ECE 451
Automated Microwave Measurements Laboratory

Experiment No. 11

Generating X-Parameters in ADS from Circuit Level Models

Purpose

In this experiment, we will use Agilent ADS to generate X-parameters from a circuit-level design of a Power-Amplifier (PA). We will then be using these X-parameters in simulation to extract 1-dB compression point and third-order intercept (TOI) points via 1-tone Harmonic Balance (HB), Circuit Envelope (CE). Our aims are to develop an intuitive understanding of how X-parameter system level simulations compare with the circuit level SPICE simulations and demonstrate how powerful the X-parameter formulism is in characterizing an entire system by a 'black-box' design approach. Lastly, we will develop an appreciation for simulation of X-parameters using 2-tone HB, CE simulation on both the X-parameter model as well as circuit level design of our PA. Such a technique is very powerful as traditional two-tone measurements are very tedious and expensive when using a NVNA.

Motivation

In a typical RFIC design flow for modern communication systems we often see a tradeoff in simulation accuracy, allotted design time and IP protection. In traditional design flow a foundry would create a SPICE model for a transistor in a given process technology and then hand it over to an IC design house. This IC design house is the team that will actually design the circuit and send it back to the foundry for fabrication. Circuits are always designed for a particular application and have to meet certain specification pertaining to that application. The system engineers whose task is to meet their customer's needs typically set design specifications. Often the end customer, foundry, IC design house and the system engineers/system integrators are disparate entities and can even be competing firms thus Intellectual Property (IP) protection is a big concern today. Most significant advantage of X-parameters over other network parameters as well as standards like IBIS-AMI is that they provide complete IP protection by characterizing any given circuit's linear as well as non-linear behavior. X-parameters significantly speed up simulation times and allow the system integrators to characterize the entire system with a true black-box approach. This paradigm shift protects the IP of the IC design house, as they no longer need to share the circuit level design details with the system integrators. System engineers can take the X-parameter model in the form of a '.xnp' file and accurately capture the small-signal linear behavior as well as all the non-linearities, amplitude/phase perturbations on all harmonics during large –signal behavior. The X-parameter models are not only capable of describing circuits at a schematic level but are also able to characterize packaged components including the effects parasitics. Furthermore, the ability to cascade X-parameters allows the system integrators to speed up the analysis and design time without compromising on accuracy like they do today while using traditional behavioral modeling techniques. This final experiment of the semester will demonstrate how to characterize an entire circuit using a 'black-box' approach by generating X-parameters from a transistor-level circuit schematic of a PA and then using ADS to simulate its small-signal linear as well as the large-signal non-linear behavior.

Pre-lab questions

1. What is X-parameter? Why is it needed?

2. Is Harmonic Balance the steady-state or transient simulation? What kind of information HB simulation can give?

ADS Simulation Setup using 1-Tone Harmonic Balance

In this section of the experiment we will generate X-parameters of a transistor level PA and perform 1-Tone HB simulations on the model as well as circuit-level schematic. The circuit schematic is available on the website, it is the same schematic we used in the last experiment.

1) We start by generating the X-parameters of the PA. To do this create a new schematic in ADS and place the Amp symbol for the above transistor level circuit.

2) Now in the upper left pallet select 'Simulation-X_Param'. You will find all the components needed for the X-parameter generation schematic shown below in Figure 2 under this pallet.
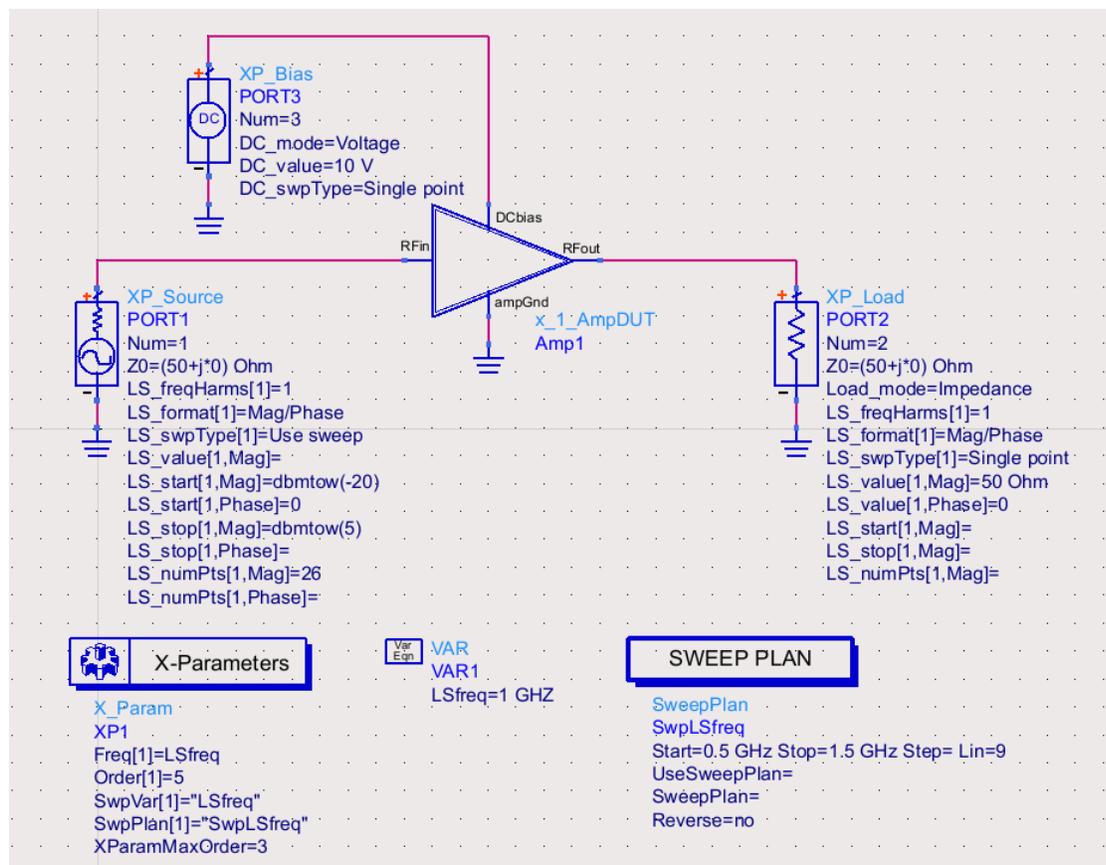

Figure 2: 1-Tone X-Parameter Generation Schematic

3) Save this schematic by the name 'a0_XparSim' and simulate the data set. We will use the data-set 'a0_XparSim.ds' while comparing the circuit level and X-parameter Harmonic Balance simulations.

4) Now create a new schematic and recreate the schematic shown in Figure 3. We will perform a Frequency sweep for the circuit level PA as well as the X-parameter model of the PA using HB. Save this schematic by the name 'a1_FreqSweep'. You will find the 'P_1Tone' from the drop-down pallet named 'Sources-Freq Domain' and find the HB simulator under 'Simulation-HB'. Finally, select the 'X-Port' component under 'Data Items' pallet and import the 'a0_XparSim.ds' dataset into the X3P component. Simulate the schematic and compare the plots for dbm and phase curves for the first, second and third harmonics. The output would look similar to that shown in Figure 3.
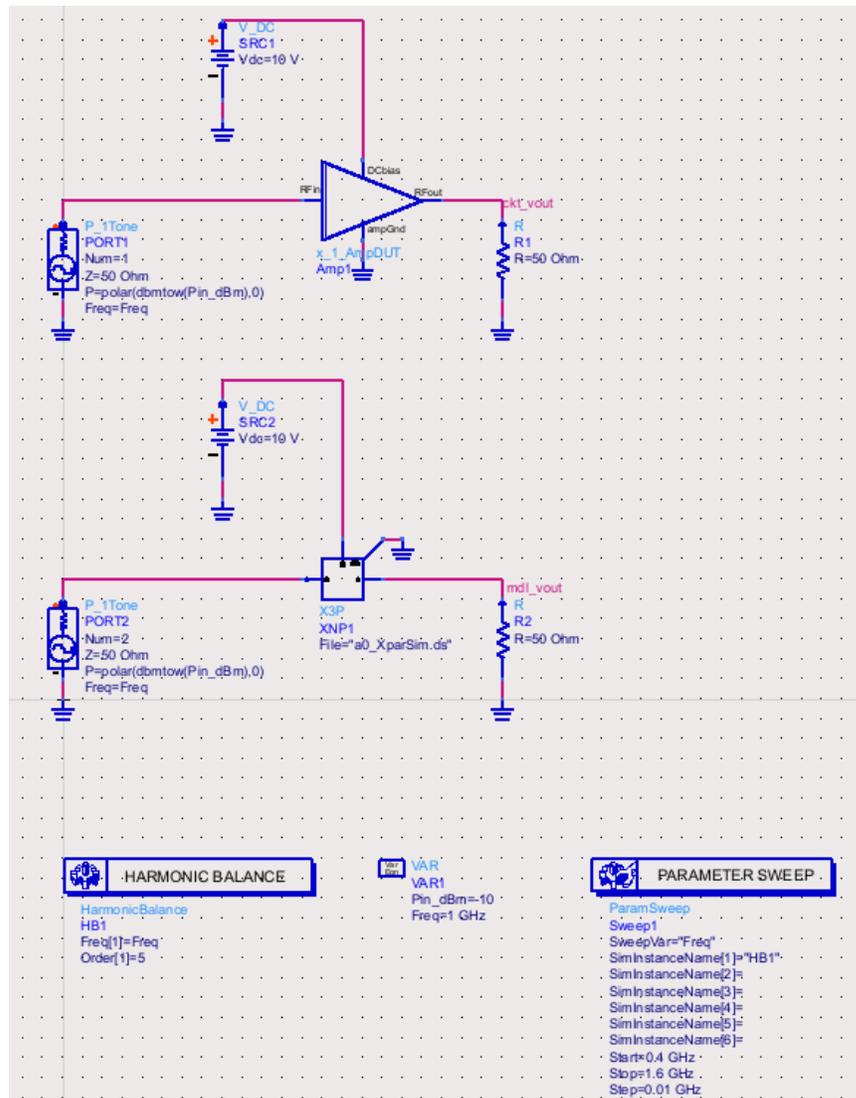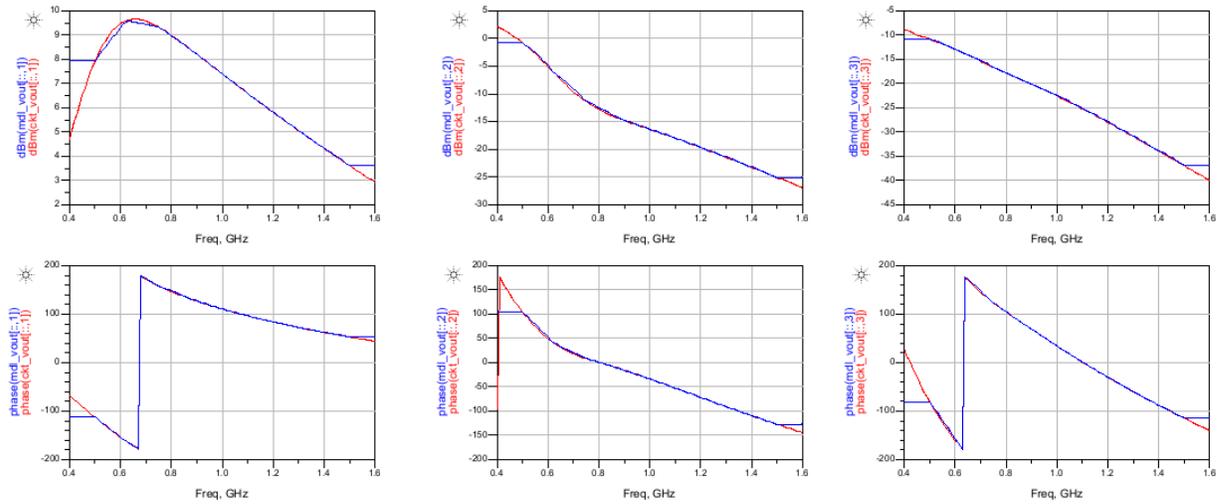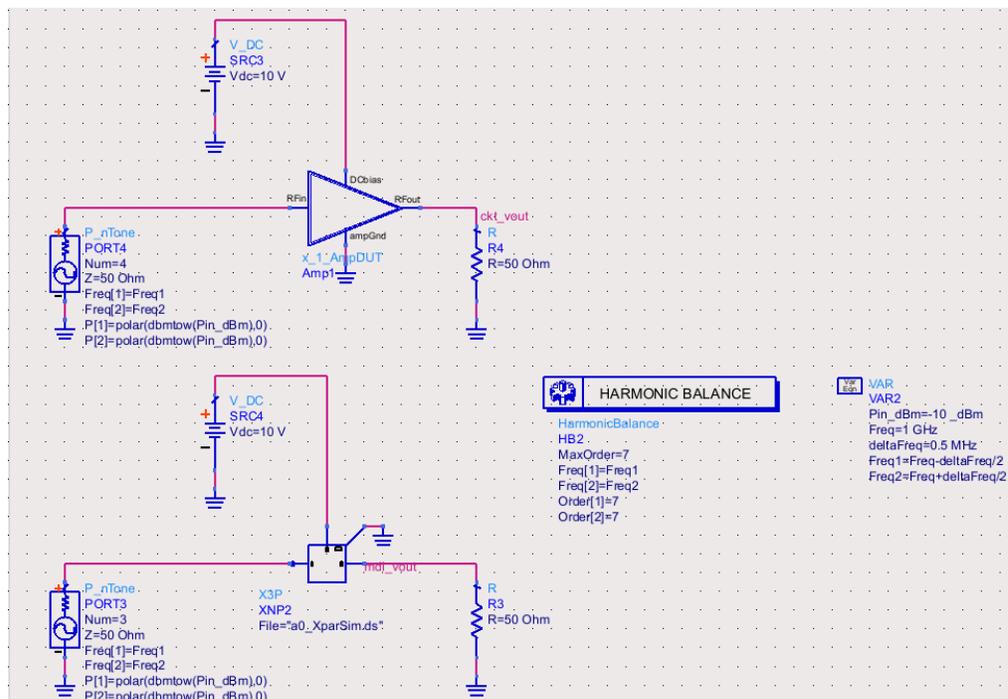
Figure 3: Frequency Sweep using HB Simulation

ADS Simulation Setup using 2-Tone Harmonic Balance

In this section of the experiment we will use the 1-Tone X-parameters we generated and perform 2-Tone HB simulations on the model as well as circuit-level schematic.

1) Create a new schematic and recreate the setup shown below in Figure 4. Save this schematic by the name 'b0_TwoTones_HB'.
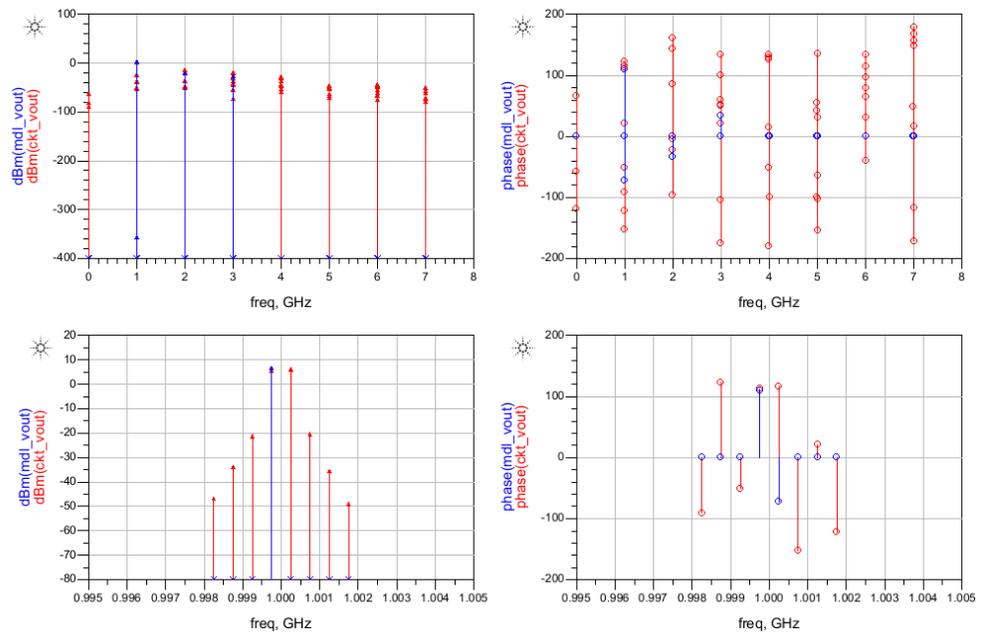
Figure 4: 2-Tone HB Simulation

2) We will once again perform a Frequency sweep for the circuit level PA as well as the X-parameter model of the PA using HB. You will find the 'P_nTone' from the drop-down pallet named 'Sources-Freq Domain' and find the HB simulator under 'Simulation-HB'. Finally, select the 'X-Port' component under 'Data Items' pallet and import the 'a0_XparSim.ds' data-display into the X3P component. Simulate the schematic and compare the plots for dbm and phase curves for the two-tone setup. The output would look similar to that shown in Figure 4.

TOI Calculation using HB Simulation in ADS

In this section of the experiment we will generate X-parameters of a transistor level PA using two closely spaced large signal tones and perform CE simulations on the model as well as circuit-level schematic.

1) In order to perform the TOI calculations using the HB simulator in ADS we need a 2-Tone X-parameter over a LSOP. Create a new schematic now similar to that shown in Figure 11 to generate the 2-Tone Large Signal X-parameter model.

2) In the upper left pallet select 'Simulation-X_Param'. You will find all the components needed for the X-parameter generation schematic shown below in Figure 11 under this pallet.

3) Save this schematic by the name 'e5_XparSim_2LSswp' and simulate the data set. We will use the data-set 'e5_XparSim_2LSswp.ds' while computing the TOI points in the HB simulation setups.

4) Now create a new schematic and recreate the schematic shown in Figure 12. We will perform a TOI calculation for the circuit level PA as well as the X-parameter model of the PA using HB. Save this schematic by the name 'e6_TOI_HB_2LSswp'. You will find the 'P_nTone' from the drop-down pallet named 'Sources-Freq Domain' and find the HB simulator under 'Simulation-HB'. Finally, select the 'X-Port' component under 'Data Items' pallet and import the 'e5_XparSim_2LSswp.ds' dataset into the X3P component.
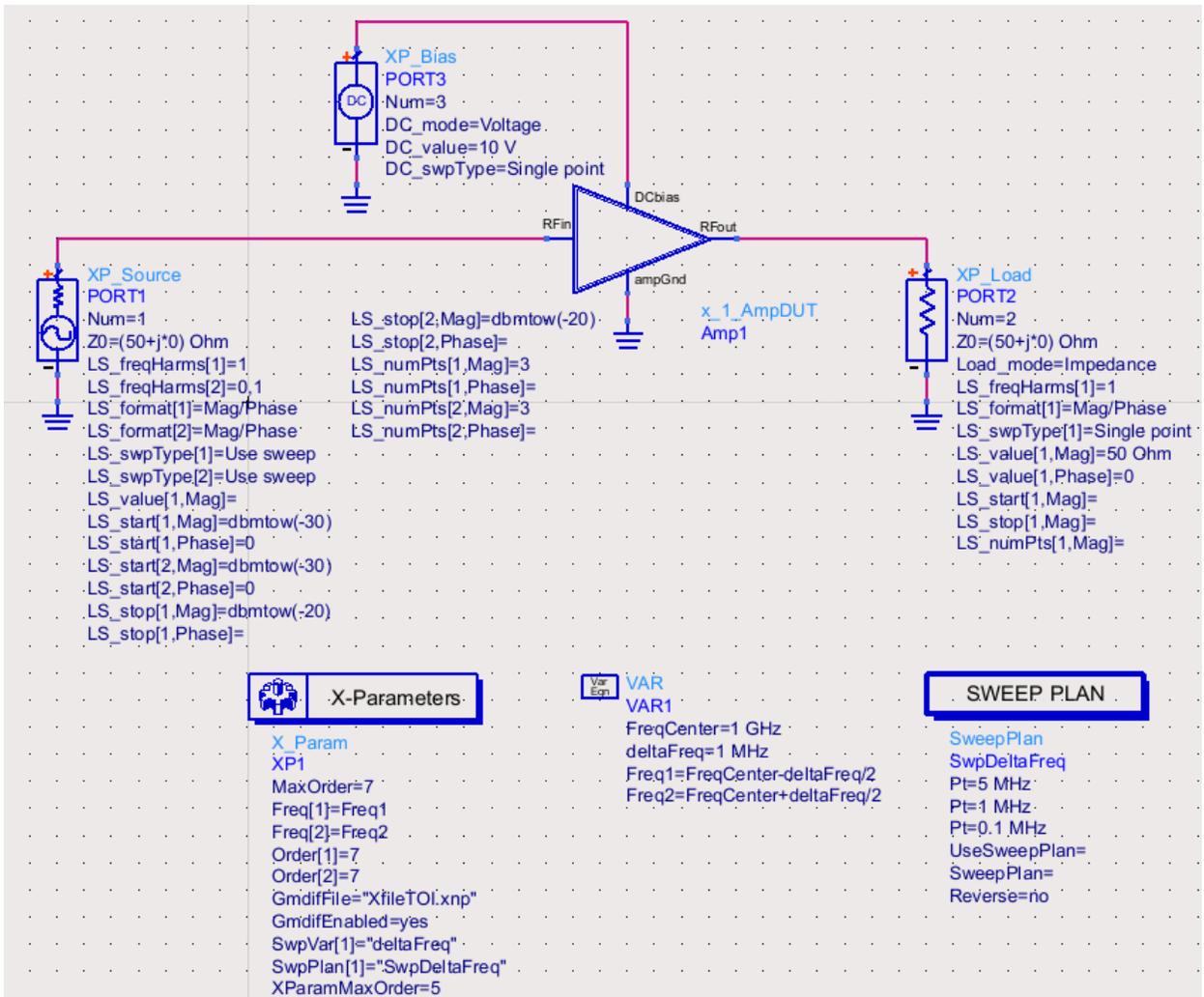
XP_Bias
PORT3
Num=3
DC_mode=Voltage
DC_value=10 V
DC_swpType=Single point

DC

DCbias

RFin

RFout

ampGnd

x_1_AmpDUT
Amp1

XP_Source
PORT1
Num=1
Z0=(50+j*0) Ohm
LS_freqHarms[1]=1
LS_freqHarms[2]=0,1
LS_format[1]=Mag/Phase
LS_format[2]=Mag/Phase
LS_swpType[1]=Use sweep
LS_swpType[2]=Use sweep
LS_value[1,Mag]=
LS_start[1,Mag]=dbmtow(-30)
LS_start[1,Phase]=0
LS_start[2,Mag]=dbmtow(-30)
LS_start[2,Phase]=0
LS_stop[1,Mag]=dbmtow(-20)
LS_stop[1,Phase]=

LS_stop[2,Mag]=dbmtow(-20)
LS_stop[2,Phase]=
LS_numPts[1,Mag]=3
LS_numPts[1,Phase]=
LS_numPts[2,Mag]=3
LS_numPts[2,Phase]=

XP_Load
PORT2
Num=2
Z0=(50+j*0) Ohm
Load_mode=Impedance
LS_freqHarms[1]=1
LS_format[1]=Mag/Phase
LS_swpType[1]=Single point
LS_value[1,Mag]=50 Ohm
LS_value[1,Phase]=0
LS_start[1,Mag]=
LS_stop[1,Mag]=
LS_numPts[1,Mag]=

X-Parameters

X_Param
XP1
MaxOrder=7
Freq[1]=Freq1
Freq[2]=Freq2
Order[1]=7
Order[2]=7
GmdifFile="XfileTOI.xnp"
GmdifEnabled=yes
SwpVar[1]="deltaFreq"
SwpPlan[1]="SwpDeltaFreq"
XParamMaxOrder=5

VAR
VAR1
FreqCenter=1 GHz
deltaFreq=1 MHz
Freq1=FreqCenter-deltaFreq/2
Freq2=FreqCenter+deltaFreq/2

SWEEP PLAN

SweepPlan
SwpDeltaFreq
Pt=5 MHz
Pt=1 MHz
Pt=0.1 MHz
UseSweepPlan=
SweepPlan=
Reverse=no

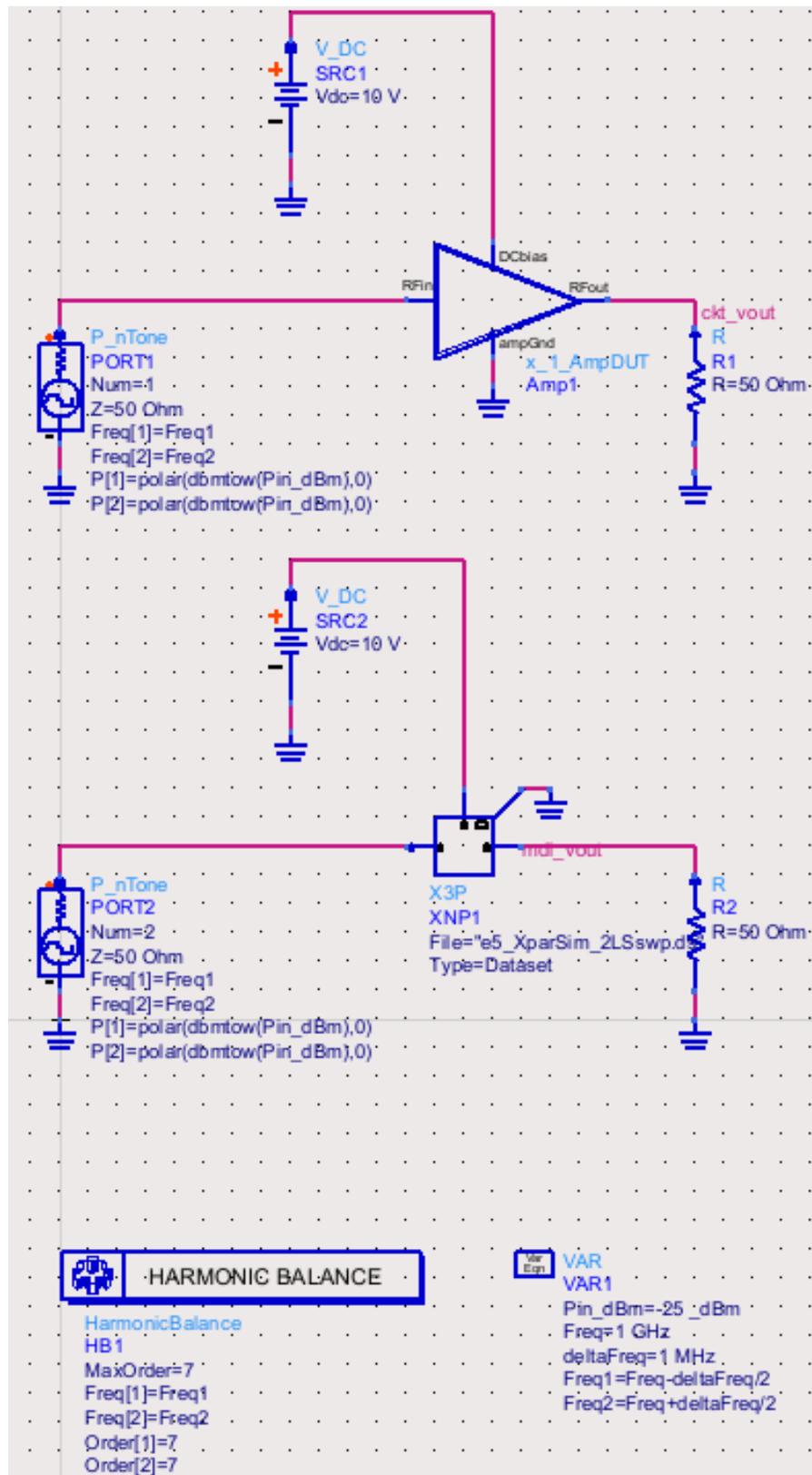**Figure 11: 2-Tone Large Signal X-Parameter Generation Schematic**

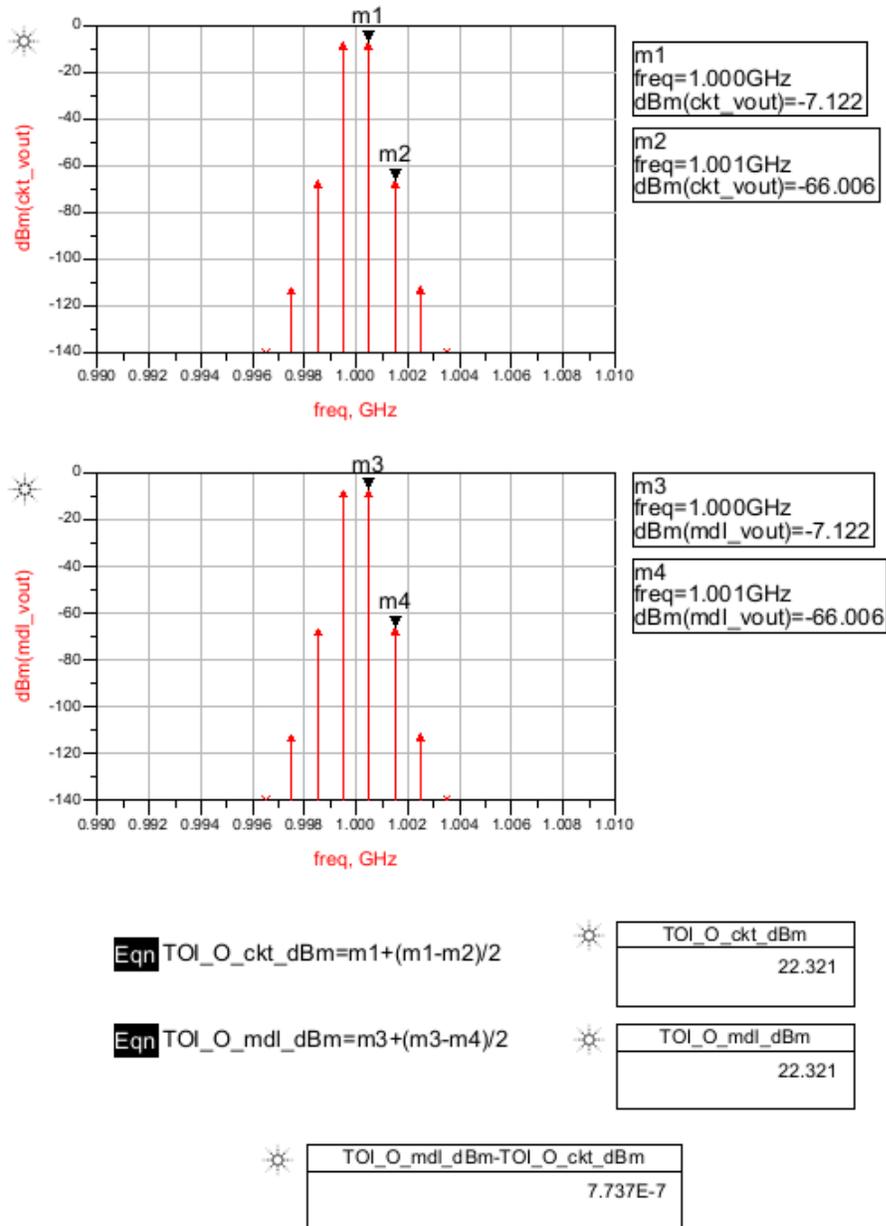**Figure 12: Simulation of TOI using HB Schematic**

Figure 12: Simulation of TOI using HB Schematic

5) Simulate the schematic and compare the plots for dbm spectrum of both circuit level amplifier as well as the behavioral X-parameter model. The output would look similar to that shown in Figure 12. Your simulation result will look similar to that shown above in Figure 10. Compare the results with the CE simulation you performed earlier.

Useful Video Tutorials for X-Parameter Generation

1. https://www.youtube.com/watch?v=JdX_VRC9nL8&index=2&list=PLtq84kH8xZ9FRa3Ra0XSxPhWQL7H_fYHp

TA Theory and Conclusion Questions

Theory:
1. How are X-parameters generated from the transistor level schematic of a circuit?
2. Describe the similarities and differences between CE and HB simulation.
3. What are the advantages of generating 2-Tone X-parameters in simulation? Why is difficult to physically measure 2-Tone X-parameters on a NVNA?

Conclusion:
1. How did the circuit level simulations for 1-Tone frequency sweep compare with the X-parameter model simulations? Elaborate on the differences between the two models if you observed any.
2. How do X-parameter models provide IP protection to a circuit designer?