Stephen Long
Professor, Electrical and Computer Engineering,
University of California, Santa Barbara

RFIC Mixer Design with ADS

About the Author

Steve Long

- University of California, Santa Barbara
- Professor, Electrical and Computer Engineering

BIOGRAPHICAL SKETCH

Stephen Long received his BS degree in Engineering Physics from UC Berkeley and MS and PhD in Electrical Engineering from Cornell University. He has been a professor of electrical and computer engineering at UC Santa Barbara since 1981. The central theme of his current research projects is rather practical: use unconventional digital and analog circuits, high performance devices and fabrication technologies to address significant problems in high speed electronics such as low power IC interconnections, very high speed digital ICs, and microwave analog integrated circuits for RF communications. He teaches classes on communication electronics and high speed digital IC design.

Prior to joining UCSB, from 1974 to 1977 he was a Senior Engineer at Varian Associates, Palo Alto, CA. From 1978 to 1981 he was employed by Rockwell International Science Center, Thousand Oaks, CA as a member of the technical staff.

Dr. Long received the IEEE Microwave Applications Award in 1978 for development of InP millimeter wave devices. In 1988 he was a research visitor at GEC Hirst Research Centre, U.K. In 1994 he was a Fulbright research visitor at the Signal Processing Laboratory, Tampere University of Technology, Finland and a visiting professor at the Electromagnetics Institute, Technical University of Denmark. He is a senior member of the IEEE and a member of the American Scientific Affiliation.

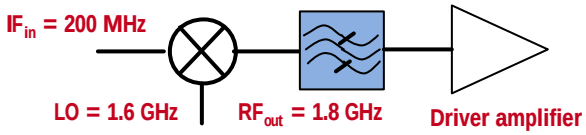
Motivation – Why ADS for RFIC mixer design?

- **Mixer DesignGuide provides analysis tools for:**
  - **DC, RF spectrum, impedance matching, gain, gain compression, N_dB compression, IMD and TOI, noise figure, dynamic range, ACPR**
  - **Parameter, frequency, RF and LO power sweeps**
  - **Library of mixer examples**
- **Speeds up learning curve for ADS –**
  - **Become effective more quickly**
  - **Set up complicated simulations that would take days to prepare in a few minutes**

The mixer DesignGuide is intended to enhance productivity of RF designers by providing an extensive collection of analysis tools that can be easily loaded into your project from a pulldown menu. Each pair of these analysis network and displays, which could take days to set up and verify, can be easily adapted for your mixer circuit simulation requirements.

Introduction

- **Design sequence very dependent on application**
  - **Upconversion application selected as example: base station**
  - **Gilbert cell MOSFET double-balanced differential mixer**



  - **0.35 mm CMOS process; 3.3 volt supply**
  - **Design for largest dynamic range**
  - **Convert to single-ended output**

A transmit mixer application is selected to illustrate a design procedure that is enabled by the Mixer DesignGuide. The input baseband or IF signal is centered at 200 MHz. The output is at 1.8 GHz. We will assume that the mixer is intended for a base station power amplifier application.

The mixer will use 0.35 µm MOSFETs with a default device model parameter set. Of course, you will need to substitute your own verified MOSFET model parameters for the default set. Otherwise, there would be no hope of any correspondence between simulation and measurement for the mixer characteristics that are more sensitive to model nonlinearities. This would especially be true for intermodulation simulations and noise.

Learning Objectives:

Design a high dynamic range mixer for transmit applications

- **Learn how to make use of the Agilent ADS Mixer DesignGuide**
- **Understand the important design and analysis tools for this application**
- **Specify performance: Gain, NF, P_{1dB}, TOI, Dynamic Range**
- **Improve the design: add resonator and convert to single-ended output**

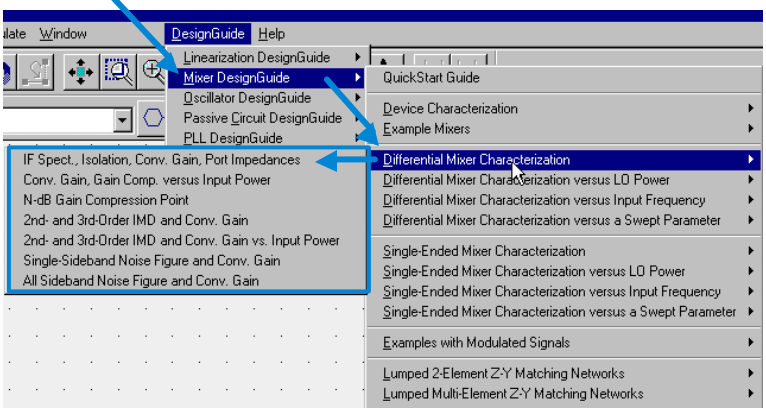
Always see the NOTES pages for additional information throughout...

There are many different performance specifications for mixers. Some are of interest for receive applications where the input signal level is not under the control of the designer. In this case, the maximum linearity under large signal drive conditions is often very critical. Noise figure may be of secondary concern.

For the transmit application used here as an illustration, the designer has control of the signal level. Then, the design strategy shifts to trading off noise and IMD behavior in order to achieve the largest useable dynamic range.

As an extra illustration, after the intrinsic mixer performance is evaluated, the design will be modified to improve conversion gain and image rejection by tuning the mixer output. Secondly, a differential-to-single ended converter will be added to interface to an off-chip bandpass filter.

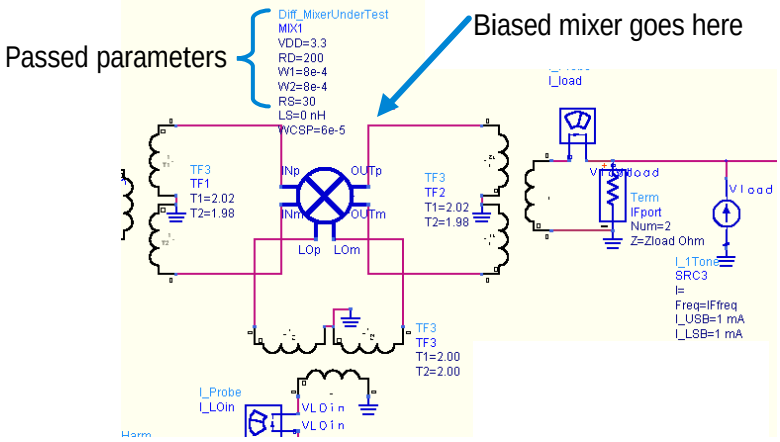
Using the ADS Mixer DesignGuide:
First, select the analysis type...



The analysis tools are accessible by the DesignGuide pulldown menu. Select Mixer DesignGuide, then scroll through the list to find the relevant analysis. Then, the schematic and display panels will be loaded into your project.

Differential Mixer Test Bench Example

Proceed by replacing the default mixer circuit with your mixer
Set parameters and select the analysis schematic template from the DesignGuide pulldown menu.



RFIC Mixer Design with ADS
19 April, 2001

Agilent Technologies

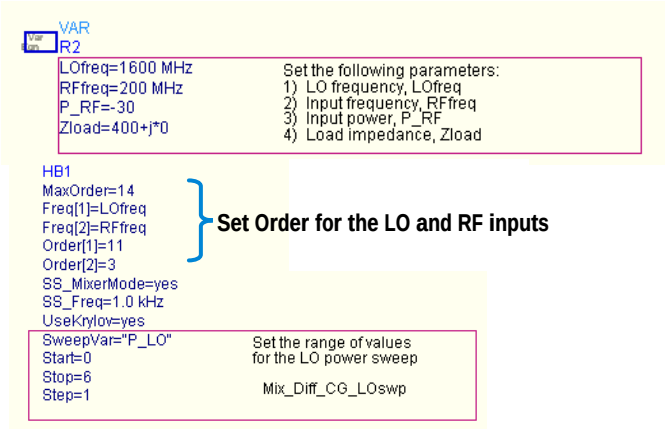
Page 7

The mixer under test is constructed as an ADS subnetwork. The mixer itself can be replaced with or modified to become your own design. Select the mixer, push down into the subnetwork, and replace the circuit with your own design. If you use the Diff_MixerUnderTest as your subnetwork, and insert your design, the design is automatically inserted into all of the analysis circuit templates. Or, you can save your design under a different name, select it using the component library icon on the toolbar, and replace the default mixer with your own.

You can declare any of the circuit parameters to be accessible outside of the subnetwork by using the File > Design Parameters panel. In this example, VDD, RD (drain resistance), WCSP (current source control width), W1 and W2 (transconductance and switch MOSFET widths), and source degeneration resistance (RS) and inductance (LS) are all available for a parameter sweep.

Set up the simulation conditions

- **Set variables and simulation controller sweep range**



You then will configure the simulation controller, HB in this example, with the appropriate parameters.

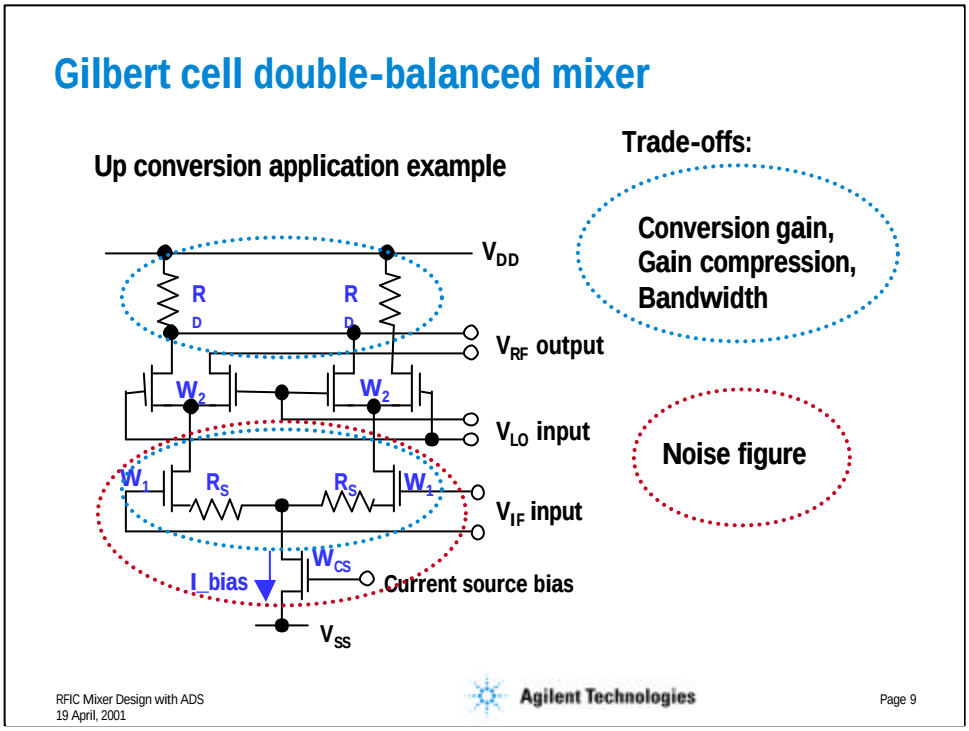
Order[1] number of LO harmonics - should be large for switching mixers

Order[2] number of harmonics at the mixer signal input - small if input amplitude is small; larger if you are simulating the mixer near the 1 dB compression point

MaxOrder maximum sum of the LO and Input harmonics considered in the solution. Generally, you would use the sum: Order[1]+Order[2]

SweepVar: This is the swept parameter, in this example the LO power. Set the range and step size used for the simulation.

Note that the data file size will increase with the order and with the number of sweep steps.



We will utilize the DesignGuide mixer library as a starting point for the design exercise. This is a schematic of a MOSFET version of the Gilbert active double-balanced mixer. The lower FET diff pair serves as a transconductance amplifier. The upper FETs provide a fully balanced, phase-reversing current switch. A DC bias generator is included (not shown) which will keep the MOSFETs in their active region.

The large signal handling capability of the mixer will depend mainly upon the linearity of the transconductance amplifier, and is measured by determining the maximum input voltage (or power in some cases) that causes a 1 dB compression in the conversion gain. The maximum linear input voltage range can be increased by increasing the source degeneration resistors, Rs. While source inductance can also provide beneficial degeneration, in this case, we have a very low input IF frequency, 200 MHz. The inductance values required would be too large for RFIC implementation, thus we are stuck with the resistors (they will add noise). The load resistors could also cause gain compression if the voltage swing at the drains is large enough to cause the output to clip under large signal drive conditions.

The double-balanced design rejects IF and LO feedthrough to the output if the output is taken differentially. This is because the LO component in the output is a common mode signal while the RF output is differential.

For a more complete explanation of how the Gilbert cell mixer operates, refer to the reference list at the end of this presentation.

Design procedure

The example design sequence is suited for an upconversion mixer. Our goal is to increase dynamic range. Conversion gain and matching are not as critical.

1. **LO amplitude: Conversion gain, V_{in} at 1 dB gain compression**
2. **Gain Compression: source resistance Rs, drain resistance, Rd**
3. **Noise figure: Rs, I_bias**
4. **Dynamic Range vs. Input Voltage**
5. **Spectral spreading and ACPR with digital modulation**

A mixer that is to be used for base station transmit applications requires high linearity and low noise so that the least amount of spurious power is spread into the adjacent channel. We will optimize our mixer in the following sequence:

1. LO amplitude. You want to make sure the mixer commutating switch is fully activated. Excess distortion can be produced with a weakly conducting or slowly activated switch. Use the conversion transducer gain and 1 dB gain compression input level to determine when the LO voltage is sufficient.

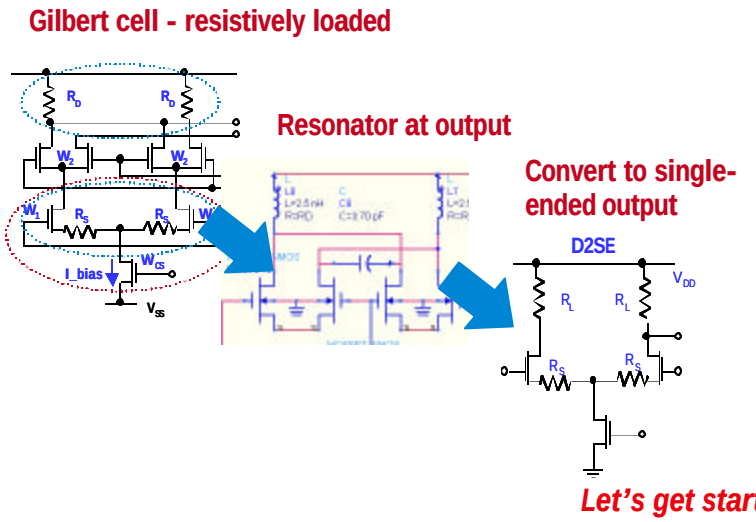
2. Evaluate the influence of source and drain resistance on the 1 dB compression level. This will give insight into the principal mechanisms that limit linearity.

3. The added noise of the mixer will affect the minimum signal level and thus limit dynamic range. There will be a tradeoff between noise, gain, and gain compression.

4. The two-tone 3rd order intermodulation distortion power and the noise figure determine the mixer dynamic range vs. input voltage. Since for transmit applications you have complete control over your input voltage, find the optimum dynamic range - the mixer's "sweet spot" for best performance. Or, alternatively, if you have a fixed signal level, design the mixer to provide the best dynamic range at that signal level.

5. Finally, test the mixer under more realistic signal excitation - using a CDMA source, for example, to emulate a multicarrier environment. This is a more severe test than the two-tone IMD one, and is much more time consuming to simulate since a large number of symbols must be used for accurate results.

Design sequence



RFIC Mixer Design with ADS
19 April, 2001

Agilent Technologies

Page 11

Once the basic resistively loaded Gilbert cell mixer is characterized, two modifications will be employed to improve performance. First, the mixer drain nodes will be tuned with inductors and a capacitor for resonance at the output frequency. This improves conversion gain if inductors with reasonable Qu can be fabricated. It also decreases the amplitude of the undesired output image because of its bandpass transfer function. The image must be removed anyway, and it's presence can only degrade the distortion of the output stage by increasing the peak voltage present at its input.

The output of the mixer will need to be filtered off-chip with a SAW filter before further amplification, so a single ended output is more efficient. The last stage is added to perform a differential to single ended conversion. It must have good common mode rejection to suppress LO feedthrough and good linearity so that it doesn't degrade dynamic range.

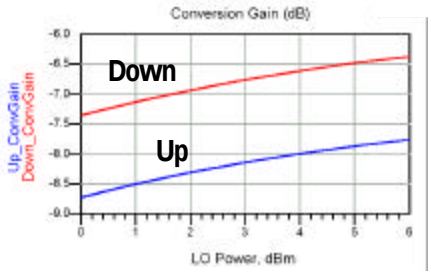
1. Determine LO voltage: Conversion gain & gain compression

- **Sweep LO power**

- **Conversion gain – P_{LO}**
- **Gain Compression – P1dB**

Differential Mixer Characterization versus LO Power

Isolation, Conv. Gain, Port Impedances
NdB Gain Compression Point



LO Power dBm	LO voltage @ LOfreq	1.0 dB gain compression input power level (dBm)	Conversion gain
0.000	0.589 / -22.529	-6.825	-9.721
2.000	0.743 / -21.791	-6.891	-9.305
4.000	0.938 / -21.168	-6.924	-9.993
6.000	1.182 / -20.657	-6.957	-9.753

RFIC Mixer Design with ADS
19 April, 2001

Agilent Technologies

Page 12

The first step is to determine a suitable LO voltage that provides a reasonable compromise between conversion gain and LO power and at the same time does not limit the 1 dB gain compression input voltage. The MOSFETs forming the commutating switch (upper level) must be driven hard enough to present a low series resistance to the load. Most of the mixer analysis schematic and display templates available in the DesignGuide library include an LO power sweep capability. Use the menu as shown to select a conversion gain simulation as a function of LO power. Also, a NdB Gain Compression analysis can be used to evaluate the dependence of gain compression on LO drive.

From these simulations, we see that the input power at which gain compresses by 1 dB (P1dB) is not a strong function of LO voltage, but conversion gain is somewhat dependent. The more gate voltage applied to the upper tier of MOSFETs, the lower their series resistance relative to the drain resistance and thus the higher the conversion gain. We also can see that there is a conversion loss which gets worse at the higher output RF frequency of 1.8 GHz, but we can improve on this later by tuning the RF output of the mixer.

2. V_{1dB} dependence on R_S, R_D

Differential Mixer Characterization versus a Swept Parameter

N-dB Gain Compression Point

- **We can see a strong dependence of gain compression on Rs**
- **R_D has little effect on compression, so limiting is occurring at the input**

Nearly constant

Swept Parameter		1.0 dB gain compression input (dBm)	input (Volts)	Conversion gain	output (Volts)
Rs	10.000	-11.116	0.172 / -2.405	-4.969	0.099 / 112.719
	20.000	-8.739	0.227 / -2.116	-6.935	0.104 / 112.356
	30.000	-7.007	0.277 / -1.928	-8.500	0.106 / 112.125
	40.000	-5.386	0.334 / -1.790	-9.879	0.109 / 111.865

Swept Parameter		1.0 dB gain compression input (dBm)	input (Volts)	Conversion gain	output (Volts)
R_D	100.000	-7.007	0.277 / -1.928	-8.500	0.106 / 112.125
	200.000	-7.007	0.277 / -1.928	-9.110	0.140 / 92.635
	300.000	-7.007	0.277 / -1.928	-10.313	0.149 / 83.422

RFIC Mixer Design with ADS
19 April, 2001

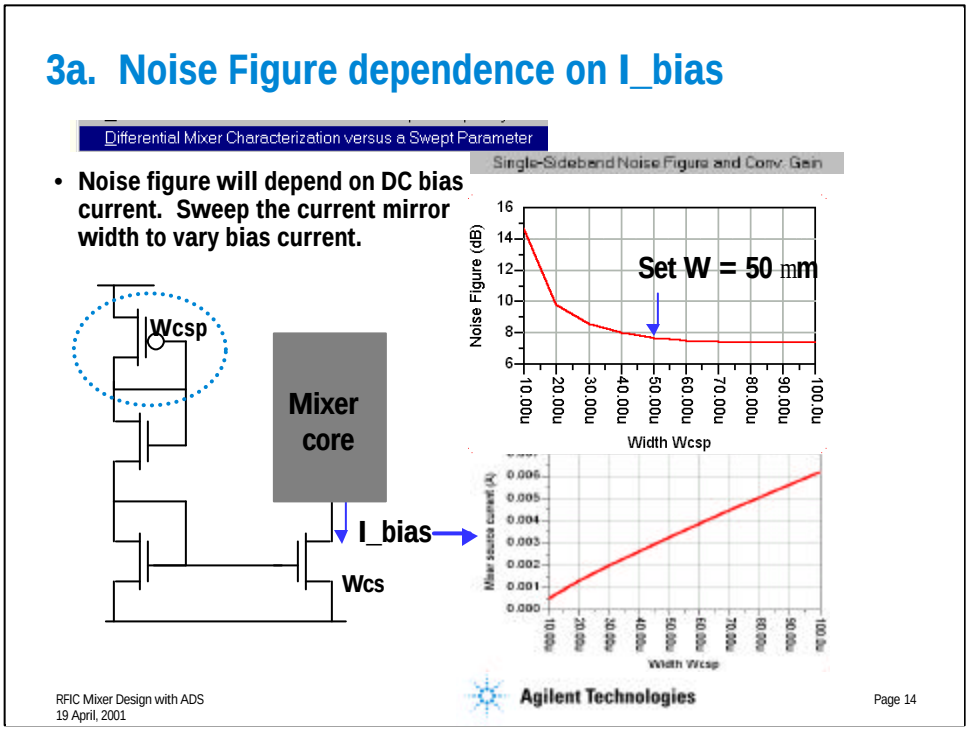
Agilent Technologies

Page 13

Gain compression is evaluated using the N-dB Gain Compression Point analysis schematic. The 1dB gain compression input power and input voltage are found for swept parameters. In this case, the influence of R_S and R_D on V_{1dB} was determined. The R_S sweep used $R_D = 100\Omega$. The R_D sweep set $R_S = 30\Omega$. Conversion gain is measured at the 1 dB compressed level. Alternatively, a two-dimensional sweep could also be set up using an extra Parameter Sweep controller.

In an RFIC mixer where the input might not be matched to a source impedance, the input voltage is a more important metric of gain compression than the input available power (P1dB) since available power assumes a conjugately matched source and load. Also, in a multi-signal environment, the peak input voltage can be quite large at the instant in time when all signals add in phase. It is this peak voltage that determines the distortion limits of the mixer. For example, the two-tone IMD simulations will predict a 1 dB compression power 6 dB lower than single tone simulations because the peak voltage will be twice as high for the same power per tone.

It is also interesting to note that the conversion power gain depends inversely on R_D. In the simulation, the external load resistance was set to 2 R_D so that the output power (power absorbed in the load) is also the available output power, $P_{out} = V_{out}^2/4R_D$. The voltage gain would be expected to follow R_D/R_S but increases less rapidly than anticipated, probably due to the output RC time constant bandwidth limitations.



We can simulate the mixer single-sideband noise figure as a function of DC bias current through the Gilbert cell (mixer core). The DC current is varied by sweeping the width of the PMOS current source Wcsp and the mixer current mirror width Wcs using a parameter sweep.

SSB noise figure is appropriate because only one input frequency is applied to the mixer, but wideband noise at the image frequency and from LO harmonics is included in the signal to noise calculation. We find that the NF is reduced with increasing I_bias, but reaches a point of diminishing returns. Thus, a width of 50 μm was selected as a compromise between power and noise.

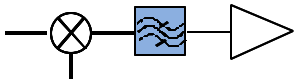
The device widths in this mixer have been selected to minimize noise [3].

3b. Noise Figure dependence on Rs

- **The noise figure will also be strongly affected by Rs.**

Swept Parameter Value	Noise Figure, dB	Down Conversion Gain, dB	Up Conversion Gain, dB
10.00	6.48	-2.55	-3.18
20.00	7.97	-4.71	-5.35
30.00	9.22	-6.43	-7.07
40.00	10.30	-7.86	-8.60

- **We find that we must trade off NF and V1dB. This will influence dynamic range**



  - **Noise floor = MDS = -174 dBm/Hz + 10 log BW + NF**
  - **Conversion gain is also varied, and may affect input referred noise**

RFIC Mixer Design with ADS
19 April, 2001

Agilent Technologies

Page 15

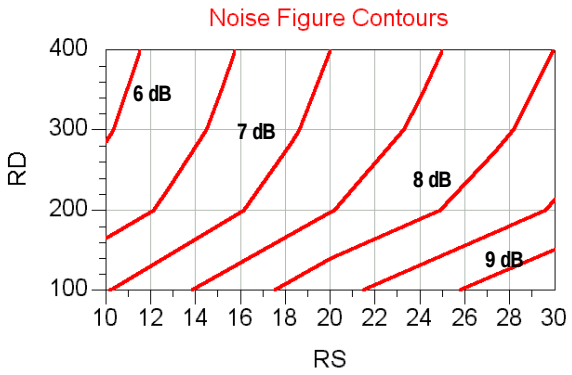
We also find a strong dependence of SSB NF on the source resistance. This is expected because the thermal noise contributed by the resistor is directly in the input voltage loop of the differential pair. Thus, we will need to trade off V1dB and noise figure to obtain the largest dynamic range of the mixer.

The dynamic range at low input signal power levels will be limited by the carrier to noise ratio. The noise power for a minimum detectable signal (S/N = 1) depends on both NF and the noise bandwidth. This bandwidth will normally be set by an external SAW filter between the mixer and the driver amplifier. The filter is also required to reject the output difference ($F_{LO} - F_{IN}$) image frequency at 1.4 GHz.

The conversion gain (a loss in this case) may also increase the noise figure because the drain resistor thermal noise is input referred through the gain. Thus, we will also want to investigate a tuned output to eliminate some of this noise.

3c. Noise Figure dependence on R_S, R_D

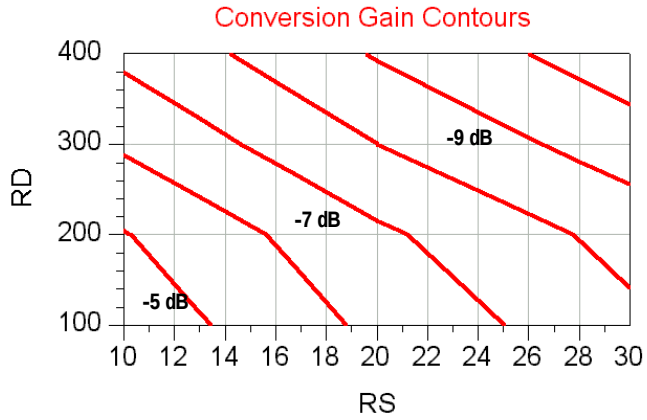
- **You can perform a two parameter sweep and plot contours of noise figure.**



You can also perform a two parameter sweep by selecting a second Parameter Sweep controller. In this example, the variation in noise figure with RS and RD that was displayed in tables on the previous slide can now be plotted as constant NF contours using the contour function in the function library.

3d. Up Conversion Gain dependence on R_S, R_D

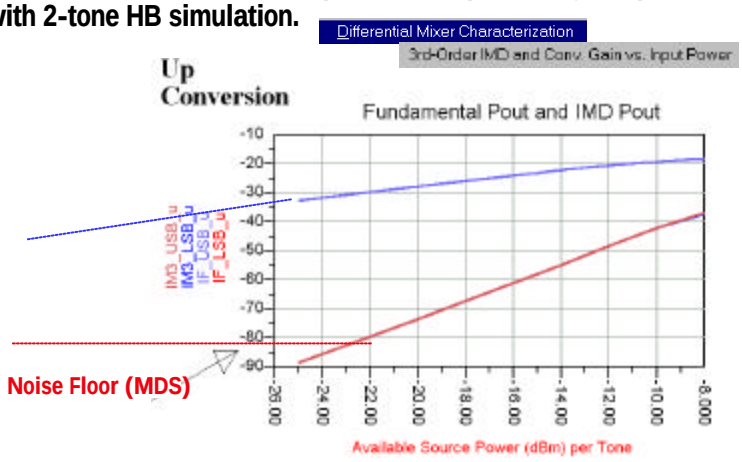
- **And also a contour plot for conversion gain:**



You can do the same thing with the conversion gain data.

4a. Carrier to IMD ratio

- **Both carrier / noise and carrier / IMD can limit dynamic range**
- **Determine the 3rd order IMD power vs. input voltage or power with 2-tone HB simulation.**



RFIC Mixer Design with ADS
19 April, 2001

Agilent Technologies

Page 18

At higher input signal levels, the dynamic range of the mixer is limited by the distortion. The third-order intermodulation distortion products are the most damaging because they show up in-band and cannot be rejected by the filter.

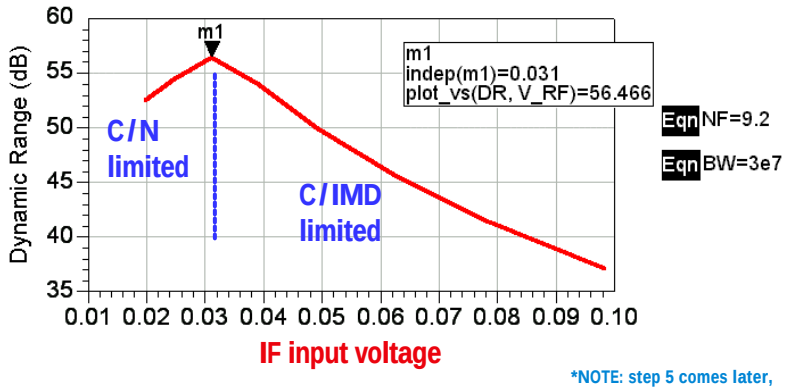
A two-tone third-order IMD simulation with an RF power sweep can be used to display the carrier-to-IMD power ratio. The IMD power present in the output will increase at 3 times the rate of increase of input power. Thus, the difference between output power and IMD power shrinks with increasing input.

At low input signal levels, the noise floor, set by the mixer noise figure and the noise bandwidth of the mixer-bandpass filter-amplifier cascade, will set a lower limit to the output power from the mixer. The dotted lines above show this noise floor in red. The blue dotted line represents the mixer output power vs. RF input power at this lower input regime. It has a slope of 1. You can see that the difference between output power and noise floor shrinks as the power decreases.

The maximum dynamic range is found at the inflection point.

4b. Calculate dynamic range vs input voltage

- **Combine data from IMD RF power sweep and SSB NF simulations**
- **Plot dynamic range for RS = 30**Ω



*NOTE: step 5 comes later, but first...

Here, we have taken outputs from two simulations: IMD RF power sweep and the SSB NF. The dynamic range is controlled by the least of these two conditions:

DR = Pout (dBm) – MDS (dBm) for low input levels (noise limited)

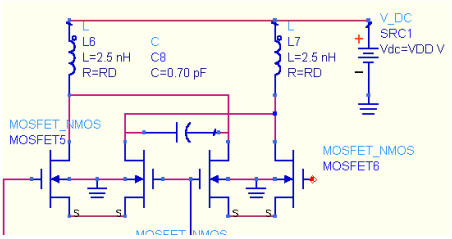
DR = Pout (dBm) – PIMD (dBm) for higher input levels (distortion limited)

Rs	DR (dB)	Vin (V) (differential)	NF (dB)
10	57.7	0.017	6.5
20	57.3	0.025	8
30	56.4	0.031	9.2
40	56.0	0.039	10.3

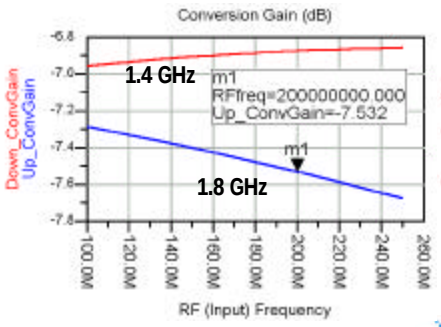
The dynamic range peak will depend on the noise bandwidth. For narrower bandwidths, the noise floor will drop and the peak DR will increase but shift to lower differential input voltage. The 30 MHz noise bandwidth was chosen because of the base station application. The transmitter should be capable of covering an entire frequency band.

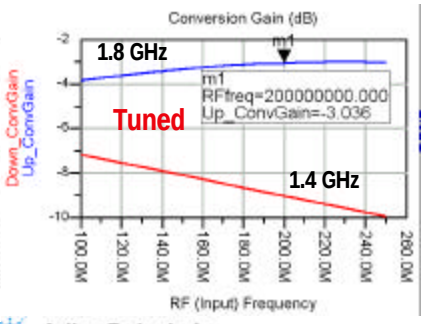
Improve mixer conversion gain and noise figure

- Tune the output of the mixer
  - Absorb capacitance
- Frequency sweep



Resistive load





RFIC Mixer Design with ADS
19 April, 2001

Agilent Technologies

Page 20

The low conversion gain of the resistively loaded mixer will cause higher noise due to the drain resistors. By resonating the output at 1.8 GHz, the conversion gain is increased and the gain at the image (1.4 GHz) is reduced. The comparison between the resistive loaded case and the tuned case shows an increase in conversion gain by about 3.5 dB.

You can perform an RF frequency sweep to find the resonant frequency. From that, you can calculate how much capacitance is contributed by the drain-to-substrate junction and absorb it into the resonator.

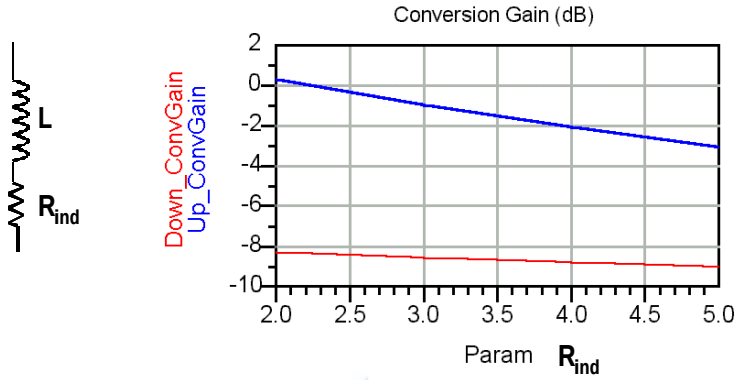
An unloaded Q = 5 is assumed for the inductor.

Gain reduction due to inductor Q

Differential Mixer Characterization versus a Swept Parameter

Isolation, Conv Gain, Port Impedances

- **We do find, however, that the gain is sensitive to the unloaded Q of the inductor. R_{ind} represents the series resistance of the inductor.**
- **Q unloaded is varied from 12 down to 5.**



RFIC Mixer Design with ADS
19 April, 2001

Agilent Technologies

Page 21

On chip inductor Q is limited by metal losses and substrate conduction in bulk silicon processes. An ordinary digital IC process will produce low Qu in spiral inductors. CMOS or BiCMOS RFIC processes can achieve higher Q inductors by using thicker dielectrics and thicker metal. Q values in the range of 5 to 15 are typical.

The low conversion gain is also due in both cases to an unmatched input. We will consider this later.

Tuned output - noise figure

Differential Mixer Characterization versus a Swept Parameter

Single-Sideband Noise Figure and Conv. Gain

- **The noise figure is reduced by about 0.5 to 1 dB when the output of the mixer is tuned. Again, this depends on the inductor Q.**

Swept Parameter Value	Noise Figure, dB	Down Conversion Gain, dB	Up Conversion Gain, dB
20.00	7.00	-6.74	1.42
30.00	8.08	-8.38	-0.22
40.00	9.01	-9.75	-1.59

RFIC Mixer Design with ADS
19 April, 2001

Agilent Technologies

Page 22

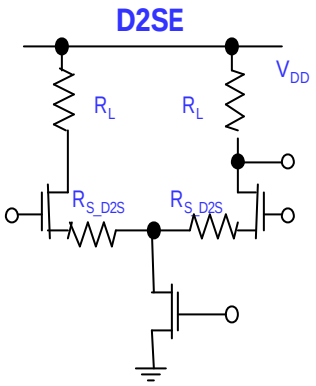
RD = 2.5 RL = 400

Unfortunately, for realistic unloaded inductor Q values (on bulk Silicon) of the order of 5, the benefits of tuned output are diminished. The conversion gain is improved by about 4 dB and the noise figure by only 0.5 dB. There would be much more benefit on a CMOS RF Analog, SOI or GaAs processes where higher Q values can be obtained.

Having said that, we will continue to evaluate the tuned solution.

Active Balun: differential to single-ended RF out

- **Connect differential amplifier stage to output of tuned mixer.**
- **Choose either direct output as shown (with off-chip load resistor) or use a source follower.**
- **Size the MOSFETs according to the output current and voltage required. Their input capacitance can be absorbed in the mixer tank circuit.**
- **Determine R_{S_D2S} so that the D2SE block does not degrade the dynamic range.**



The next step will be to convert the RF output from a differential signal to single-ended with an active balun. You must perform this conversion rather than just taking one output from the mixer because the mixer differential output is necessary for rejection of LO feedthrough. Since we need a SAW filter between the mixer output and the driver stage, a single-ended output is sufficient. While passive baluns can be made for 1.8 GHz, we will benefit in cost and size by placing an active balun on-chip. This differential amplifier stage is used to convert the differential output of the tuned mixer to a single output. The gate capacitances of the D2SE stage can be absorbed into the resonator at the mixer drain nodes. The D2SE stage must also be designed so that it does not dominate the IMD generation of the mixer. R_{S_D2SE} can be adjusted to set the V_{1dB} level.

The output driver could use an off-chip load resistor with open drain output connection as suggested by the circuit simulated here. The load resistance will probably be determined either by the filter impedance or by transmission line impedance. The bias current for the D2SE converter stage will be dictated by this impedance level. The device widths must also be chosen so that they can handle the necessary drain current and provide adequate voltage gain. The addition of a source follower to the output is another option.

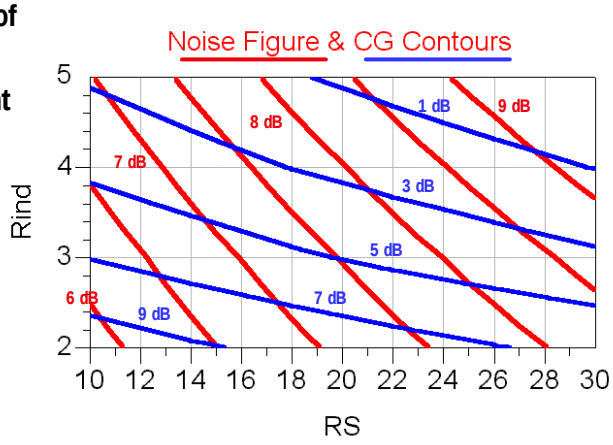
Evaluate mixer with D2SE stage

- **First simulate with differential mixer analysis tools to compare with resistively loaded and tuned mixer performance**
  - **Noise figure and conversion gain**
  - **IMD and dynamic range**
- **Then, adapt single-ended (SE) mixer analysis tools from the DesignGuide to evaluate with SE input and output**

For the initial design evaluation, we will continue to measure the differential output so that comparisons can be made between the differential tuned mixer and the mixer with output buffer. Then, the mixer will be evaluated in a single-ended configuration.

Noise Figure and Conversion Gain Contours

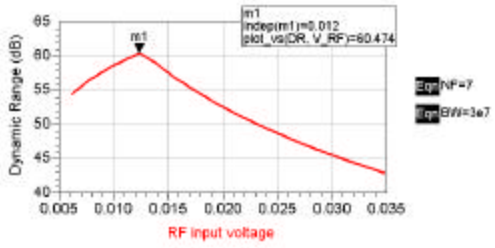
- **Large dependence of gain and NF on RS**
- **Gain very dependent on Rind**



The SSB noise figure simulation is performed again with parameter sweeps for RS and Rind. We can see that there is little noise sensitivity to Rind, however, it strongly affects the conversion gain. RS affects both NF and conversion gain and it also will also affect the carrier-to-IMD ratio vs. IF input voltage.

Dynamic range simulations

- **Dynamic range vs. RS of mixer. R_{ind} = 5** W
- **Noise figure dominates over the IMD behavior at this bandwidth since DR improves with smaller RS**
- **Dynamic range also improves with reduction in R_{ind}.**

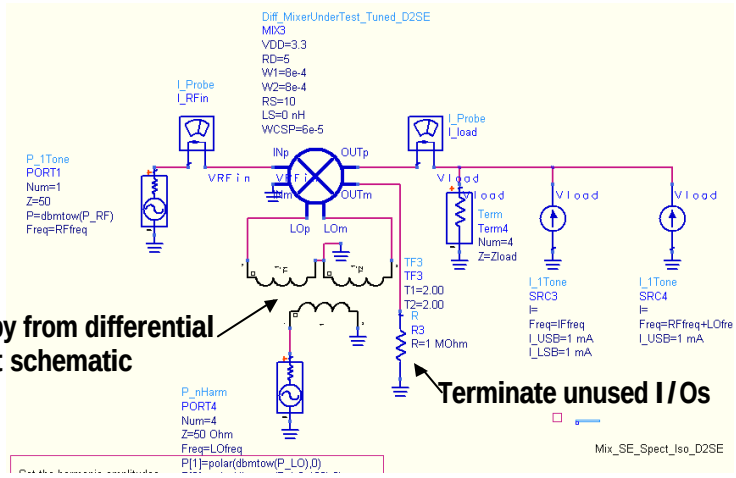


RS	NF (dB)	DR (dB)	Vin (mV)
10	7	60.5	12
20	8.5	59.8	17
30	9.7	59.2	22

The Mixer TOI/IMD simulation is performed again for RS of 10, 20, and 30 ohms. We can see that the dynamic range slowly improves for smaller RS. This will be very dependent on the noise bandwidth, however. For our simulations, a 30 MHz bandwidth was assumed.

Test as single ended mixer

Modify SE schematic to evaluate our mixer



A DesignGuide schematic intended for evaluation of single-ended mixers was copied from the menu and modified. Our tuned mixer with the D2SE output stage was inserted from the component library. Unused inputs were terminated: the input was grounded and the output terminated in a large resistance.

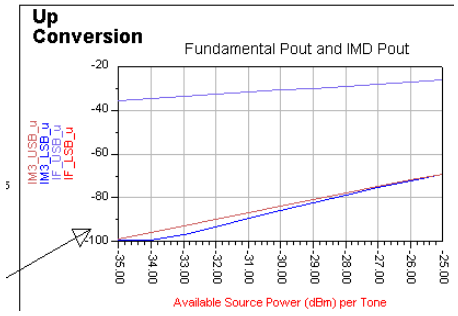
The LO is differential. A transformer and source was copied from a differential test schematic and pasted into this schematic. An active LO SE to differential stage could also be designed and added to the mixer if desired.

Single-ended NF and IMD performance

Single-Ended Mixer Characterization versus a Swept Parameter

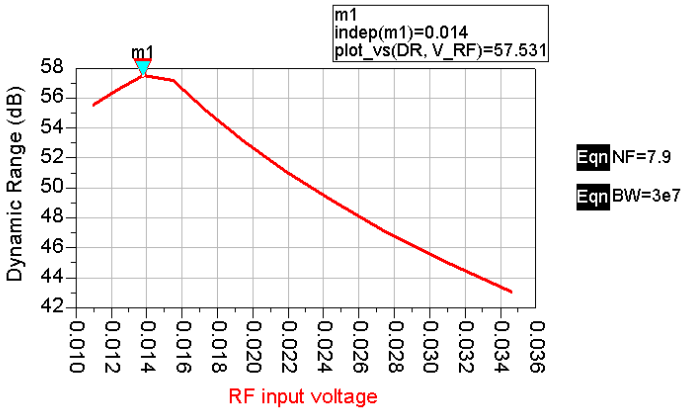
- **NF higher; CG lower than differential mixer**
- **Use NF and IMD vs RF power to calculate dynamic range for the single-ended mixer connection**

Swept Parameter Value	Noise Figure, dB	Down Conversion Gain, dB	Up Conversion Gain, dB
10.00	7.89	-9.48	-0.36
20.00	9.46	-11.49	-2.37
30.00	10.78	-13.11	-4.00



Again, noise figure and IMD vs RF power sweeps were performed for a range of RS values from 10 to 30 ohms. This is combined to determine dynamic range on the next slide.

Single-ended mixer: dynamic range



RFIC Mixer Design with ADS
19 April, 2001

Agilent Technologies

Page 29

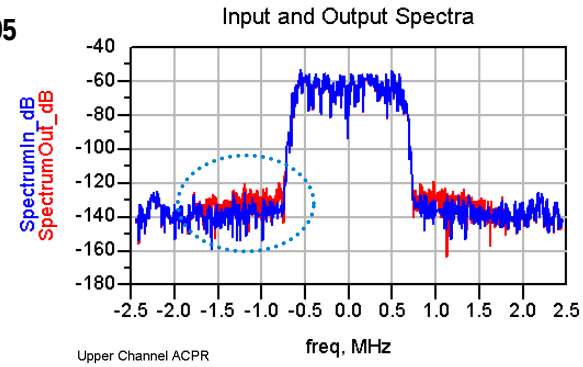
The best result was for the RS = 10 ohm case. We see a peak dynamic range of 57.5 dB at an input voltage of 14 mV.

5. Simulate mixer with CDMA input

Examples with Modulated Signals

Simulation with CDMA Source

- **Circuit envelope simulation with IS-95 CDMA modulation**
- **128 symbols**
- **ACPR increased**
- **Vin = 12 mV (-33 dBm)**



Lower Channel ACPR

TransACPR(1)
-82.470

Upper Channel ACPR

TransACPR(2)
-81.919

RFIC Mixer Design with ADS
19 April, 2001

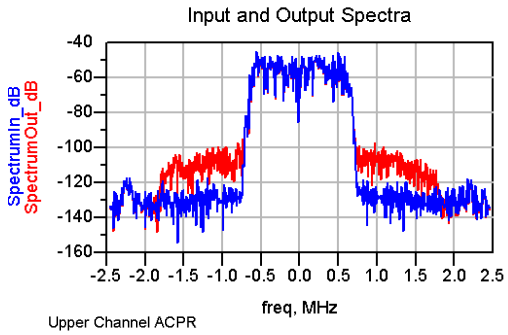
Agilent Technologies

Page 30

A more severe test of linearity requires simulation with a digital signal source such as this CDMA example. An IS-95 CDMA source with very good ACPR was used to drive the mixer input. When the input RF signal level was set to the optimum value for mixer dynamic range, relatively little spectral regrowth is observed. To save time, only 128 symbols were used in the circuit envelope simulation. A more accurate simulation might require in excess of 1000 symbols.

Evaluate at higher drive level

- **Input available power increased to –25 dBm**
- **Effects of IMD generation and gain compression effects are evident with wideband source – ACPR is much higher**



Lower Channel ACPR

TransACPR(1)
-69.409

Upper Channel ACPR

TransACPR(2)
-68.581

When the signal level is increased, there is much more distortion evident. The input level in this simulation corresponds to about 30 mV of drive voltage.

IF input impedance

Single-Ended Mixer Characterization

IF Spect., Isolation, Conv. Gain, Port Impedances

- **The RF input port impedance can be matched if baseband / IF generation is from off-chip.**
- **We can see at 200 MHz, the input impedance is dominated by capacitive reactance.**

Reference Impedance for Rho (refelection coefficient) and VSWR calculations.

Eqn Z0=50

Looking into the RF (Input) Port:

Frequency	Impedance	Reflection Coefficient	VSWR
200.MHz	8.47 - j1.40E2	0.96 / -39.20	52.28

RFIC Mixer Design with ADS
19 April, 2001

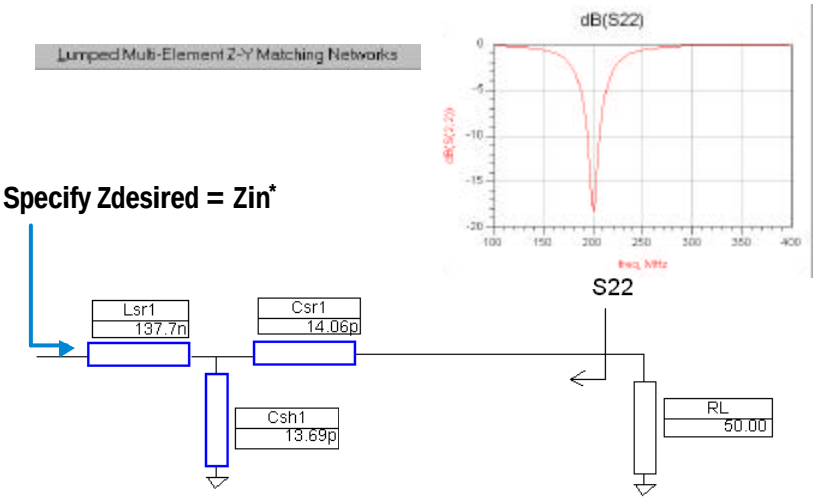
Agilent Technologies

Page 32

We noted earlier that the input of the mixer is badly mismatched. This may not be of much concern if the baseband and IF driver circuits are on the same chip with the upconversion mixer. In that case, the voltage levels are more of interest.

If you are interested in driving from off chip, we can see above that the input impedance is dominated by capacitive reactance. A matching network could increase the conversion gain significantly if this were of interest.

Impedance matching utility



- **Specify Zdesired = Zin***

RFIC Mixer Design with ADS
19 April, 2001

Agilent Technologies

Page 33

The Mixer DesignGuide contains several impedance matching utilities that could be used to design and evaluate matching networks.

Conclusion

Learning objectives met:

- **Learn how to make use of the Agilent ADS Mixer DesignGuide**
- **Understand the important design and analysis tools for this application**
- **Specify performance: Gain, NF, P_{1dB}, TOI, Dynamic Range**
- **Improve the design: add resonator and convert to single-ended output**

We have now completed a design study of an upconversion transmit mixer. The procedure illustrated here is by no means unique, and you may find ways of getting the same information by other sequences of steps.

Also, the DesignGuide analysis schematics can be further modified to include nested sweeps. These can provide a two-dimensional perspective on the design space to gain further insight (in exchange for increased simulation time and data file size).

You can also make use of the ADS optimizer to automatically achieve the design goals. This could require combining the simulations on more than one analysis schematic onto a single multi-level schematic, or possibly creating a look-up table and interpolation function for one of the critical performance parameters to speed up the optimization process.

References

- Gray, P. R. and Meyer, R. G., *Design of Analog Integrated Circuits*, 4th Ed., Chap. 10, Wiley, 2001.
- Gilbert, B., "*Design Considerations for BJT Active Mixers*", Analog Devices, 1995.
- Lee, T. H., *The Design of CMOS Radio-Frequency Integrated Circuits*, Chap. 11, Cambridge U. Press, 1998.
- Agilent EESof Design Seminar, "*Fundamentals of Mixer Design*," 1999.
- Agilent EESof Design Seminar, "*RFIC Mixer Design*", 1999.

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。

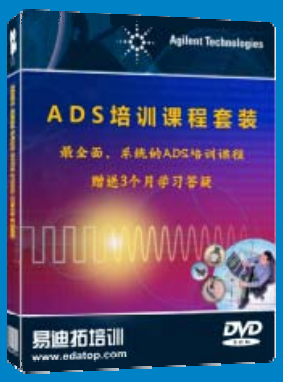
易迪拓培训课程列表：http://www.edatop.com/peixun/rfe/129.html

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…

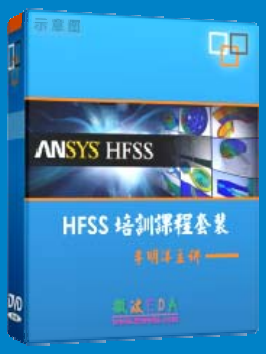
课程网址：http://www.edatop.com/peixun/rfe/110.html

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