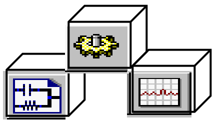
Topic 7:

Harmonic Balance



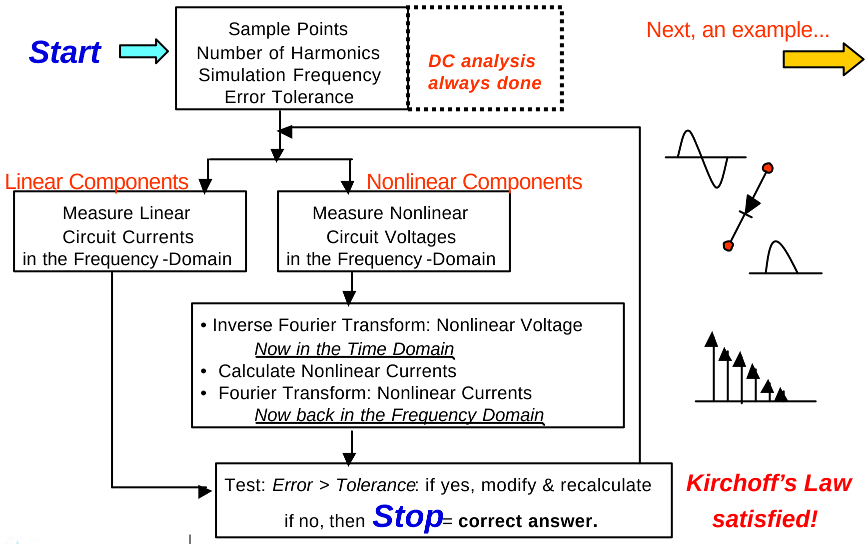
Harmonic Balance Simulation

Analyze circuits with Linear and Non-linear components:

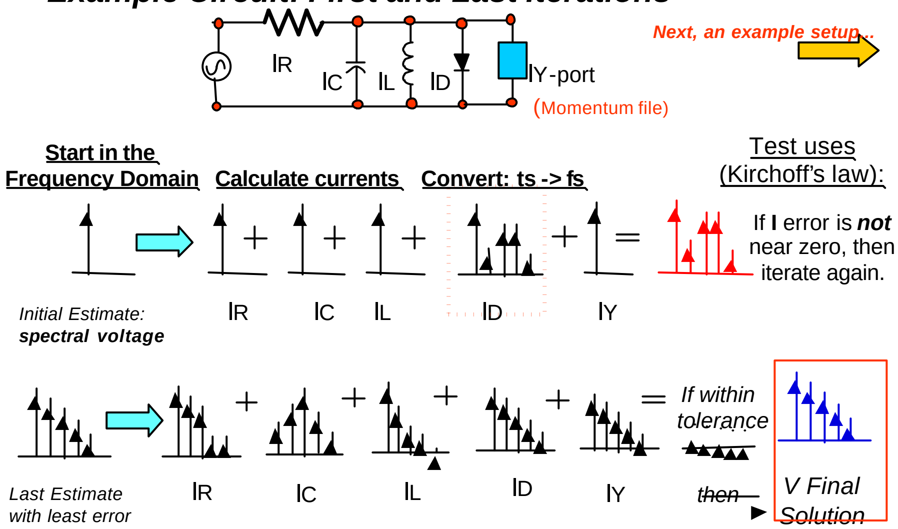
- *You define the tones, harmonics, and power levels*
- *You get the spectrum: Amplitude vs. Frequency*
- *Data can be transformed to time domain (ts function)*
- *Solutions use Newton-Raphson technique*
- *Krylov subspace method also available (large circuits)*
- *Use only Frequency domain sources*
- *Similar to Spectrum Analyzer*

HB flowchart...

Harmonic Balance Simulation Flow Chart



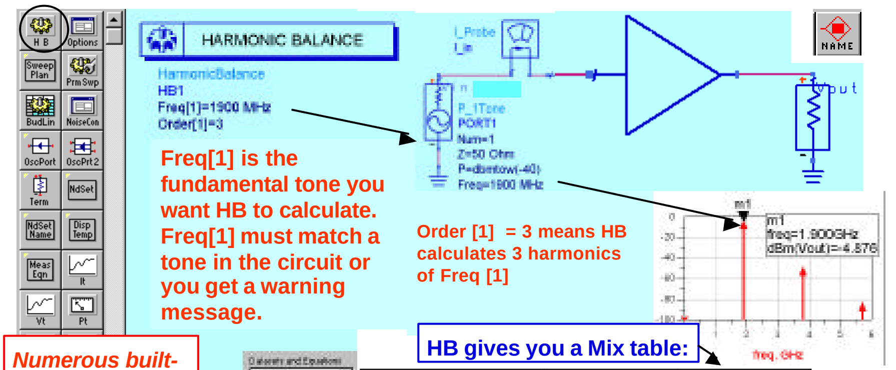
Example Circuit: First and Last Iterations



NOTE: Try building the circuit, simulate, and write an equation to sum the currents. The IY-port could be S-parameter data from Momentum or other NWA data.

Basic 1 Tone HB simulation setup

Basic HB controller and source setup gives you spectral tones:



Freq[1] is the fundamental tone you want HB to calculate. Freq[1] must match a tone in the circuit or you get a warning message.

Order [1] = 3 means HB calculates 3 harmonics of Freq [1]

Numerous built-in sources and measurement equations.

HB gives you a Mix table:

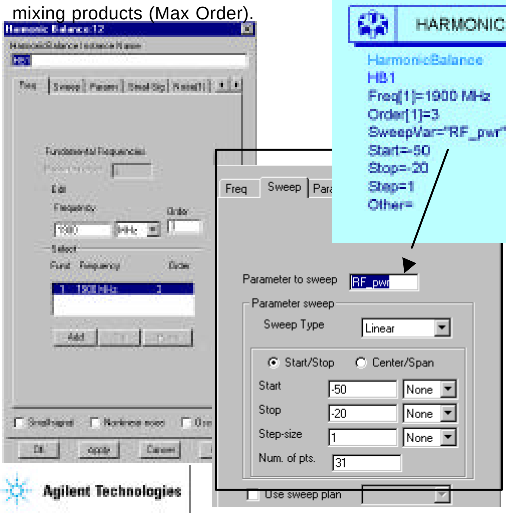
freq	Vout	Mix
0.0000 Hz	0.000 / 0.000	0
1.900GHz	0.180 / -14.199	1
3.800GHz	0.001 / -170.939	2
5.700GHz	1.963E-5 / 46.135	3

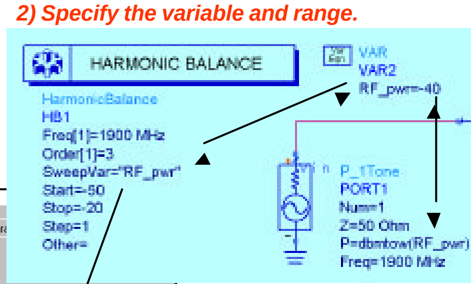
Next, sweeping variables...

Swept variables in Harmonic Balance

HB Freq tab: specify tones (Freq), harmonics (Order), and mixing products (Max Order).

1) Initialize the VAR to sweep.
2) Specify the variable and range.





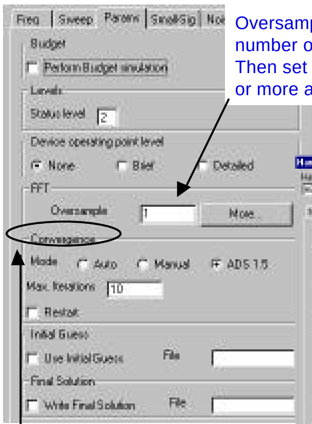
3) Be sure the VAR, the source, and simulation controller all have the same information.

NOTE: Swept variables always go to the dataset.

Next, other tabs...

Other settings (tabs) in Harmonic Balance

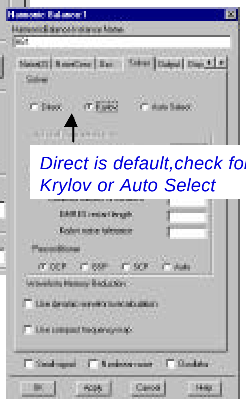
Params



Oversample: Set status level to 4, see number of samples for non-linears. Then set oversample for convergence or more accuracy.

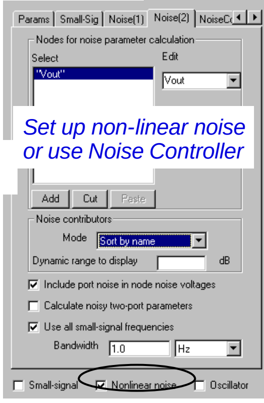
Convergence can be set to Auto for larger non-linear circuits. Initial guess/file is used for Transient assisted HB: use for circuits that do not converge with HB alone.

Solver



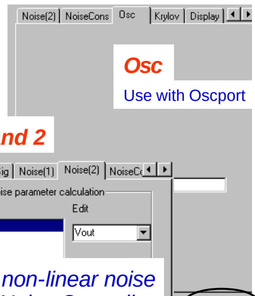
Direct is default,check for Krylov or Auto Select

Noise 1 and 2



Set up non-linear noise or use Noise Controller

Osc



Use with Oscport

XDB...

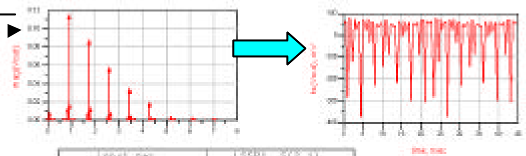
Related HB controllers XDD and LSSP ...

HARMONIC BALANCE
HarmonicBalance
HB1
Freq[1]=1.0 GHz
Order[1]=3

LSSP
LSSP
HB3
Freq[1]=1.0 GHz
Order[1]=3
LSSP_FreqAtPort[1]=

GAIN COMPRESSION
XDB
HB4
Freq[1]=1.0 GHz
Order[1]=3
GC_XdB=1
GC_InputPort=1
GC_OutputPort=2
GC_InputFreq=1.0 GHz
GC_OutputFreq=1.0 GHz
GC_InputPowerTol=1e-3
GC_OutputPowerTol=1e-3
GC_MaxInputPower=100

Transform HB spectrum into the time domain with ts function: ts(Vout).



[illegible]	LSSP1..S(2,1)
1.000	-3.005 + j3.256
2.000	-3.003 + j3.243
3.000	-3.001 + j3.229
4.000	-2.999 + j3.212
5.000	-2.997 + j3.192
6.000	-2.996 + j3.168
7.000	-2.994 + j3.135
8.000	-2.992 + j3.092
9.000	-2.991 + j3.042
10.000	-2.989 + j2.989

Next, sources...

XDB simulation results: 1 dB compression

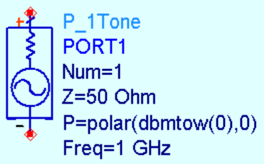
inpwr[1]	outpwr[1]
-31.251	-21.268

You will use HB and XDB in the lab!

Types of Power Sources for HB

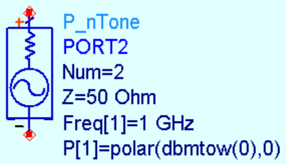
Default power function for these sources is **polar**,

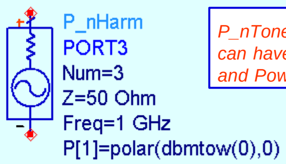
but you can simplify it on the screen as: dmbtow(0)
Therefore, dbmtow(0) *is the same as* polar(dbmtow(0),0)



Notice that these sources are also **ports** (OK for S-param analysis).

Also, they can be considered ***noiseless*** like sources in a measurement system.





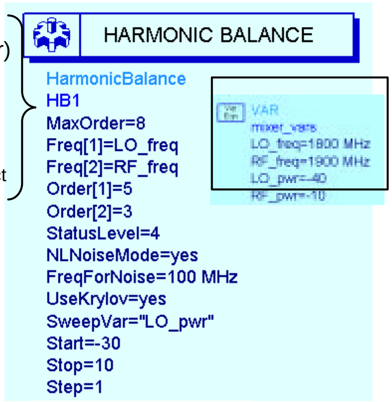
P_nTone and P_nHarm can have multiple Freqs and Power.

Next, a mixer example...

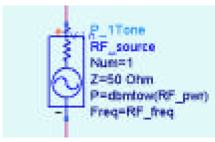
Example: HB simulation setup for a mixer with swept LO power

Mixer example:

Freq [1] fundamental tone (most power: LO for mixer)
Freq [2] fundamental tone (RF for mixer)
Order [1] number of harmonics for Freq [1]: LO.
Order [2] number of harmonics for Freq [2]: RF.
MaxOrder = mixing products, depends on Order[n].
NOTE: Here if MaxOrder = 9 , you won't get 9th order product because Order[1] and [2] only go up to the 8th order.



LO and RF sources:



Do not do this: Freq = LO_freq MHz or MHz units will multiply.

LO_pwr goes to the dataset automatically. RF_pwr can be sent using Output tab.

data

Example data: use mix function on Mix table

DC term=0. Freq, harmonics [order], and products [max order] are indexed:

Mixer example: Max order=8

LO order=5 RF order=3

freq	LO Mix(1)	RF Mix(2)
0.0000 Hz	0	0
100.0MHz	-1	1
200.0MHz	-2	2
300.0MHz	-3	3
1.500GHz	4	-3
1.600GHz	3	-2
1.700GHz	2	-1
1.800GHz	1	0
1.900GHz	0	1
2.000GHz	-1	2
2.100GHz	-2	3
3.300GHz	5	-3

LO: Freq[1]=1800 MHz RF: Freq[2]=1900 MHz

To get dBm of IF (100 MHz) at Vout, use the *mix* function:

Arguments in parentheses ( ) and curly braces {generate the matrix }, required for *Mix table*.

8th order term uses +5th & -3th, but not: -3th & +5th (+5th of RF does not exist).

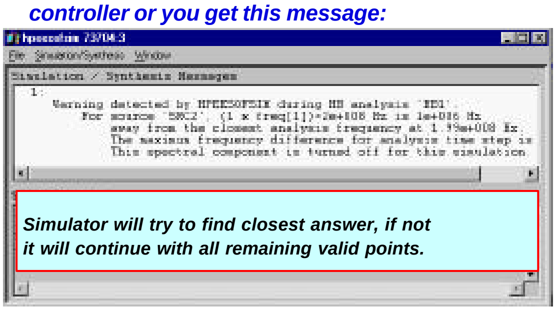
QUIZ: Can you use this equation: dBm(Vout[1]) for this data? Is it valid?

Answer: ***YES*** *- if no other dependencies exist - it's the same as:* **dBm(mix(Vout,{-1,1}))**

Next, HB convergence...

Harmonic Balance convergence & errors

Freq [x] in each source must match Freq [x] in the controller or you get this message:



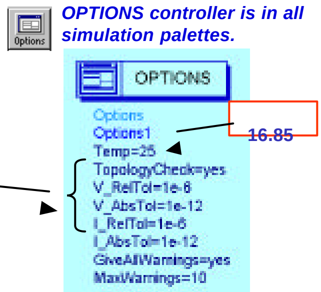
HB convergence error message:
"cannot sweep to desired level"
or "arc length continuation error"

Solutions: *loosen V and I tolerances in the Options controller by 10x (for example, set: I_AbsTol= e-11), or reduce the step size for power or frequency sweeps.*
Also, try Transient assisted HB!

TIPS

NOISE TEMP error for all noise simulations: Set Temp=16.85 to eliminate any error message.

OPTIONS controller is in all simulation palettes.



TIP about “quotes”, brackets, braces, etc.

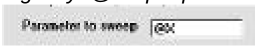
QUOTES:

• Only when editing on the screen for string value parameters, if necessary.

• When in doubt, double click and use the dialog boxes.

Exceptions - Swept variables are always in quotes and controller names (“HB1”) in opt goals.

In dialog only: @ stops quotes when not needed.



If you see 2 quotes “”X””, remove one set!

REVIEW: Parentheses, Brackets, Curly braces:

Double colon is a wildcard in ADS:

(parentheses for function arguments)
[brackets for one, two, or three dimensional data]:
{curly braces for vectors and the mix function}:

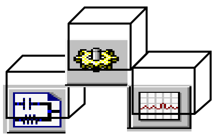
LAB

Examples: **dBm(Vout [1])** **dBm(mix(Vout,{-1,1}))** **mag(Vout [1:: 6])**

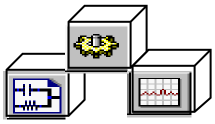
What the lab is about ...

Lab 7:

Harmonic Balance Simulations



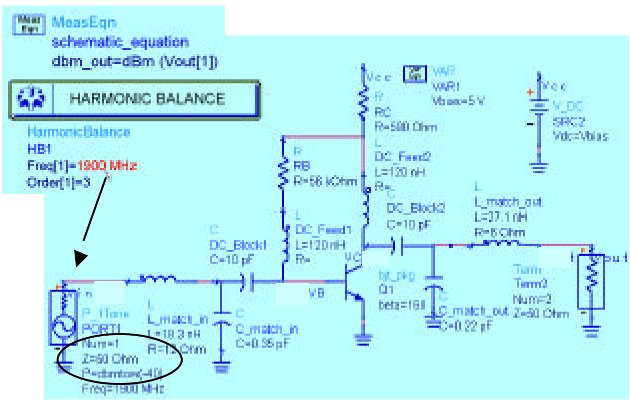
Steps in the Design Process



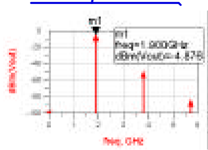
- Design the RF sys behavioral model receiver
- Test conversion gain, spectrum, etc.
- Start amp_1900 design – subckt parasitics
- Simulate amp DC conditions & bias network
- Simulate amp AC response - verify gain
- Test amp noise contributions – tune parameters
- Simulate amp S-parameter response
- Define amp matching topology and tune input
- Optimize the amp in & out matching networks
- Filter design – lumped 200MHz LPF
- Filter design – microstrip 1900 MHz BPF
- Transient and Momentum filter analysis
- **Amp spectrum, delivered power, Zin - HB**
- **Test amp comp, distortion, two-tone, TOI**
- CE basics for spectrum and baseband
- CE for amp_1900 with GSM source
- Replace amp and filters in rf_sys receiver
- Test conversion gain, NF, swept LO power
- Final CDMA system test CE with fancy DDS
- Co-simulation of behavioral system

You are here: → Amp spectrum, delivered power, Zin - HB

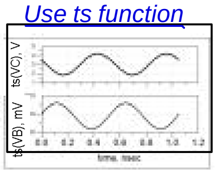
First, one tone HB and Meas Eqn



Plot Spectrum



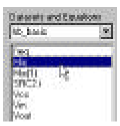
Use ts function



List MeasEqn results

dbm_out
-4.876

Dataset contains node voltages and Mix table.

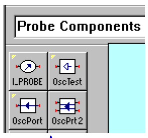


freq	Vout	Mix
0.0000 Hz	0.000 / 0.000	0
1.900GHz	0.180 / -14.199	1
3.800GHz	0.001 / -170.939	2
5.700GHz	1.963E-5 / 46.135	3

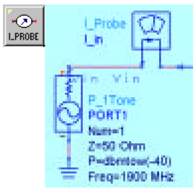
Equation uses Vout[1]

Next, simulate Power Delivered and Zin

Probe Components palette



NOTE for Oscillator testing: Use OscTest to determine if oscillation exists (S-param). Use OscPort to determine the frequency of oscillation (HB). See examples!



Rename the probe: I_in

Data display equations calculate power using voltage Vin and current I_in.

Eqn P_del_dBm = 10*log (0.5*real (Vin[1]*conj(I_in.i[1])))+30

NOTE: 0.5 is for 1/2 peak value and +30 give dBm (ref to 0.001 W)

Z_in is calculated at 1900 MHz which is index value [1]. Also, Z_in is used in dBm argument instead of default of 50.

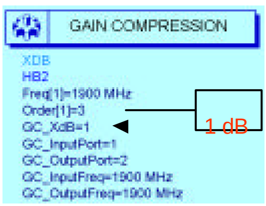
Eqn Z_in = Vin[1] / I_in.i[1]

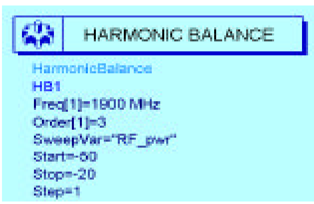
Z_in
47.619 / 0.686

dBm(Vin[1],Z_in)	dBm(Vin[1])	P_del_dBm
-40.003	-40.214	-40.003

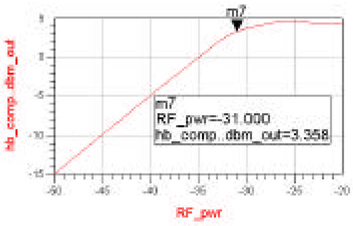
XDB and power swept compression

2 ways to simulate gain compression using HB





inpwr[1]	outpwr[1]
-30.671	3.498

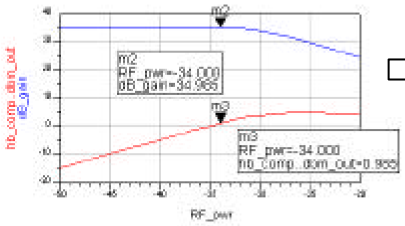


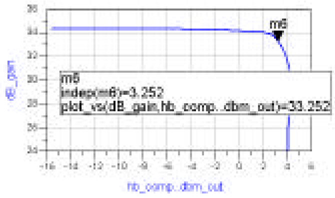
XDB can be set up very quickly for almost any circuit!

Write equations using swept power data

Eqn dB_gain = hb_comp..dbm_out - hb_comp..RF_pwr

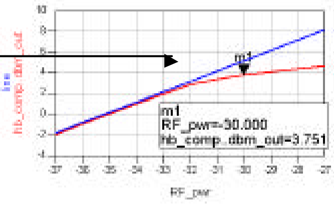
Plot_vs function





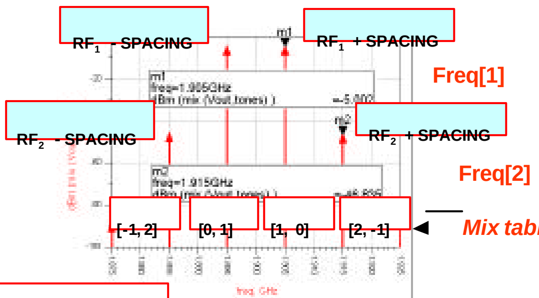
Create a line: nonlinear to linear

Eqn line = hb_comp..RF_pwr + dB_gain [0]

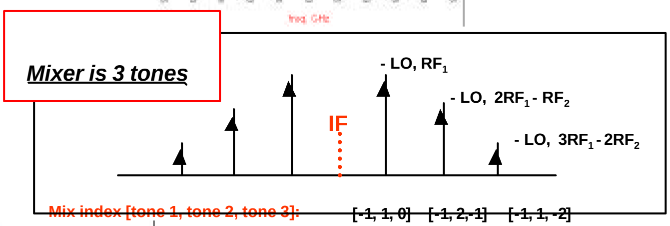


Simulating closely spaced tones...

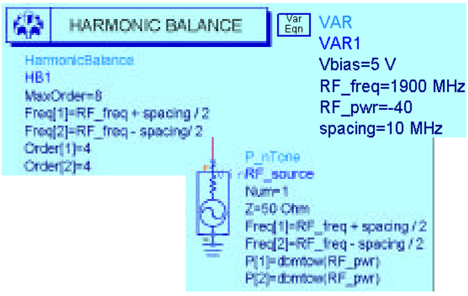
Use 2 tones, such as RF +/- spacing (VAR)



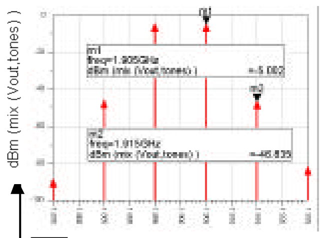
Lab setup and data



Two-tone HB simulation, data, DDS equation



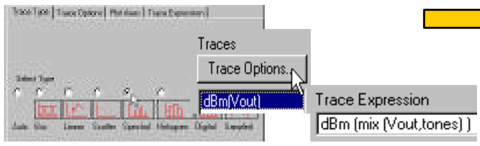
Spacing @ 10 MHz = 1.895 and 1.905 GHz



Eqn *tones* generates the index values!

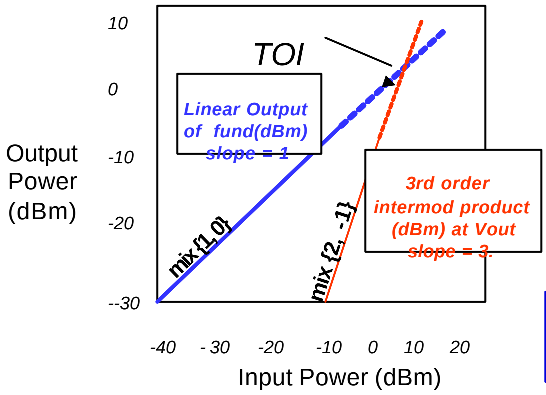
Eqn tones=[{1,0},{0,1},{2,-1},{1,-2}]

Use [brackets to generate a matrix] and { curly braces to vector the data from Mix table}



TOI or IP3 Measurement

When the input power drives the non-linear device into saturation or distortion, third order products near the desired frequency can become large. The point at which 3rd order products intercept the linear rise in output power is the intercept point TOI or IP3.



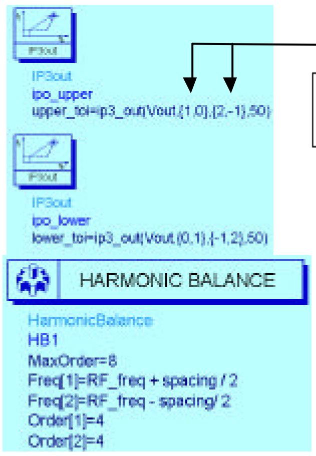
A measurement equation is used to get the answer...

Lab setup and data

NOTE for mixer 3 tones use:
mix{-1,1,0}
mix { 1, 2, -1}

TOI simulation setup using IP3 equations

Built-in measurements use functions - you set the arguments.



2-tone Mix HB data

1.885GHz	-1	2
1.895GHz	0	1
1.905GHz	1	0
1.915GHz	2	-1

Result of IP3 eqns in DDS:

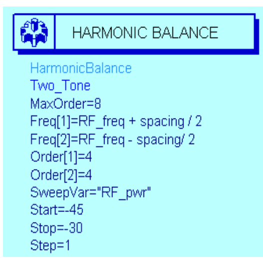
lower_toi	upper_toi
15.679	15.914

MIXERS: use this setup for 3 tone TOI.

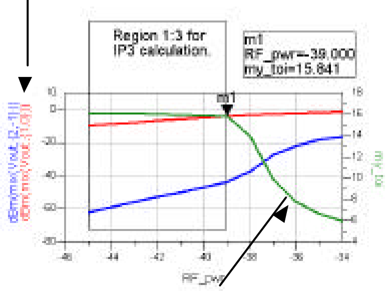
HarmonicBalance
HB1
MaxOrder=10
Freq[1]=LO_freq
Freq[2]=RF_freq + f_spacing / 2
Freq[3]=RF_freq - f_spacing / 2
Order[1]=7
Order[2]=3
Order[3]=3

OPTIONAL: Sweep RF pwr vs TOI equation

Compare swept values to values in the TOI measurement range:



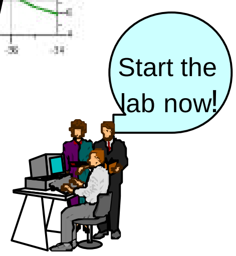
Swept values used for IP3



Eqn my_toi = ip3_out(Vout,{1,0},{2,-1},50)

The Eqn, ***my_toi***, is on the right Y axis.
When RF_pwr is greater than 39dBm, RF and third order slopes are no longer 1:3.

NOTE : The Extra Exercise shows HB swept frequency!



射频和天线设计培训课程推荐

易迪拓培训(www.edatop.com)由数名来自于研发第一线的资深工程师发起成立，致力并专注于微波、射频、天线设计研发人才的培养；我们于 2006 年整合合并微波 EDA 网(www.mweda.com)，现已发展成为国内最大的微波射频和天线设计人才培养基地，成功推出多套微波射频以及天线设计经典培训课程和 ADS、HFSS 等专业软件使用培训课程，广受客户好评；并先后与人民邮电出版社、电子工业出版社合作出版了多本专业图书，帮助数万名工程师提升了专业技术能力。客户遍布中兴通讯、研通高频、埃威航电、国人通信等多家国内知名公司，以及台湾工业技术研究院、永业科技、全一电子等多家台湾地区企业。

易迪拓培训课程列表：http://www.edatop.com/peixun/rfe/129.html

射频工程师养成培训课程套装

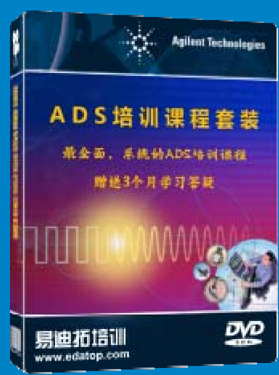
该套装精选了射频专业基础培训课程、射频仿真设计培训课程和射频电路测量培训课程三个类别共 30 门视频培训课程和 3 本图书教材；旨在引领学员全面学习一个射频工程师需要熟悉、理解和掌握的专业知识和研发设计能力。通过套装的学习，能够让学员完全达到和胜任一个合格的射频工程师的要求…

课程网址：http://www.edatop.com/peixun/rfe/110.html

ADS 学习培训课程套装

该套装是迄今国内最全面、最权威的 ADS 培训教程，共包含 10 门 ADS 学习培训课程。课程是由具有多年 ADS 使用经验的微波射频与通信系统设计领域资深专家讲解，并多结合设计实例，由浅入深、详细而又全面地讲解了 ADS 在微波射频电路设计、通信系统设计和电磁仿真设计方面的内容。能让您在最短的时间内学会使用 ADS，迅速提升个人技术能力，把 ADS 真正应用到实际研发工作中去，成为 ADS 设计专家...

课程网址： http://www.edatop.com/peixun/ads/13.html



HFSS 学习培训课程套装

该套课程套装包含了本站全部 HFSS 培训课程，是迄今国内最全面、最专业的 HFSS 培训教程套装，可以帮助您从零开始，全面深入学习 HFSS 的各项功能和在多个方面的工程应用。购买套装，更可超值赠送 3 个月免费学习答疑，随时解答您学习过程中遇到的棘手问题，让您的 HFSS 学习更加轻松顺畅…

课程网址：http://www.edatop.com/peixun/hfss/11.html

CST 学习培训课程套装

该培训套装由易迪拓培训联合微波 EDA 网共同推出，是最全面、系统、专业的 CST 微波工作室培训课程套装，所有课程都由经验丰富的专家授课，视频教学，可以帮助您从零开始，全面系统地学习 CST 微波工作的各项功能及其在微波射频、天线设计等领域的设计应用。且购买该套装，还可超值赠送 3 个月免费学习答疑…

课程网址：http://www.edatop.com/peixun/cst/24.html

HFSS 天线设计培训课程套装

套装包含 6 门视频课程和 1 本图书，课程从基础讲起，内容由浅入深，理论介绍和实际操作讲解相结合，全面系统的讲解了 HFSS 天线设计的全过程。是国内最全面、最专业的 HFSS 天线设计课程，可以帮助您快速学习掌握如何使用 HFSS 设计天线，让天线设计不再难…

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

联系我们：

※ 易迪拓培训官网：http://www.edatop.com

※ 微波 EDA 网：http://www.mweda.com

※ 官方淘宝店：http://shop36920890.taobao.com