Agilent EEsof EDA Tech Info Session

Top 10 Tips and Tricks for Harmonic Balance Simulation and Convergence

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Speaker Introduction

- **Jaime Wooten is a software development engineer for Agilent EEsof EDA responsible for the harmonic balance simulator in ADS and RFDE.**
- **She earned her BSEE and MSEE from the University of California, Santa Barbara.**
- **Outside of work Jaime enjoys doing triathlons (swimming, biking, running), playing the piano, and going to Borders bookstore.**

Outline

- HB overview, simulation flow
- HB setup

1. Order
2. Max Order
3. Convergence mode (Outer solver)
4. (Inner) Solver - Direct vs. Krylov

- Convergence problems, remedies & parameters to adjust for convergence

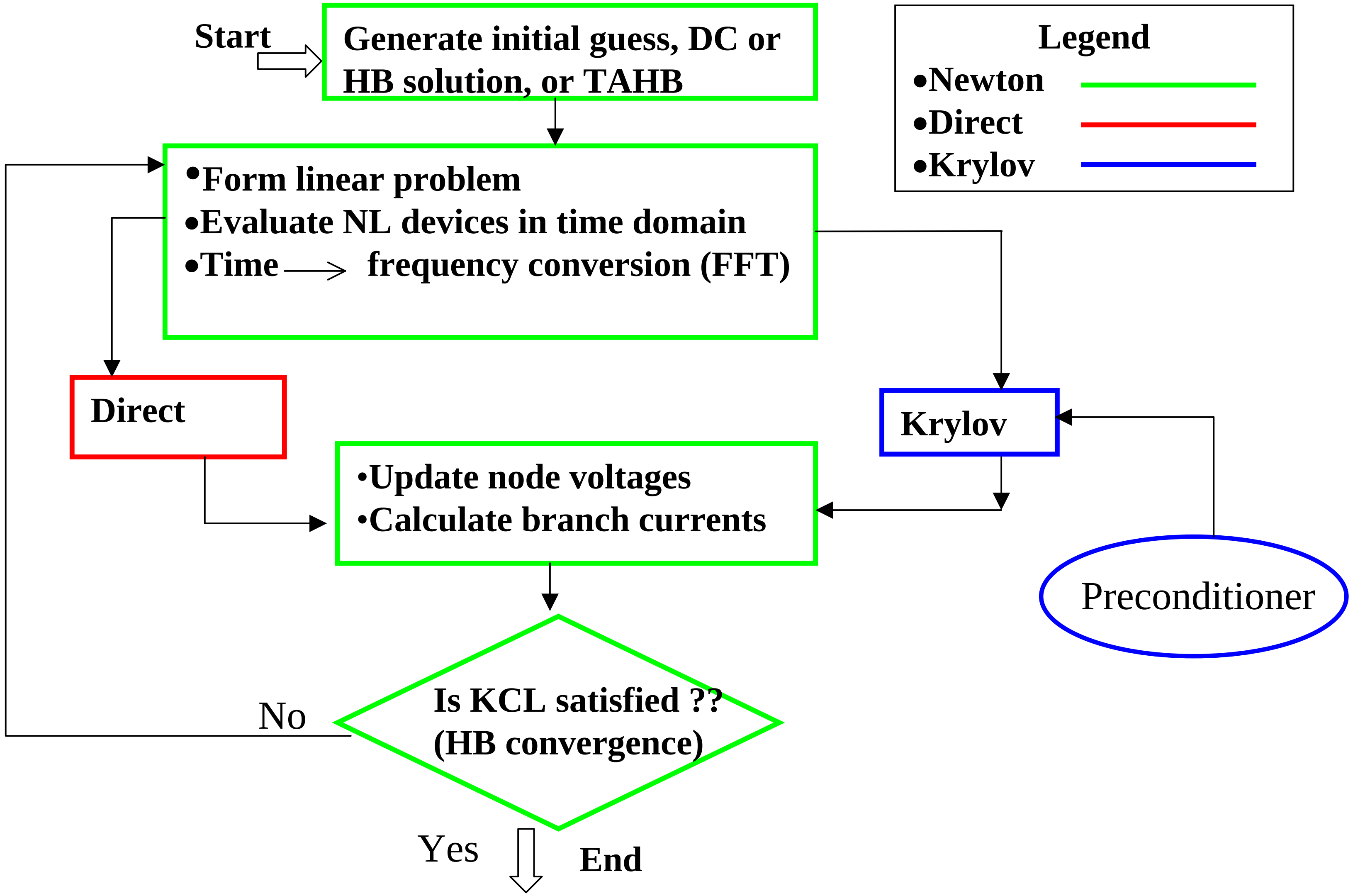
5. Oversample
6. Parameter Sweeps
7. Transient Assisted Harmonic Balance (TAHB)
8. The Most Nonlinear Tone
9. Nonlinear Device DC Characteristics
10. Additional Krlyov Parameters – GMRES Restart Length, Preconditioners

- Summary

Harmonic Balance Overview

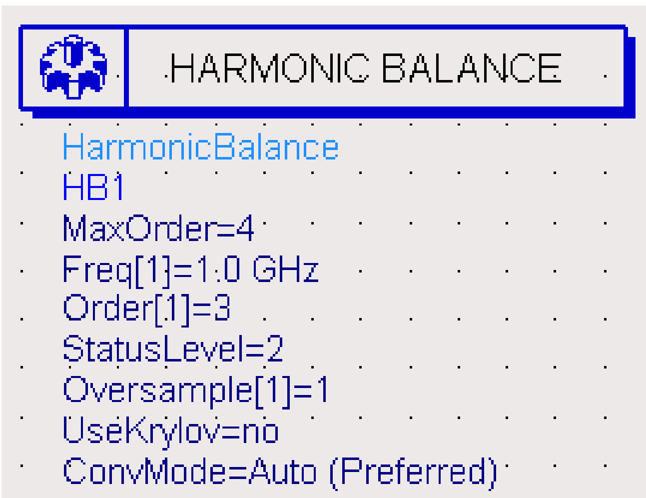
- The objective of harmonic balance is to compute the steady state solution of nonlinear circuits and systems excited by single, multiple, or quasi periodic sources.
- The HB solution is determined using a Fourier series representation of the node voltages and branch currents. This representation results in a the system of equations (which are governed by Kirchhoff's Current Law - KCL) in the frequency domain.
- Harmonic balance uses Newton's method (Outer or nonlinear solver) to compute the Fourier coefficients for the solution to the system of equations. For each Newton iteration, the amount by which KCL is violated is computed. HB convergence is achieved when this amount is driven to a small value.
- Newton's method generates a linear system of equations at each iteration, which is solved using an inner, linear solver. These are Direct and Krylov.

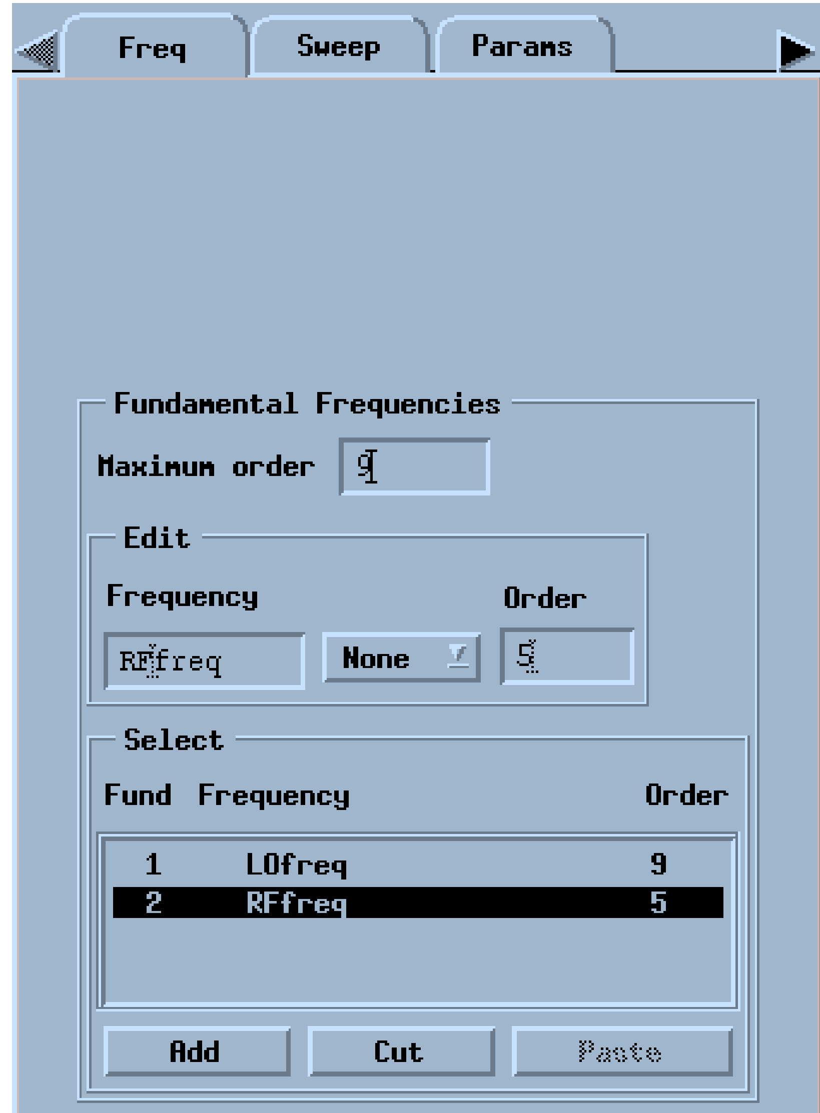
Harmonic Balance Overview - Simulation Flow



Harmonic Balance Setup

Tips & Terms 1-4



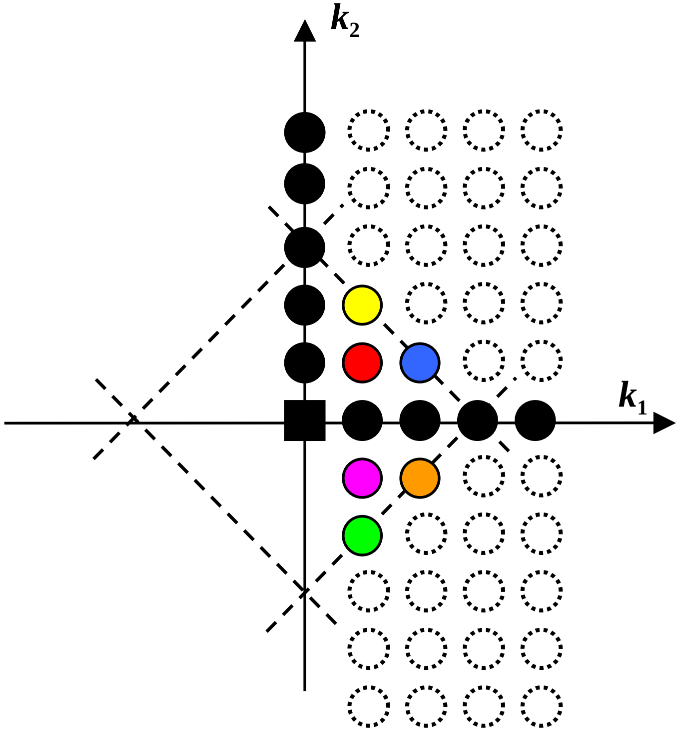


1. Order

- What is order?
  - Number of harmonics used in the Fourier representation of waveforms in HB.
- Set order to 2^N-1, i.e. 7, 15, 31, ...
  - This gives optimal memory allocation when using the Direct solver
  - It also gives optimal speed performance when using the Krylov solver
  - Increasing the order will give a better representation of the HB solution, especially when the circuit contains square-like or sharp edged waveforms

2. MaxOrder

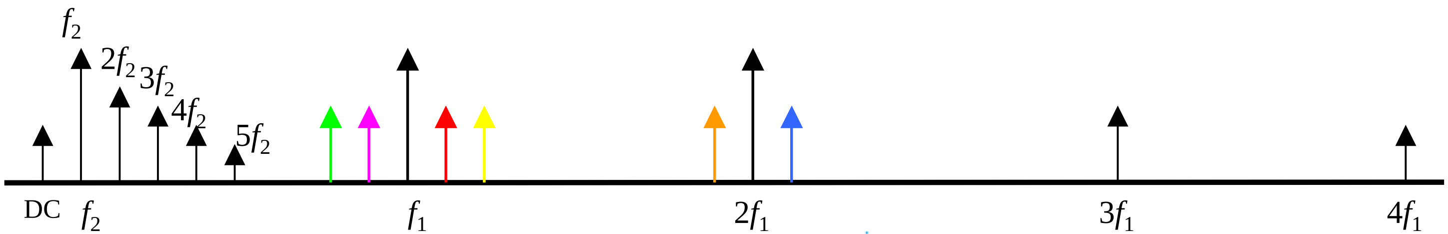
- **What is MaxOrder ?**
  - **Number that determines which mixing products will be computed in HB**



f_1-f_2
$2f_1$-f_2
f_1-$2f_2$
f_1+f_2
$2f_1$+f_2
f_1+$2f_2$

Legend
- DC Component
- Non-Mixed Simulation Frequency
- Mixed Simulation Frequency
- Mixed Simulation Frequency for MaxOrder > 3
- Diamond Truncation

- Two tone simulation, Freq[1]=f_1 with Order[1]=4, Freq[2]=f_2 with Order[2]=5, MaxOrder=3.
- $f_1 >> f_2$ for picture clarity



2. MaxOrder (cont.)

- **Set MaxOrder to get the desired mixing tones.**
- **If there are more mixing tones in the output than are necessary, reduce MaxOrder to get only the desired tones. This will increase the speed of the simulation since the problem size will be smaller.**

Avoid redefining tones

- **Make certain that in multi-tone simulations, tones are NOT defined more than once. In other words, a 1 GHz tone with 3 harmonics means that 2 GHz and 3 GHz are already included in the simulation for computing the HB solution, and these should not be listed as one of the Freq[*i*]'s.**

Freq[1]=1 GHz, Order[1]=3

Freq[2]=300 MHz, Order[2]=3

MaxOrder=4

Set of frequencies (Hz) for computing the HB solution, include: DC, fundamentals, harmonics, and mixing terms.

0, 100M, 300M, 400M, 600M, 700M, 900M, 1.0G, 1.3G, 1.4G, 1.6G, 1.7G, 1.9G, 2.0G, 2.3G, 2.6G, 2.7G, 3.0G, 3.3G

~~**Freq[3]=1.4 GHz**~~

~~**Freq[4]=2.3 GHz**~~

3. Convergence mode

- What is convergence mode?
  - Type of outer (nonlinear) Newton solver
- Use the Auto convergence mode – enhanced Newton solver (default) for ADS2003C and above only
  - Combines capabilities of both basic and advanced convergence modes, it is both fast and robust
  - Works well on a wide range of circuits : fairly linear to highly non-linear waveforms
- If circuit does not converge with Auto, then
  - Increase MaxIters (Maximum Iterations) to 50, or 100
  - Try the Basic convergence mode
  - Try the Advanced convergence mode

3. Convergence mode (cont)

Definition of alternate convergence modes

- **Basic** – standard Newton solver (fast)
- **Advanced** – damped Newton solver (robust)
  - The damping ensures that Newton is converging toward the HB solution.
  - It runs slower due to repeated device evaluations and computing the damping factor.
  - It works well for highly nonlinear circuits

4. Solver

- What is the solver?
  - The inner (linear) solver in HB.
- Use the Direct method
  - This works well for small to medium size circuits.
  - The direct method performs well for HB oscillator simulations, and swept simulations on very nonlinear circuits.
  - For large circuits, the direct method can be much slower than Krylov.
- Switch to the Krylov method:
  - For large circuits with many devices (>50) and multi-tones (>=2)
  - In Krylov, the linear problem is solved approximately, thus allowing it to handle large circuits in a quick and efficient manner.

Convergence Problems, Remedies & Parameters to Adjust for Convergence

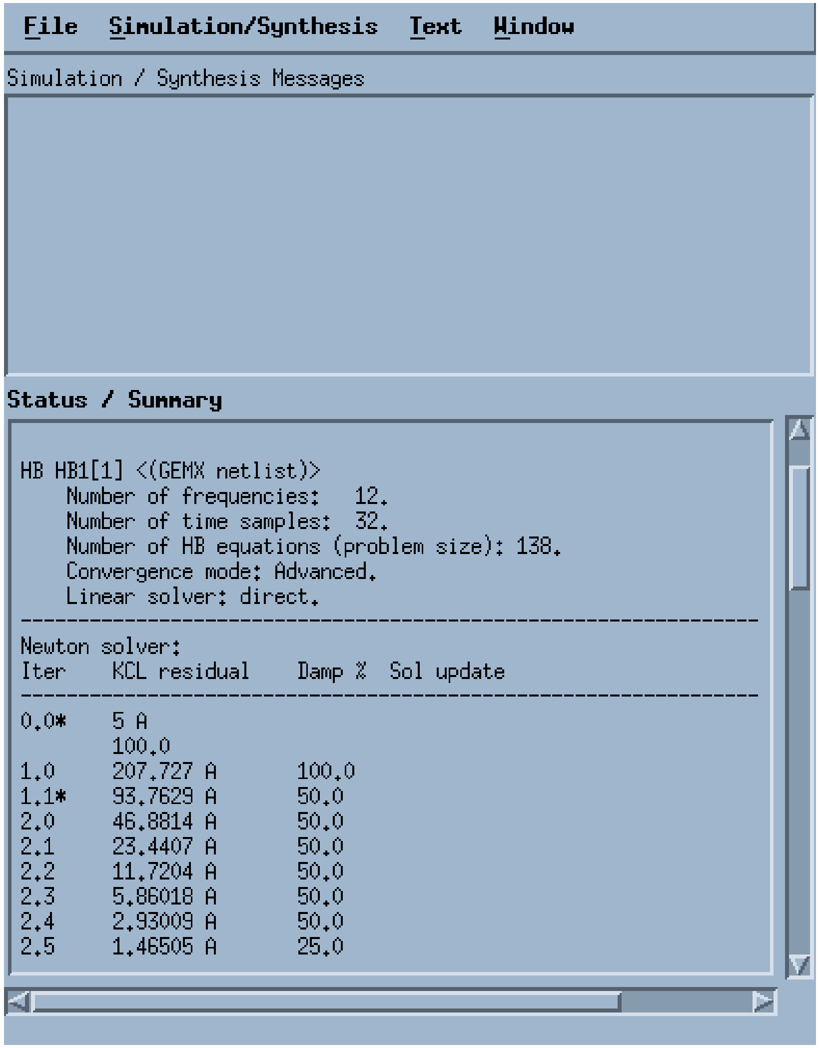
Tips & Terms 5-10

Go to the Params tab of the HB controller to adjust the status level.

Set the status level to 4, and monitor the KCL residual in the status window. The KCL residual indicates how well the simulation has converged up to that point.

Hints, warnings, and error messages, if any, will appear in the status window.

Take appropriate action based on these messages.



Status Window Messages

Error messages with convergence hints given

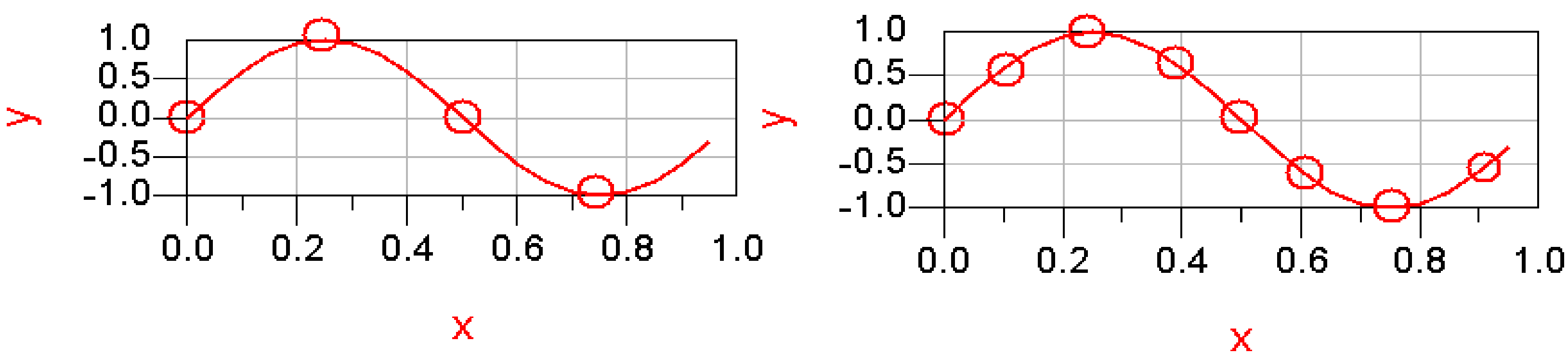
```
Simulation / Synthesis Messages
Error detected by HPEESOFSIM during HB analysis `HB1'.
    No convergence.
Error detected by HPEESOFSIM during HB analysis `HB1'.
    Max. number of Newton iterations reached.
    Convergence hints:
    o Increase max. iterations and re-simulate.
    o Select the Advanced convergence mode,
    set max. iterations to 50-100, and re-simulate.
    o Relax the tolerances and re-simulate.
    o Try to sweep a parameter.
```


5. Oversampling

- **The nonlinear devices are first evaluated in the time domain, and then converted to the frequency domain, using FFT (Fast Fourier Transform)**
- **The Oversample parameter adjusts the sampling rate of the nonlinear device evaluation.**

Oversampling

Number of samples = (2*Order+1)*Oversample, rounded to the nearest power of 2.



Order=1, Oversample=1
Number of samples=(2*1+1)*1=3 => 4

Order=1, Oversample=2
Number of samples=(2*1+1)*2=6 => 8

For each period of the input tone, the simulator will take x number of samples, determined by the values for Order and Oversample.

5. Oversampling (cont.)

- Set Oversample = 2, 4, 8, ... i.e. 2^N for circuits with many nonlinear devices.
  - Oversample is used in order to get more accurate sampling (by reducing aliasing effects) of the device waveforms in the time domain before they are converted to spectra in the frequency domain.
  - The FFT grid is discrete and goes in steps of 2^N.
  - Increasing the oversample may slow down the run time when using the Krylov solver more so than when using the direct solver.

6. Parameter Sweep Setup

- **For single parameter sweeps (in which swept parameter is NOT frequency), use the Sweep tab on the HB controller**
- **For multi-dimensional sweeps, use the sweep tab for the inner most swept parameter, and use the Parameter Sweep controller(s) for the outer most swept parameter(s).**
- **Frequency should always be selected as an outer most swept parameter.**

6. Parameter Sweep as a Convergence Tool

Single point HB simulation non convergence

- Perform a sweep around the point that does not converge to help determine if there is a range of values for which the circuit can converge.
- Perform a swept simulation up to the point for which the circuit converges, and save the solution to be used as an initial guess for the single point simulation that did not converge.
- Simulate the single point with this saved solution as the initial guess, since it may give the Newton solver a better initial guess than the DC solution .

6. Swept HB simulation non convergence

- Adjust convergence parameters and keep restarting the swept simulation from the beginning.
- Split the sweep into two (or more) parts and use the solution from the first part of the sweep as an initial guess for the second part of the sweep.
- Perform a single point simulation for the point which fails to determine if the simulation will converge for just that one particular point of the sweep

- Example of sweeping input power from –20 to 10 dBm
- Suppose the sweep converged only up to 5 dBm. Save the 5 dBm solution.
  - Adjust parameters such as Order, Oversample, number of iterations and resimulate (sweep from 5 to 10 dBm) with the 5 dBm initial guess to see if the circuit will converge beyond 5 dBm.
- A second, more detailed example of sweeping RFfreq on a mixer is given in the Comprehensive Guide to Harmonic Balance

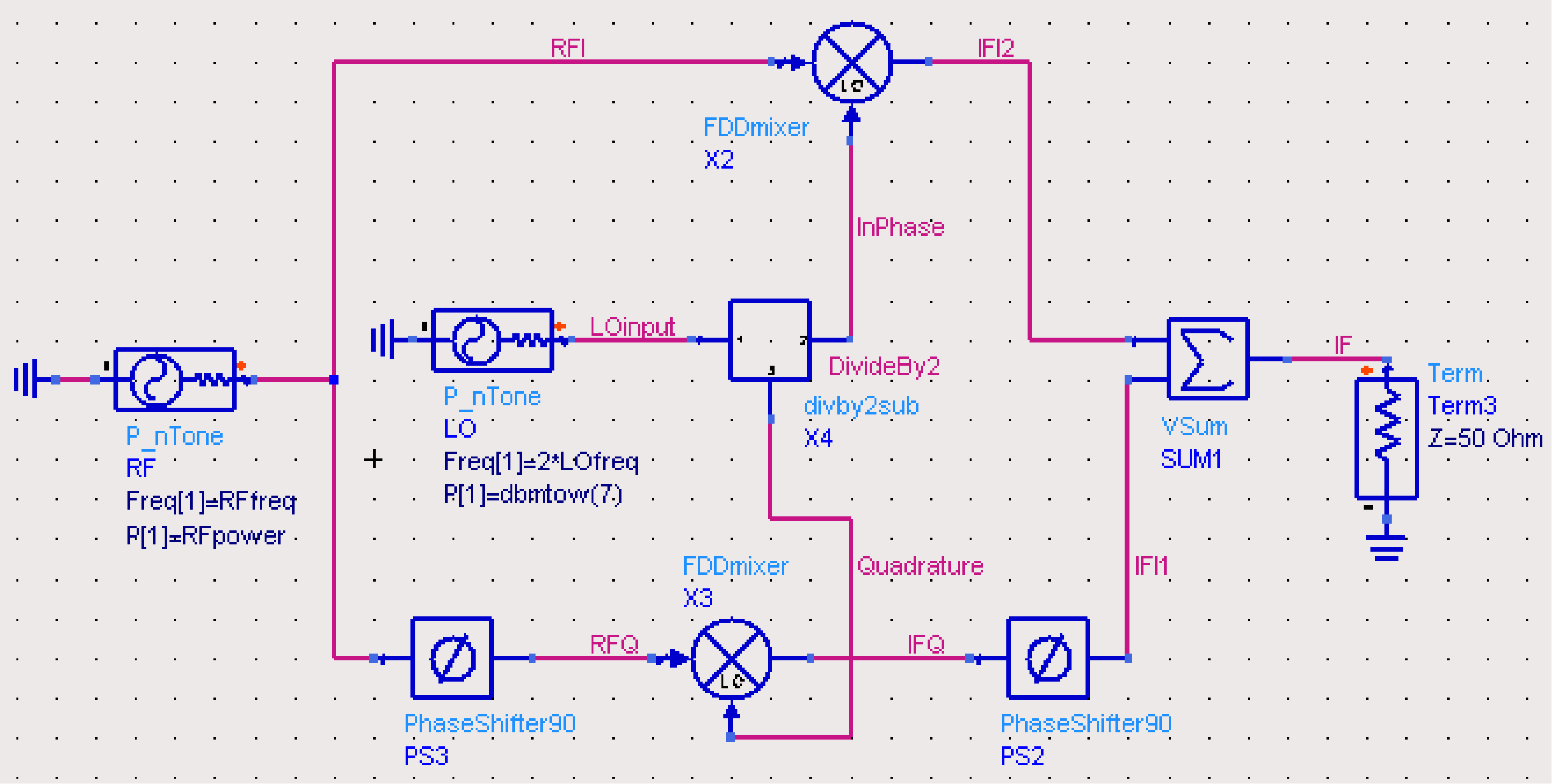
7. Transient Assisted Harmonic Balance (TAHB)

- Use transient simulation results to give Newton a good initial guess
  - Set the transient start and stop times
  - Set Max Time Step small enough to accommodate the largest signal frequency
  - Set the frequency and order on the Freq tab of the transient controller. Check off Write Solution and give the name of the file to be used as an initial guess for the HB simulation
- Run the transient simulation
  - Plot the transient waveform(s) to ensure that the circuit is very near steady state. If necessary, re-run the transient simulation to capture only the portion that is near steady state and does not contain initial overshoots.
  - The TAHB guess does not need to contain all the HB frequencies, i.e., a multitone HB simulation can use a single tone transient initial guess. One could simulate a mixer in transient with only the nonlinear LO, save the solution, and use that for the initial guess in a multitone (LO, RF, and IF) HB simulation.

7. TAHB (cont.)

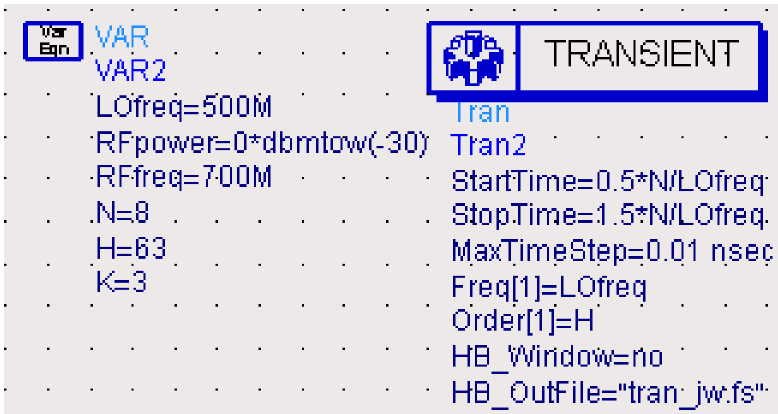
- Harmonic Balance simulation
  - Set the frequency and order on the Freq tab of the HB controller. These should be consistent with the freq and order set in the transient simulation.
  - Check off Use Initial Guess and give the name of the file from the transient simulation to be used as an initial guess for the HB simulation (from the Params tab)

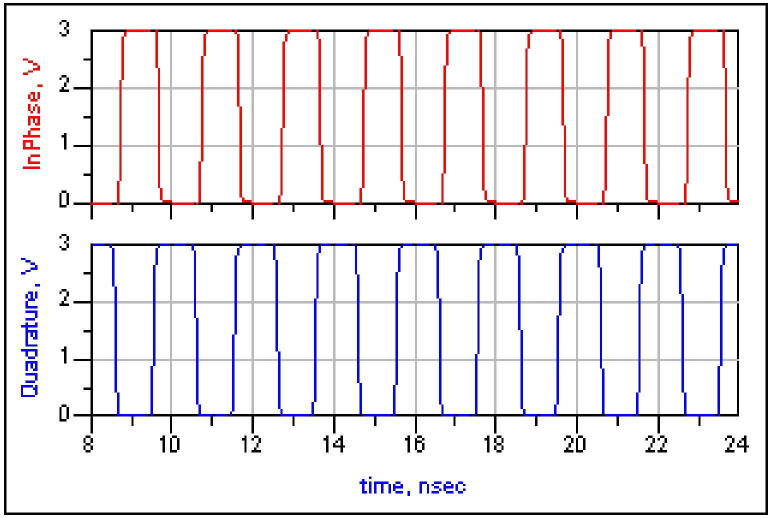
7. Image Rejection Mixer with Divider, using TAHB

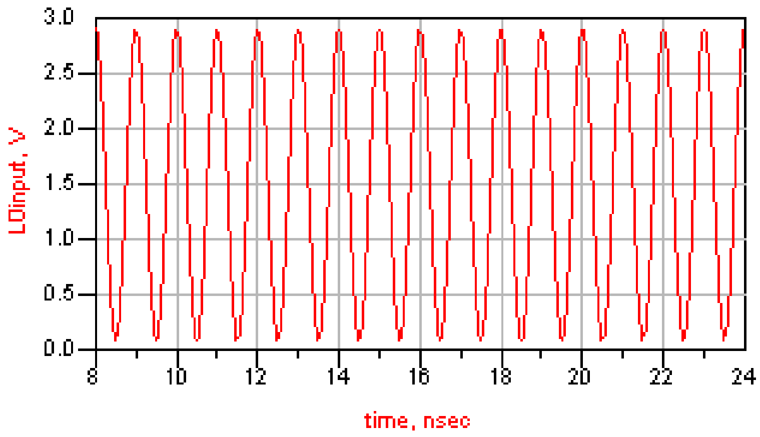


7. Image Rejection Mixer with Divider, using TAHB

• **One tone transient simulation**







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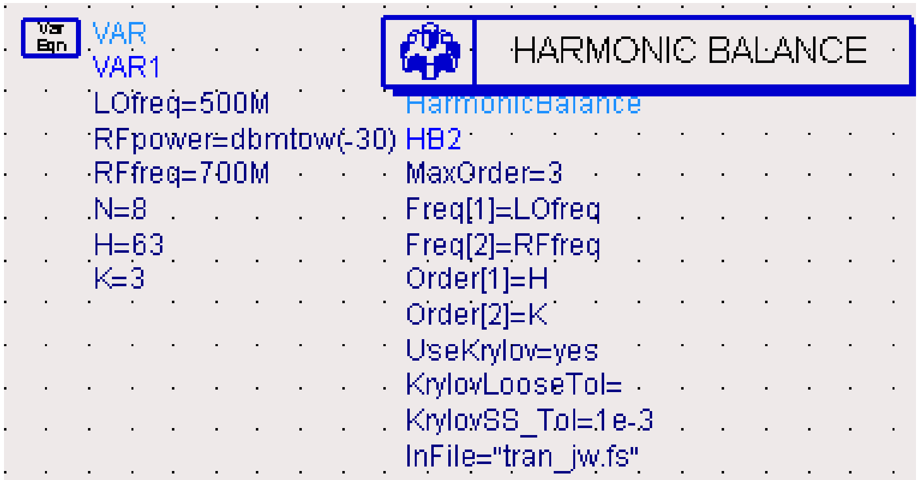
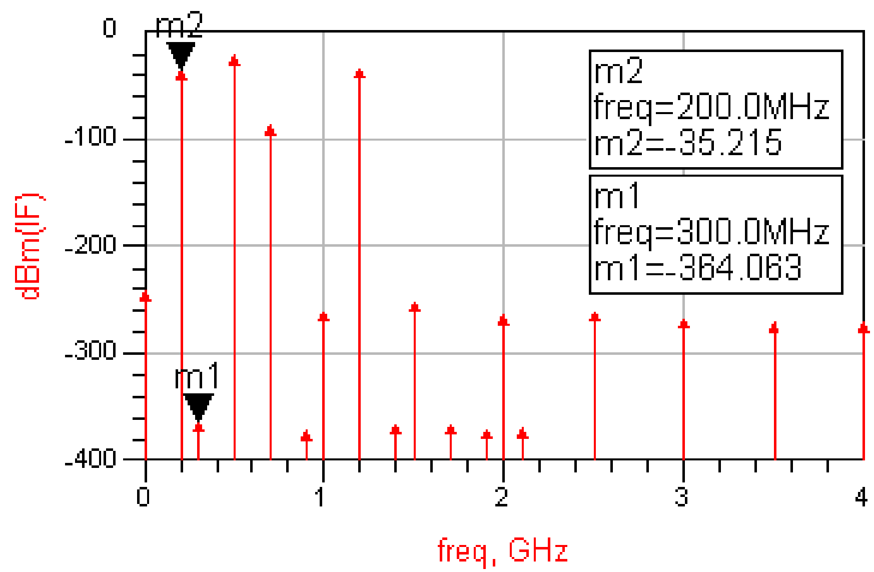
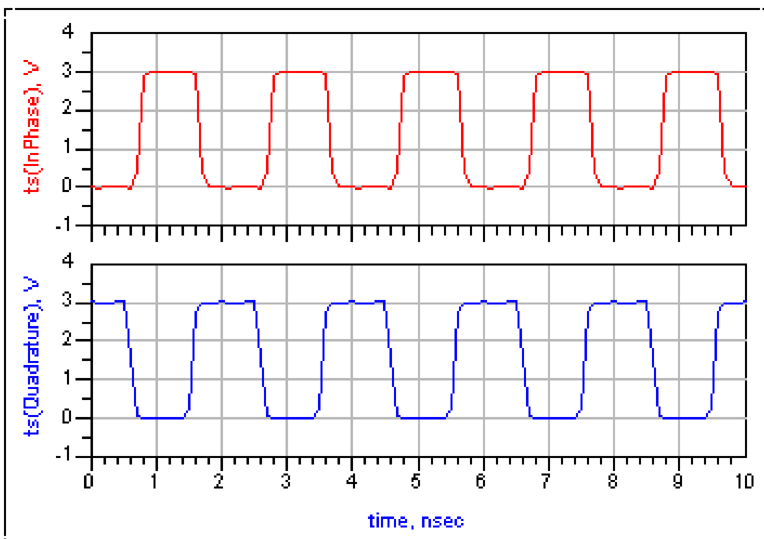
7. Image Rejection Mixer with Divider, using TAHB

• **Multi-tone TAHB simulation**







Eqn ImageRejection=m1-m2

ImageRejection
-328.849

IM=2*LO-RF = 1000-700=300 MHz

IF = LO-RF = 200 MHz

8. The Most Nonlinear Tone

- **The most nonlinear tone is generally the one with the highest power.**
- **In a mixer circuit, there are two tones – LOfreq and RFfreq, and the LOfreq is almost always the most nonlinear tone.**
- **In a multitone simulation, set the first frequency on the controller, "Freq[1]" to the most nonlinear tone.**
- **Also, in a multitone simulation, additional frequencies need to be set on the HB controller corresponding to the fundamental frequencies of the additional sources.**

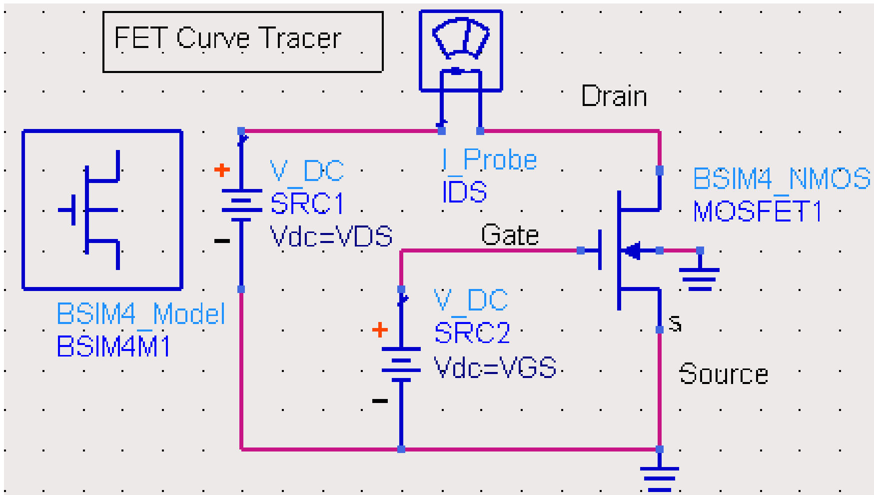
9. Nonlinear Device Models

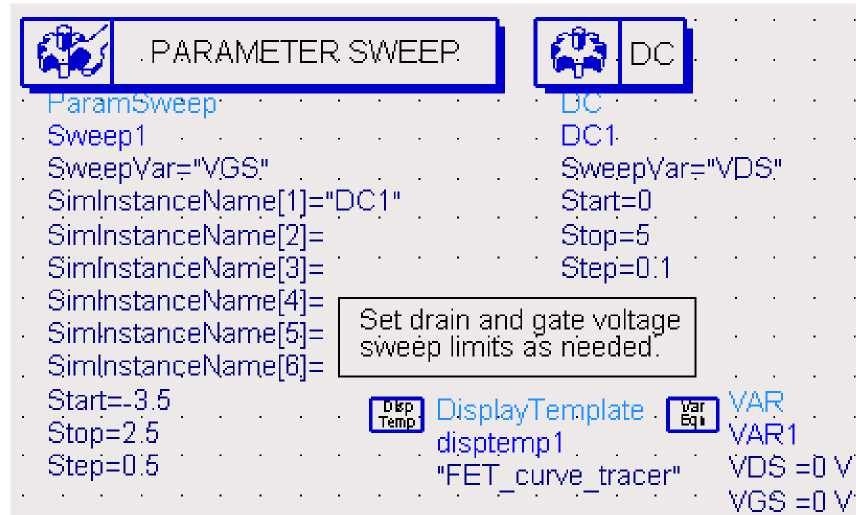
If convergence problems are suspected to be related to the nonlinear devices, then ...

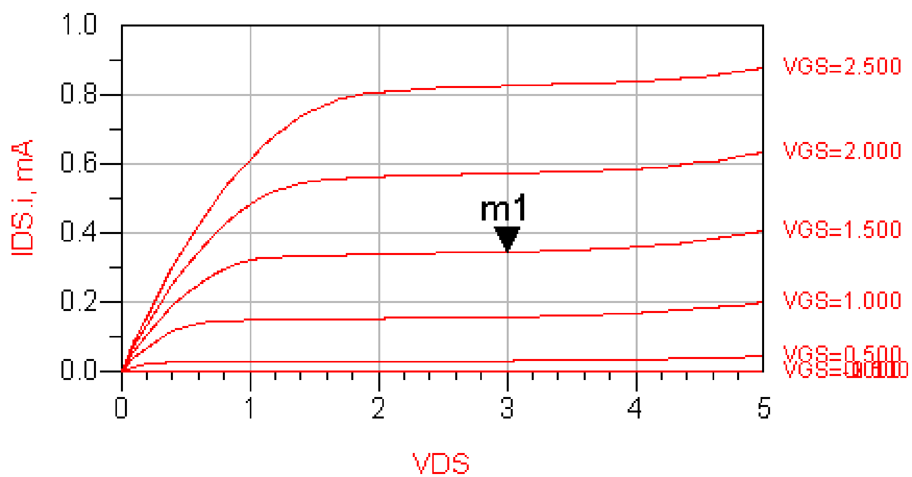
- **Construct a simple circuit, consisting of the device, the model, an input source, and an output load. Perform a DC simulation to check that the device model has continuous DC curves, and has continuous derivatives between saturation (pinch-off), ohmic (triode), forward active, and off regions.**
- **There are templates available in ADS to plot the DC curves. These are the BJT curve tracer and FET curve tracer.**
- **Make sure that the devices are biased properly, and that the model parameters are set to reasonable values.**
- **Check SDD based device models for equation discontinuities between regions, and for unprotected functions that can blow up (such as exp, sqrt, log).**

9. Nonlinear Device Models (cont)

- **Here is a picture of the FET curve tracer (and setup) template in ADS**







m1
VDS=3.00
m1=346.u
VGS=1.500000

Device Power Consumption at m1 bias point, Watts

VDS	3.000	0.001

10. Additional Krylov Parameters

GMRES Restart Length

- GMRES is (one of) the Krylov solvers and, the parameter GMRES_Restart determines the number of iterations after which the solver is restarted.
- If Krylov converges slowly, its iterations may be terminated before the linear problem can be solved to an acceptable degree of accuracy.
- Watch for the message *"GMRES terminating due to insufficient rate of convergence"*
- Increase GMRES_Restart to 50, 100, or 1000 and resimulate.

10. Additional Krylov Parameters (cont.)

Preconditioners

- They increase the convergence rate of the Krylov solver; they are needed for the Krylov solver to perform efficiently. They can have an effect on HB (Newton) convergence.
- Change the preconditioner from DCP (default) to BSP or SCP if increasing GMRES_Restart did not improve the Krylov convergence, or a message is given stating that the DCP has failed. This is a last resort type of remedy.
- The BSP and SCP are very complex preconditioners and require a large amount of memory; however, they are useful for getting convergence with very nonlinear circuits.

Changing the tolerances

- This is a last resort type of remedy, and it is NOT recommended
- Some guidelines for changing the tolerances are
  - Monitor the KCL residual in the status window and insert an Options controller on the schematic.
  - If KCL residuals are on the order of micro or nano amps, then relax the current absolute tolerance (I_AbsTol) from 1pA to 1nA.
  - If KCL residuals are on the order of milli amps, then relax the current relative tolerance (I_RelTol) from 1e-6 to 1e-4.
  - If the status window shows consecutive values in the Solution Updates (Sol update) column, then relax the voltage tolerances (V_AbsTol, V_RelTol) from 1e-6 to 1e-4.

Summary of top 10 tips & tricks for HB simulation

1. **Order -** Set 2^N-1, increase order for highly nonlinear waveforms, and to get a more accurate solution
2. **Max Order** - Mixing terms, avoid redefining tones on the HB controller
3. **Convergence Mode** - Use Auto. Increase Max Iterations, try basic, advanced.
4. **Solver** - Use direct (med. size circuits, oscillators), use Krylov (large circuits)
5. **Oversample** - Set to 2^N, increase if circuit has many nonlinear devices.
6. **Parameter Sweeps** – Set frequency as outer most swept param, split-up sweep into sections, save solution and use for next part of the sweep.
7. **TAHB** –Use for very nonlinear circuits with sharp edged wavefoms. Gives Newton a better initial guess. First tran, then HB. Verify transient initial guess.
8. **Most nonlinear tone** – Set this to Freq[1] on the HB controller
9. **Nonlinear devices** – Check DC curves, DC bias, SDDs and unprotected functions
10. **Additional Krylov parameters** – Increase GMRES_Restart, then change the preconditioner

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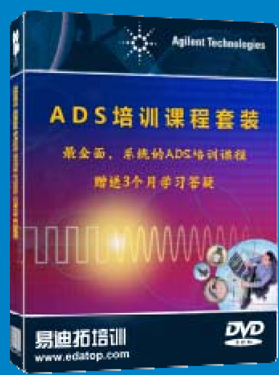

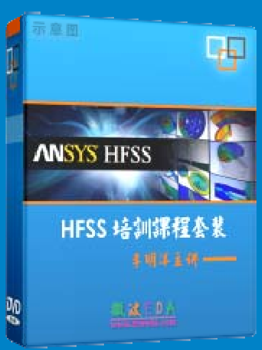

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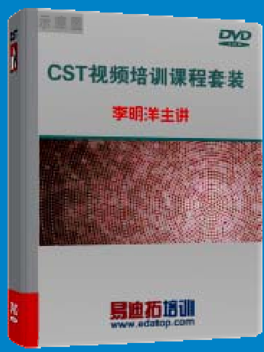

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课程网址：http://www.edatop.com/peixun/hfss/122.html

13.56MHz NFC/RFID 线圈天线设计培训课程套装

套装包含 4 门视频培训课程，培训将 13.56MHz 线圈天线设计原理和仿真设计实践相结合，全面系统地讲解了 13.56MHz 线圈天线的工作原理、设计方法、设计考量以及使用 HFSS 和 CST 仿真分析线圈天线的具体操作，同时还介绍了 13.56MHz 线圈天线匹配电路的设计和调试。通过该套课程的学习，可以帮助您快速学习掌握 13.56MHz 线圈天线及其匹配电路的原理、设计和调试…

详情浏览：http://www.edatop.com/peixun/antenna/116.html

我们的课程优势：

※ 成立于 2004 年，10 多年丰富的行业经验，

※ 一直致力并专注于微波射频和天线设计工程师的培养，更了解该行业对人才的要求

※ 经验丰富的一线资深工程师讲授，结合实际工程案例，直观、实用、易学

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