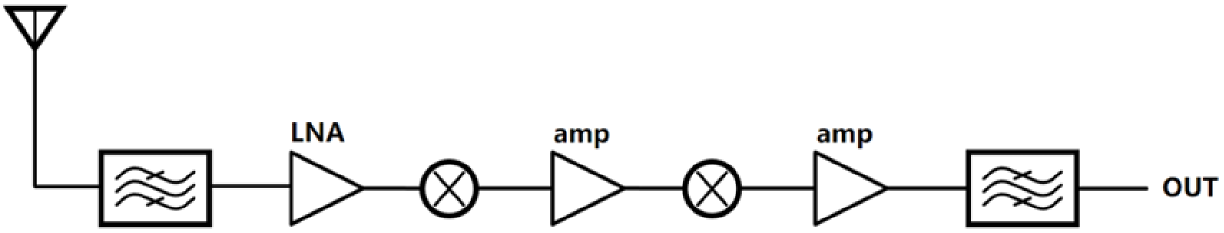
指导老师	Zhao Bo

Contents

1 Requirements

Using ADS software to build a receiver link in the frequency of **2478 MHz** band, and the power of input signal is -60 dBm. The system block diagram is as follows. Finish the calculation and simulation of the **Power**, **Gain**, **Output Power** and **Sensitivity**.



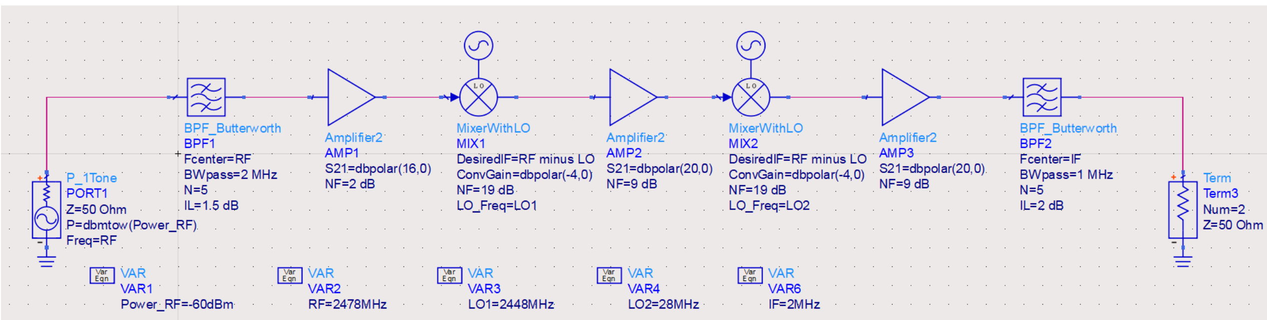
The parameters of Antenna, RF Filter, LNA, Amp, Mixer are as follows.

Antenna	Input Impedance : 50ohm		
RF Filter	Bandwidth：2MHz，Insert Loss：1.5dB，N:5		
	Power (mW)	Noise Figure (dB)	Gain (dB)
LNA	1.8	2	16
Mixer	0	19	-4
Amp	1	9	20
	Center Frequency（MHz）	**Bandwidth（MHz）**	**Insert Loss（dB）**
Low Frequency Filter	2	1	2

2 Simulation Process

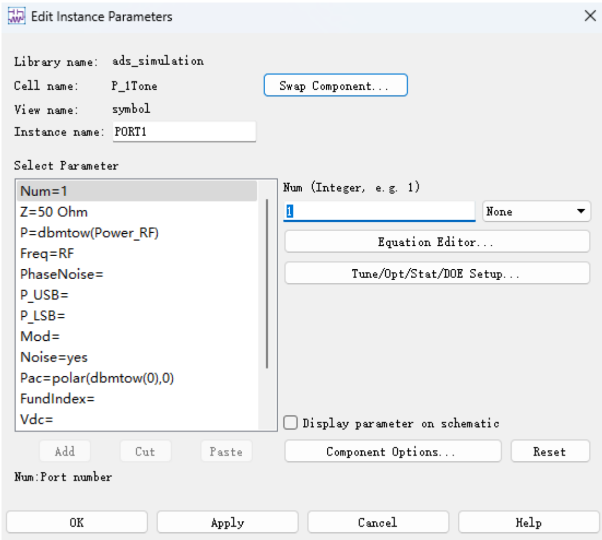
2.1 Schematic Diagram

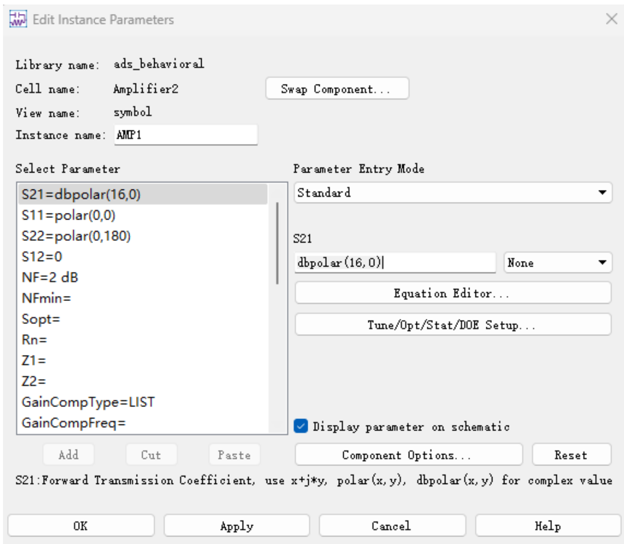
According to the requirements, we can have the schematic shown below.

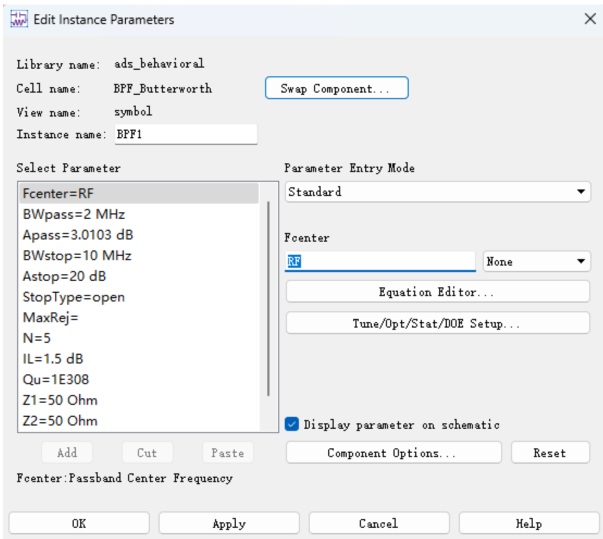


2.2 Circuit Parameters

Second, we need to determine the parameters of each circuit according to the requirements.


Edit Instance Parameters
Library name: ads_simulation
Cell name: P_1Tone
Swap Component...
View name: symbol
Instance name: PORT1
Select Parameter
Num=1
Z=50 Ohm
P=dbmtow(Power_RF)
Freq=RF
PhaseNoise=
P_USB=
P_LSB=
Mod=
Noise=yes
Pac=polar(dbmtow(0),0)
FundIndex=
Vdc=
Num (Integer, e.g. 1)
1
None
Equation Editor...
Tune/Opt/Stat/DOE Setup...
Display parameter on schematic
Add
Cut
Paste
Component Options...
Reset
Num:Port number
OK
Apply
Cancel
Help


Edit Instance Parameters
Library name: ads_behavioral
Cell name: Amplifier2
Swap Component...
View name: symbol
Instance name: AMP1
Select Parameter
Parameter Entry Mode
Standard
S21=dbpolar(16,0)
S11=polar(0,0)
S22=polar(0,180)
S12=0
NF=2 dB
NFmin=
Sopt=
Rn=
Z1=
Z2=
GainCompType=LIST
GainCompFreq=
S21
dbpolar(16,0)
None
Equation Editor...
Tune/Opt/Stat/DOE Setup...
Display parameter on schematic
Add
Cut
Paste
Component Options...
Reset
S21:Forward Transmission Coefficient, use x+j*y, polar(x,y), dbpolar(x,y) for complex value
OK
Apply
Cancel
Help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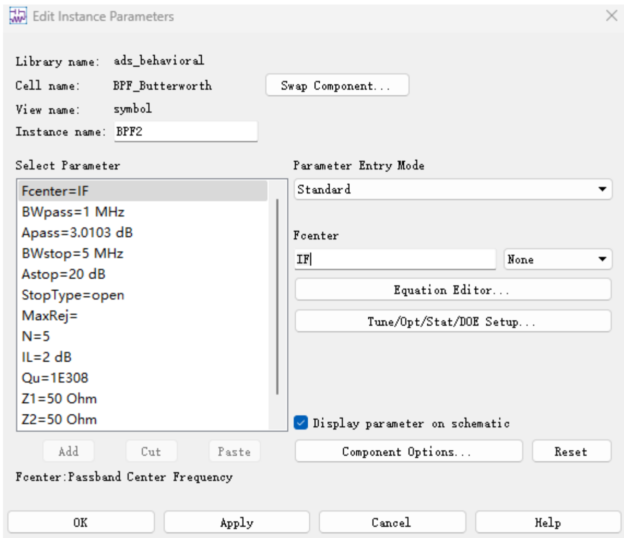
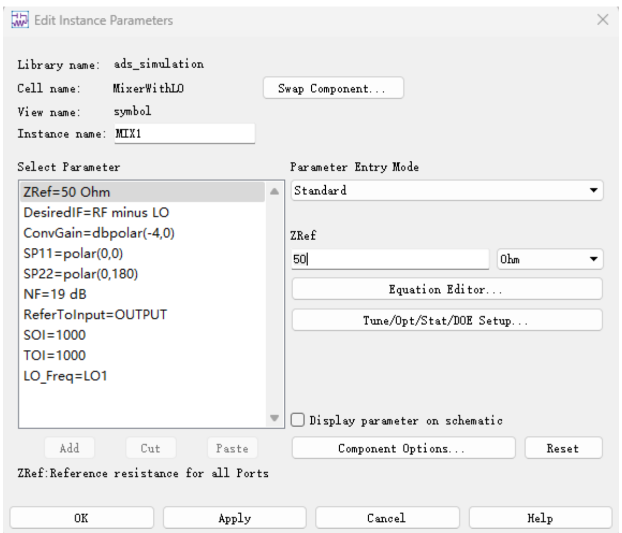
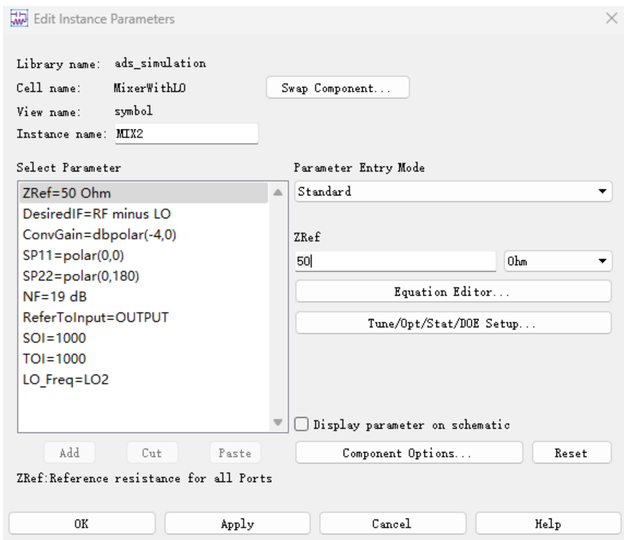
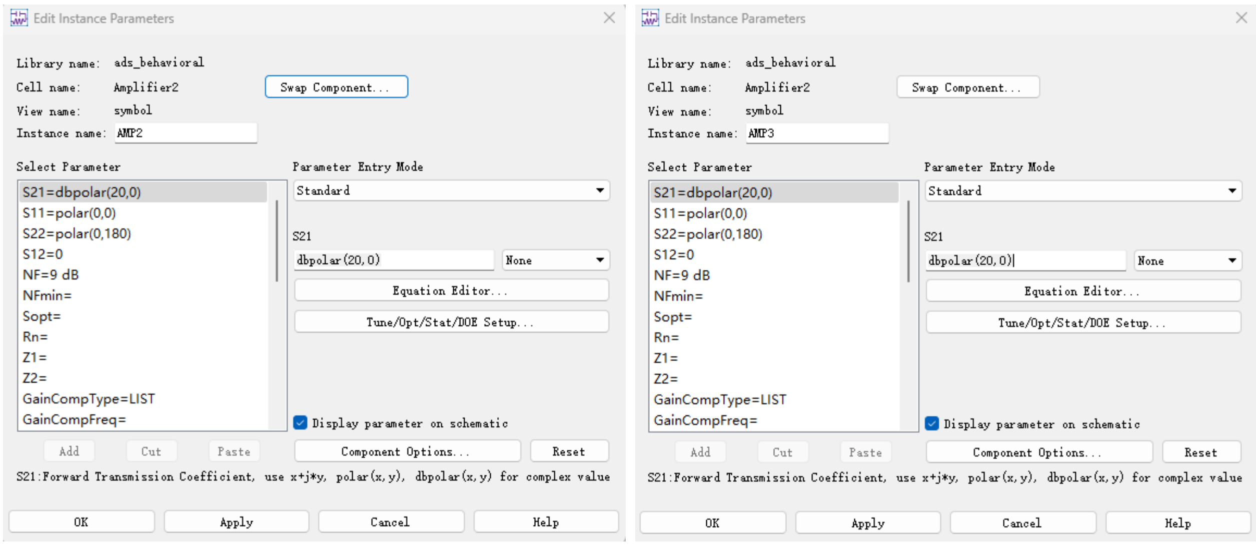
Library name: ads_behavioral
Cell name: BPF_Butterworth
Swap Component...
View name: symbol
Instance name: BPF1
Select Parameter
Parameter Entry Mode
Standard
Fcenter=RF
BWpass=2 MHz
Apass=3.0103 dB
BWstop=10 MHz
Astop=20 dB
StopType=open
MaxRej=
N=5
IL=1.5 dB
Qu=1E308
Z1=50 Ohm
Z2=50 Ohm
Fcenter
RF
None
Equation Editor...
Tune/Opt/Stat/DOE Setup...
Display parameter on schematic
Add
Cut
Paste
Component Options...
Reset
Fcenter:Passband Center Frequency
OK
Apply
Cancel
Help


Edit Instance Parameters
Library name: ads_behavioral
Cell name: BPF_Butterworth
Swap Component...
View name: symbol
Instance name: BPF2
Select Parameter
Parameter Entry Mode
Standard
Fcenter=IF
BWpass=1 MHz
Apass=3.0103 dB
BWstop=5 MHz
Astop=20 dB
StopType=open
MaxRej=
N=5
IL=2 dB
Qu=1E308
Z1=50 Ohm
Z2=50 Ohm
Fcenter
IF
None
Equation Editor...
Tune/Opt/Stat/DOE Setup...
Display parameter on schematic
Add
Cut
Paste
Component Options...
Reset
Fcenter:Passband Center Frequency
OK
Apply
Cancel
Help


Edit Instance Parameters
Library name: ads_simulation
Cell name: MixerWithLO
Swap Component...
View name: symbol
Instance name: MIX1
Select Parameter
Parameter Entry Mode
Standard
ZRef=50 Ohm
DesiredIF=RF minus LO
ConvGain=dbpolar(-4,0)
SP11=polar(0,0)
SP22=polar(0,180)
NF=19 dB
ReferToInput=OUTPUT
SOI=1000
TOI=1000
LO_Freq=LO1
ZRef
50
Ohm
Equation Editor...
Tune/Opt/Stat/DOE Setup...
Display parameter on schematic
Add
Cut
Paste
Component Options...
Reset
ZRef:Reference resistance for all Ports
OK
Apply
Cancel
Help


Edit Instance Parameters
Library name: ads_simulation
Cell name: MixerWithLO
Swap Component...
View name: symbol
Instance name: MIX2
Select Parameter
Parameter Entry Mode
Standard
ZRef=50 Ohm
DesiredIF=RF minus LO
ConvGain=dbpolar(-4,0)
SP11=polar(0,0)
SP22=polar(0,180)
NF=19 dB
ReferToInput=OUTPUT
SOI=1000
TOI=1000
LO_Freq=LO2
ZRef
50
Ohm
Equation Editor...
Tune/Opt/Stat/DOE Setup...
Display parameter on schematic
Add
Cut
Paste
Component Options...
Reset
ZRef:Reference resistance for all Ports
OK
Apply
Cancel
Help



We have to note that

- PORT1 refers to the antenna;
- AMP1 refers to the low noise amplifer;
- BPF1 refers to the RF filter and BPF2 refers to the low pass filter;
- MIX1 refers to the first mixer and MIX2 refers to the second mixer;
- AMP2 refers to the first power amplifier and AMP3 refers to the second power amplifier.

Since he receiver is two-stage heterodyne architecture, where the first down-converting frequency is provided by a PLL working at 2448 MHz, so we can calculate that the LO2 frequnecy is

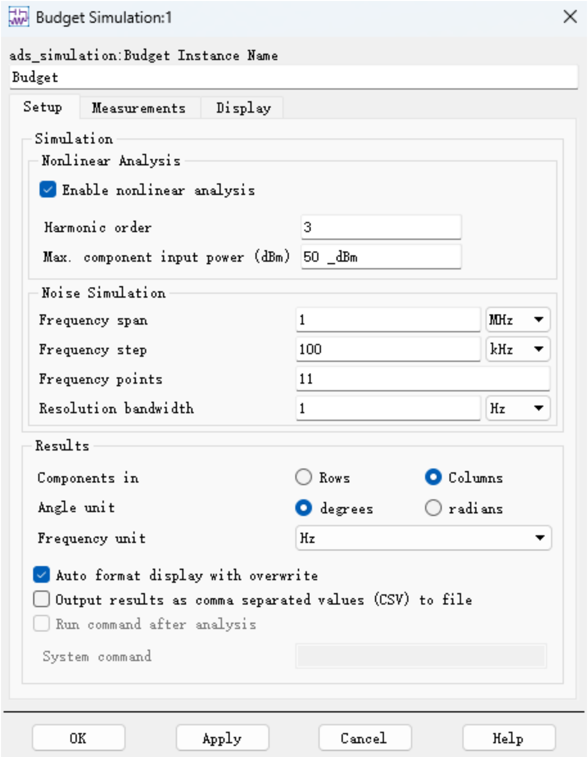
$$f_{LO2} = f_{RF} - f_{LO1} - f_{IF} = 2478 - 2448 - 2 = 28MHz$$

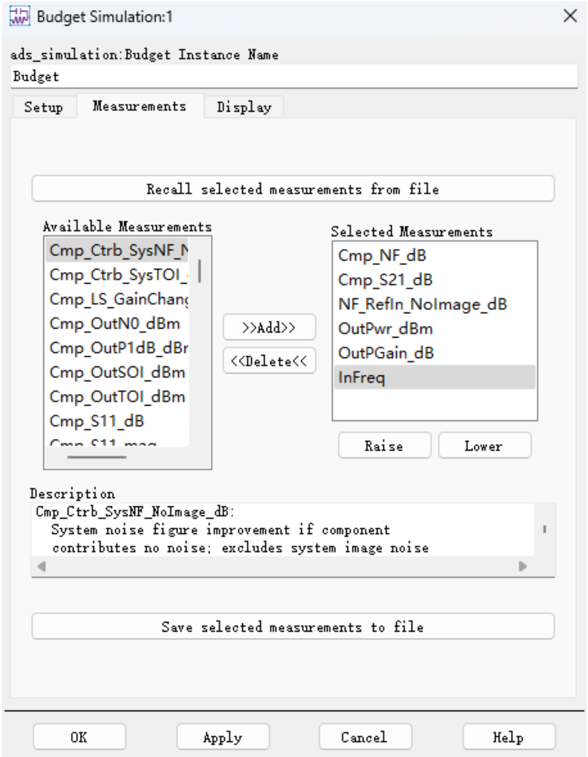
2.3 Simulation Settings

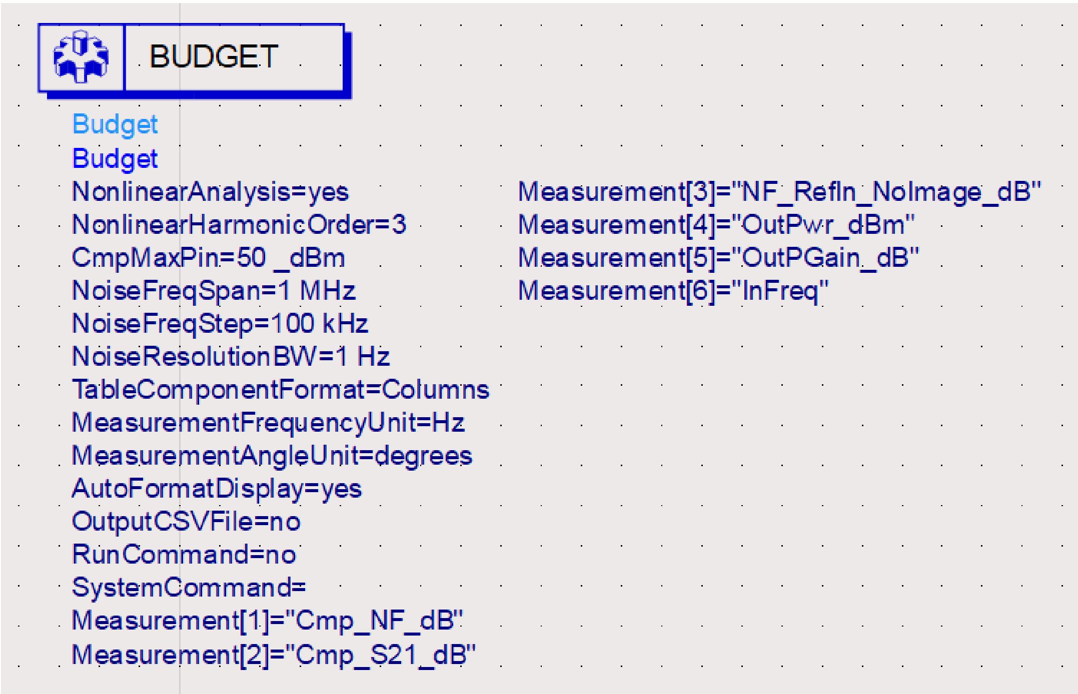
Finally we select Budget as the simulation tool. Output of Budget include

- **Cmp_NF_dB (NF of each stage)**
- **Cmp_S21_dB (Gain of each stage)**
- **NF_Refln_NoImage_dB (system noise figure)**
- **OutPwr_dBm (output power)**
- **OutPGain_dB (system Gain)**
- **InFreq (frequency)**

The parameters are shown below.


Budget Simulation:1
ads_simulation:Budget Instance Name
Budget
Setup
Measurements
Display
Simulation
Nonlinear Analysis
Enable nonlinear analysis
Harmonic order
3
Max. component input power (dBm)
50 _dBm
Noise Simulation
Frequency span
1
MHz
Frequency step
100
kHz
Frequency points
11
Resolution bandwidth
1
Hz
Results
Components in
Rows
Columns
Angle unit
degrees
radians
Frequency unit
Hz
Auto format display with overwrite
Output results as comma separated values (CSV) to file
Run command after analysis
System command
OK
Apply
Cancel
Help

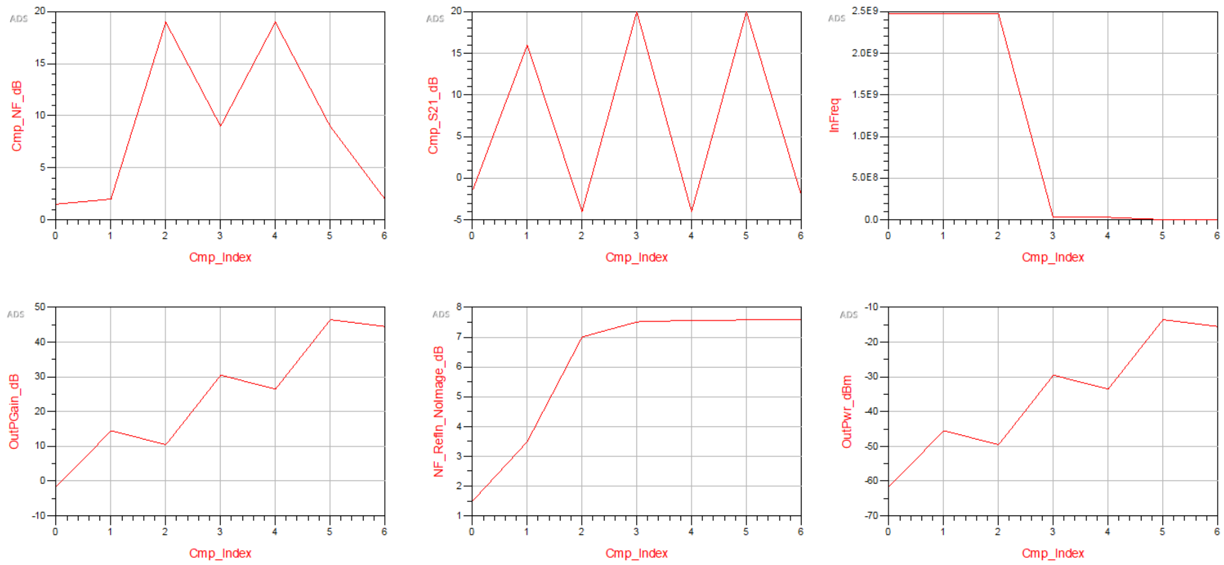

Budget Simulation:1
ads_simulation:Budget Instance Name
Budget
Setup
Measurements
Display
Recall selected measurements from file
Available Measurements
Cmp_LS_GainChang
Cmp_OutN0_dBm
Cmp_OutSOI_dBm
Cmp_OutTOI_dBm
Cmp_S11_dB
>>Add>>
<<Delete<<
Selected Measurements
Cmp_NF_dB
Cmp_S21_dB
NF_Refln_NoImage_dB
OutPwr_dBm
OutPGain_dB
InFreq
Raise
Lower
Description
Cmp_Ctrb_SysNF_NoImage_dB:
System noise figure improvement if component
contributes no noise; excludes system image noise
Save selected measurements to file
OK
Apply
Cancel
Help


BUDGET
Budget
Budget
NonlinearAnalysis=yes
NonlinearHarmonicOrder=3
CmpMaxPin=50 _dBm
NoiseFreqSpan=1 MHz
NoiseFreqStep=100 kHz
NoiseResolutionBW=1 Hz
TableComponentFormat=Columns
MeasurementFrequencyUnit=Hz
MeasurementAngleUnit=degrees
AutoFormatDisplay=yes
OutputCSVFile=no
RunCommand=no
SystemCommand=
Measurement[1]="Cmp_NF_dB"
Measurement[2]="Cmp_S21_dB"
Measurement[3]="NF_Refln_NoImage_dB"
Measurement[4]="OutPwr_dBm"
Measurement[5]="OutPGain_dB"
Measurement[6]="InFreq"

3 Simulation Results

Simulation results are shown below

Meas_Name	BPF1	AMP1	MIX1	AMP2	MIX2	AMP3	BPF2
Cmp_NF_dB	1.500	2.000	19.000	9.000	19.000	9.000	2.000
Cmp_S21_dB	-1.500	16.000	-4.000	20.000	-4.000	20.000	-2.000
NF_RefIn_NoImage_dB	1.500	3.500	7.008	7.513	7.567	7.578	7.578
OutPwr_dBm	-61.500	-45.500	-49.500	-29.500	-33.500	-13.500	-15.500
OutPGain_dB	-1.500	14.500	10.500	30.500	26.500	46.500	44.500
InFreq	2.478E9	2.478E9	2.478E9	3.000E7	3.000E7	2.000E6	2.000E6



We can get some system information according to the simulation results. The final output IF signal

RESULTS	Output Power	OUTPUT Freq	Total Gain	Total Noise
VALUE	-15.5dBm	2MHz	44.5dB	7.578dB

Table 1: System Output

frequency is 2 MHz, which meets expectations, indicating a successful simulation.

Based on the result curves, we can also verify some conclusions from the classroom:

(1). The NF curve increases, indicating that circuit components inevitably introduce noise. No matter how superior the components are, noise cannot be completely eliminated.

(2). Power amplifiers and LNAs are active components, so the signal power increases as it passes through them. However, the mixer here is passive, which results in a decrease in signal power.

(3). The RF receiver converts high-frequency signals into low-frequency signals, leading to a decrease in signal frequency.

4 Theoretical Calculation

Question.1. Calculate the **Noise Figure** of the receiver system, then compare the calculation results with the simulation results.

Soln. We can use the equation

$$NF_{tot} = NF_1 + \frac{NF_2 - 1}{G_1} + ... + \frac{NF_m - 1}{G_1 ... G_{m-1}}$$

Substitute all the data we can obtain

$$NF_{tot} = 10\lg(10^{0.15} + \frac{10^{0.2} - 1}{10^{-0.15}} + \frac{10^{1.9} - 1}{10^{1.45}} + \frac{10^{0.9} - 1}{10^{1.05}} + \frac{10^{1.9} - 1}{10^{3.25}} + \frac{10^{0.9} - 1}{10^{2.85}} + \frac{10^{0.2} - 1}{10^{4.85}}) = 7.578dB$$

RESULTS	RF Filter	LNA	MIX1	AMP1	MIX2	AMP2	LPF
NF|dB	1.5	3.5	7.01	7.514	7.567	7.578	7.578

Table 2: NF calculation results of all circuits

Compare the simulation results with calculation results, we can see that they are almost the same, so the simulation is correct.

Question.2. Calculate the **Output Power** of the receiver system, then compare the calculation results with the simulation results.

Soln. We can use the equation

$$G = G_1 \times G_2 \times ...G_m = \sum G|dB = -1.5 + 16 - 4 \times 2 + 20 \times 2 - 2 = 44.5dB$$

So we can obtain

$$P_{out} = G \times P_{in}, \qquad 10\log\frac{P_{out}}{1mW} = 10\lg G + 10\lg\frac{P_{in}}{1mW} = 44.5 + (-60) = -15.5dBm$$

Compare the simulation results with calculation results, we can see that they are almost the same, so the simulation is correct.

Question.3. Assume the **minimum input SNR** of demodulator is **12 dB** and the input Bandwidth is **2 MHz**. At temperature of 290k, noise power of 1 Hz bandwidth is **-174 dBm**, judge the **Sensitivity** of the system.

Soln.

$$Sen = -174dBm + NF|dB + SNR_{min} + 10\lg B = -174 + 7.578 + 12 + 10\lg(2 \times 10^6) = -91.412dB$$

5 Summery

The simulation and theoretical analysis of the receiver link design were successfully completed using ADS software. The simulation involved constructing a two-stage heterodyne receiver operating at a frequency of 2478 MHz with an input signal power of -60 dBm. The system components, including the antenna, RF filter, low noise amplifier (LNA), mixers, and power amplifiers, were carefully selected and their parameters determined based on design requirements.The theoretical calculations for noise figure, gain, output power, and sensitivity closely matched the simulation results, validating the accuracy of the simulation model. Overall, the simulation successfully demonstrated the design's performance, verifying both theoretical principles and practical results. This project has deepened my understanding of RF circuit design and the importance of careful component selection and simulation accuracy in achieving reliable results.