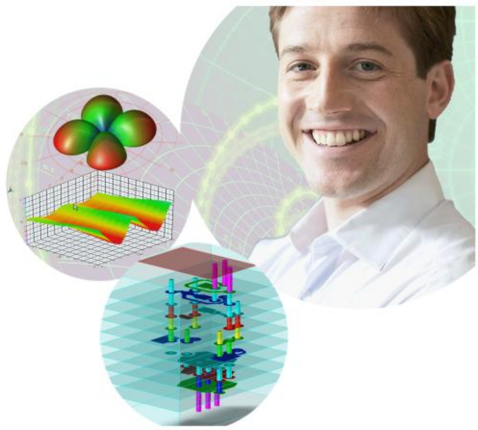
Mixer Design For LTE

3rd of 6 "How-To-Design" GENESYS seminar series

Sep 2009 to July 2010



Using Agilent GENESYS software to speed RF and Microwave board designs for circuits and subsystems

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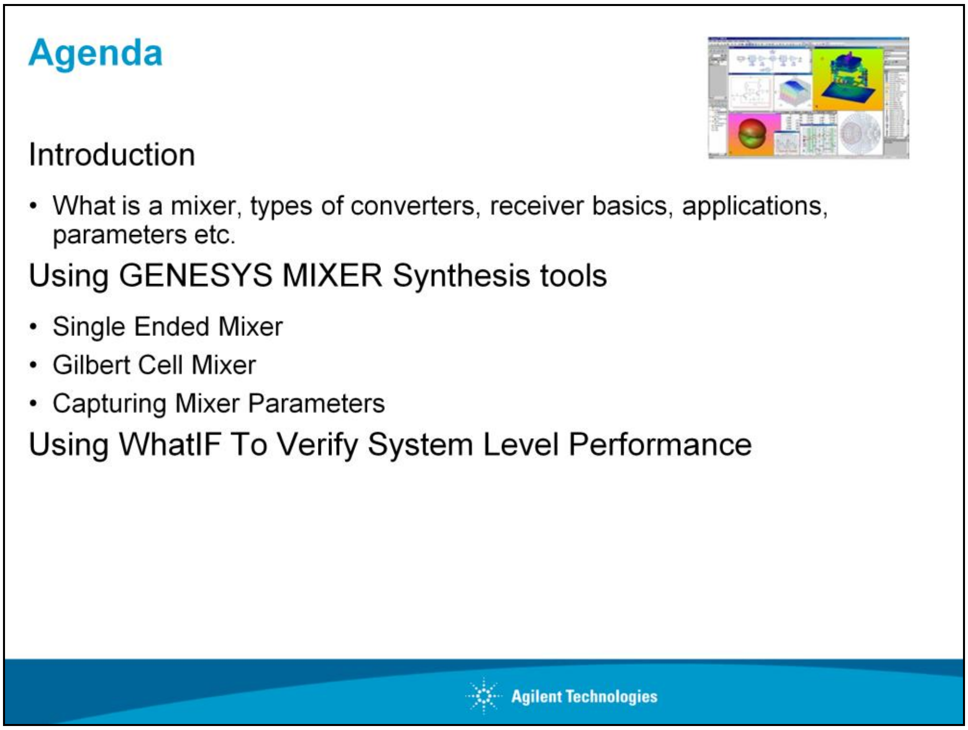
Welcome to this presentation which helps to highlight the capability of Genesys in the design of mixers for LTE applications

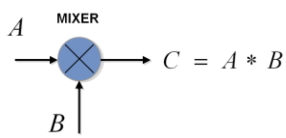


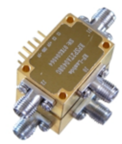
Our agenda today covers aspects of mixer function, parameters and mixer synthesis with emphasis on performance tradeoffs with different mixer topologies. We will show how, once a design has been finalized, to use the mixing parameters in system level tools such as WhatIF and Spectrasys

What Is A Mixer?

Simply, A Device That Produces A Product Of It's Inputs

- Sinusoidal Stimulus Results In Trigonometric Products
- Digital Stimulus Results In AND-ed Output





Depending upon the intended function a mixer component can either a frequency transformer or digital AND device

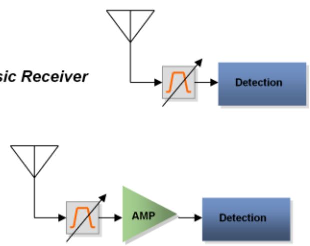
Direct Conversion

Pros and Cons

- Simple Design, Fewer Parts, Cost
- Direct Conversion To Base-band Offers Poor Selectivity An Sensitivity

Most Basic Receiver

Adding Gain



Most Basic Receiver:

1) Selectivity Limited To Tuning Circuit
2) Minimum Sensitivity, Energy At Antenna

Adding Gain:

1) Selectivity Limited By Amplifier And Tuning Circuit
2) Improved Sensitivity, Increased Noise

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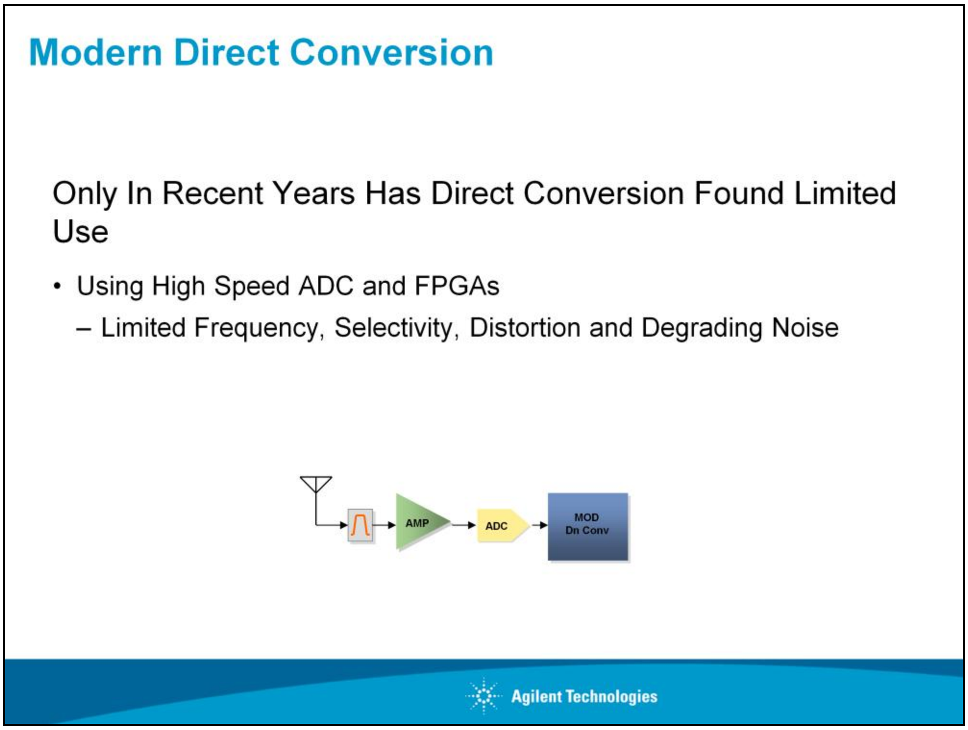
Direct conversion extracts information from the carrier by front end detection techniques. This process has been employed for many years for simple receiving systems under the nameof “Homodyne” converter where a amplifer near oscillation mode is used for amplitude detection

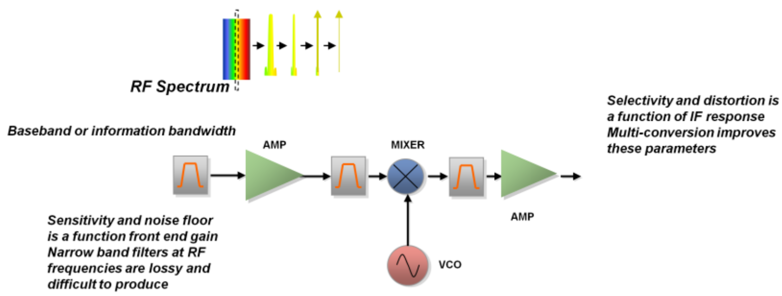


Some modern MMIC devices provide this functionality for limited performance systems. Higher RF frequencies are limited due to sampling rate of the A/D conversion processor and limited dynamic range.

Receiver Basics

Modern Conversion Receivers Offer High Selectivity In A Crowded Frequency Environment

Adding signal gain at IF frequencies is more efficient and cost effective

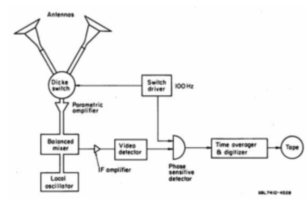


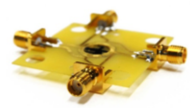
Most receiver systems, especially in the cellular application use hetrodyne conversion using one or more mixers and following IFs. This technique provides the best sensitivity and selectivity performance. Shown above is a diagram of the progressively narrower bandwidth as a result of mixing and filtering allowing a receiver to select only a narrow portion of the spectrum to extract the transmitted modulation.

Mixer Only Applications

At Very High Frequencies Where Little Or No Amplification Device Is Available

- Radiometry
  - Earth Surface Mapping
  - Collision Avoidance
  - Secure Communications
- THz Detection
  - Security Scanning
  - Medical Scanning





Terahertz Mixer

At very high frequencies where limited amplification is possible mixers translated the transmitted information to a lower frequency band which is easier to amplify.

Important Mixer Parameters

Compression point

Intercept point

Dynamic range

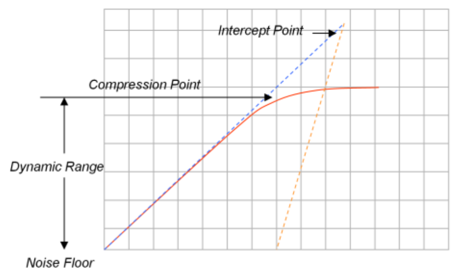
Isolation

Image rejection

Frequency range

- IF, RF, LO

Noise figure



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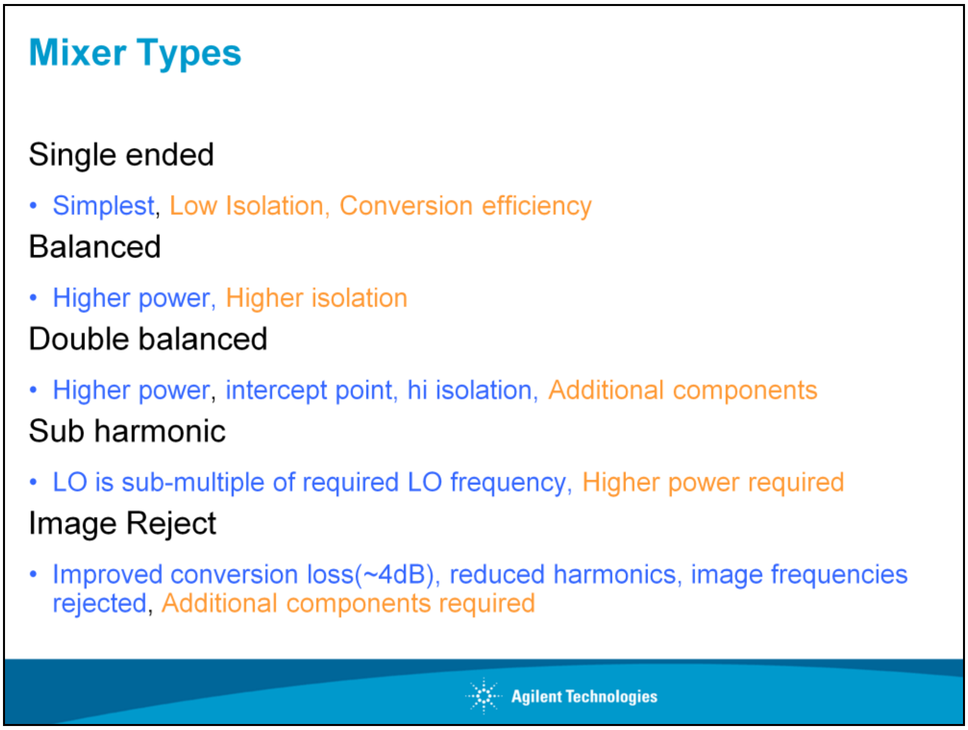
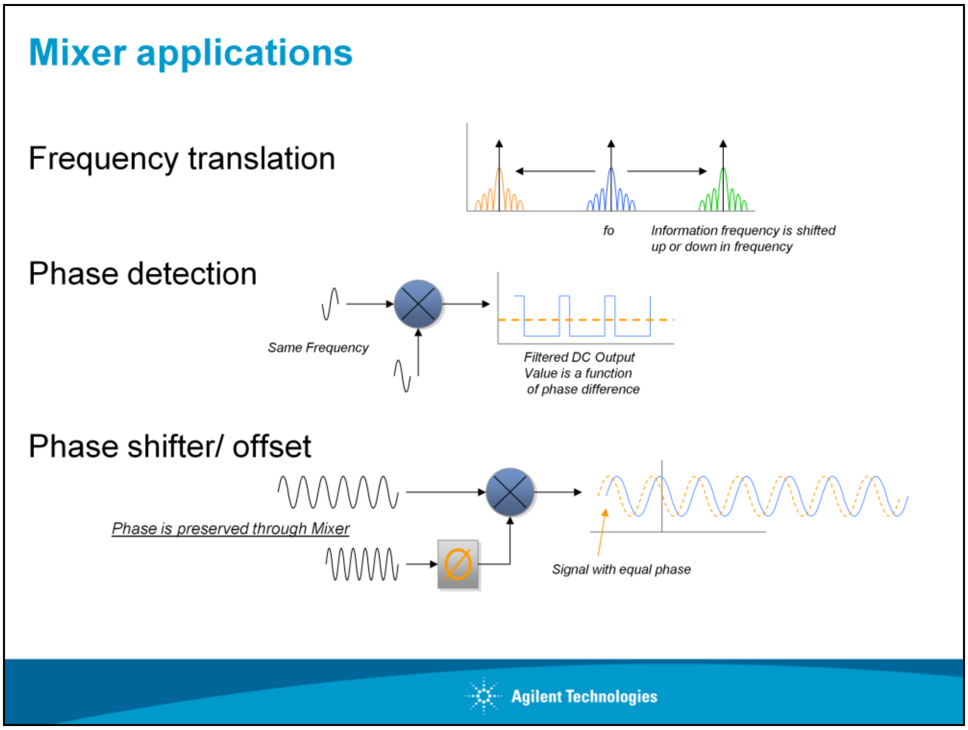
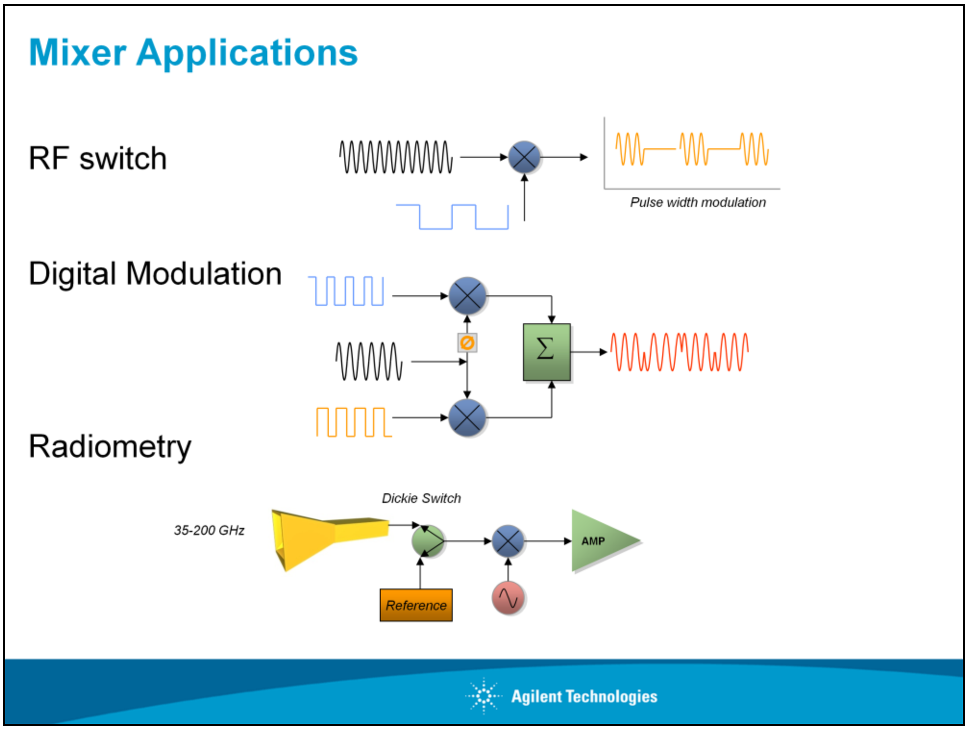
Some key mixer parameters are listed here. Compression point limits the amplitude of the incoming signal. Isolation plays a key role in limiting the spurious signals in the IF and signals that may be re-radiated through the RF port or antenna.



Here we highlight the benefits(in blue) and negatives(in orange) of several mixer types. The most common mixers used are double balanced due to the higher isolation for RF to LO and IF. Single ended mixers can be useful in second or third stage convertors.



A few applications for mixers besides frequency translation or down conversion is in phase detection and providing phase offsets. Phase detection is often used in phase lock loops.



Additional applications include using a mixer used to switch a signal on and off. Often used in digital modulation for QPSK and QAM. At higher frequencies where amplification is more difficult and expensive they form the front end of the receiver such as in a radiometer. The ferrite switch constantly swtiches to a known reference to calibrate the receiver for the incoming millimeter wave signal

Using GENESYS Synthesis

Having Established The Application We Are Faced With Choosing The Best Design

We Would Like To Be Able To Review And Compare Mixer Types: **MIXER**

We Need A Tool To Help Us Define The Critical Mixer Parameters: **WHATIF**

Finally We Want To Test Our Final Selection: **SPECTRASYS**

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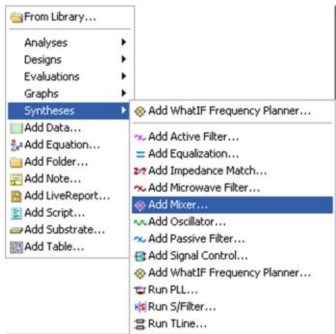
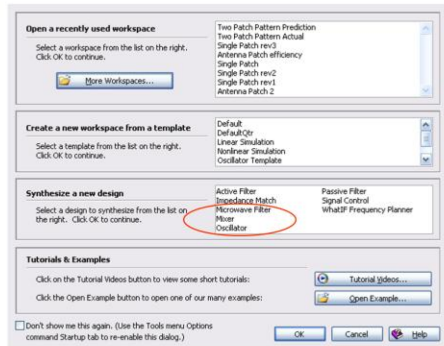
For synthesis and mixer performance comparisons we use the Genesys Mixer synthesis tool which as we will learn can help us to decide the best configuration to use for our particular application. Once we have chosen the mixer configuration and determined it's properties we will use WhatIF to view the useable IF spectrums based upon the mixer's performance.

Finally, having a system analysis tool like Spectrasys enables us to view the effect of our mixer on a receiver or transmitter chain.

GENESYS MIXER

Mixer Synthesis Can Be Launched From The Menu Tree Or New Workspace





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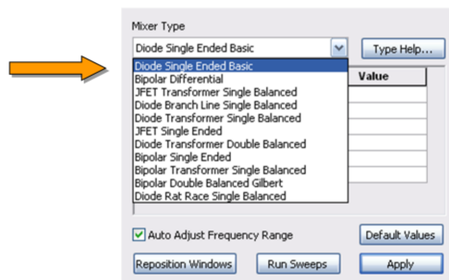
We may launch any of the synthesis tools from the drop down workspace menu or from the start up screen shown.

GENESYS MIXER

Mixer Type Selection Dialog

- Pre Package Topologies To Aide Rapid Design
- Simple Single Ended To Gilbert Double Balanced Designs

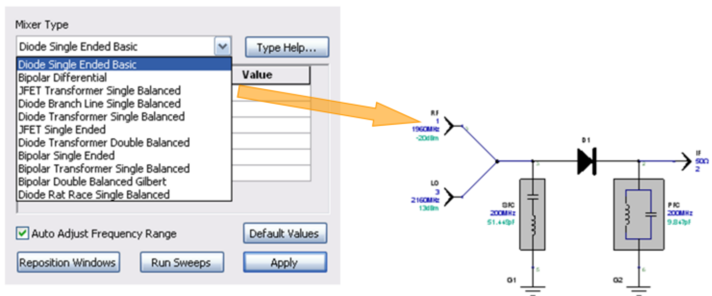


The Mixer dialog allows us to choose from a group of speicalized mixer types. Note the numerous types that are available. We will start with a simple single ended mixer.

Initial Design

So That Comparisons Can Be Made…

- We start with the simplest single ended mixer



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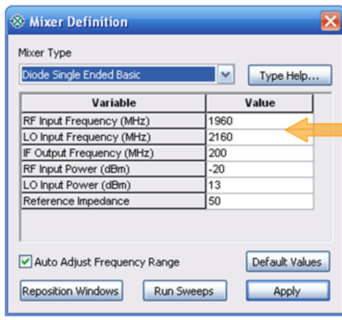
The selection of the single ended mixer results in an automatic schematic and simulation generation. Frequency dependent components were generated automatically based upon our parameter inputs.

Mixer Parameters

Having Selected A Mixer Type

- Set Mixer Parameters i.e.
  - RF, LO, and IF Frequencies and Power Levels



Power Levels Are Static Values Which Will Be Swept Over User Defined Limits

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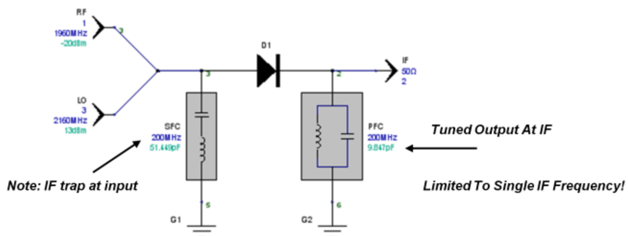
Set mixer parameters for a receiver band center frequency of 1960 MHz (LTE- 1930-1990 MHz). We will use an IF center frequency of 200 MHz. The RF and LO power levels are somewhat arbitrary, however will we see later that this type of mixer requires higher LO drive levels.

Schematic Generation

Applying The Initial Settings, GENESYS..

- Automatically generates a schematic and spectral responses



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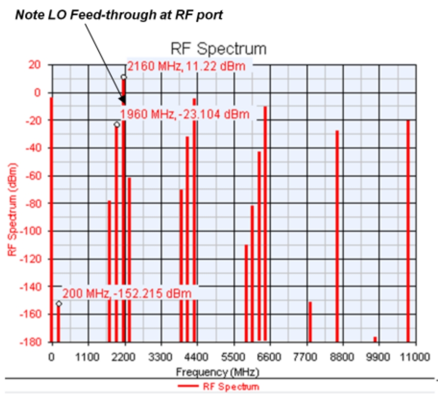
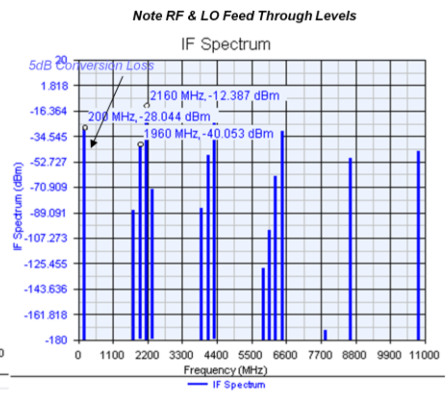
The input filter or trap and output resonator are set to the selected IF frequency. Note that there is little to no isolation from LO to RF making this mixer a poor choice for a front end mixer. Out simply design is limited to a single IF frequency due to the filters used.

Spectral Components

GENESYS Automatically Generates Port Spectral Data





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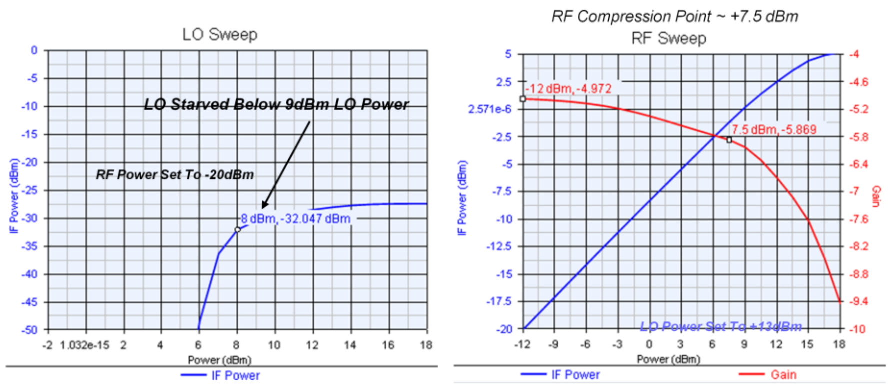
At the input port we notice that a large component of the LO energy that may effect reverse radiation or remix with the input stage. Note that there is a 3dB drop in the RF energy at the RF port, why is this? (hint: what other ports are connected to the RF port?) At the IF port we note an 8dB conversion loss. What is the isolation between the LO and IF port as well as the isolation between the RF and IF port? Remember that the LO power is 13dBm and that the RF power is -20dBm. Would this topology be suitable for a front end mixer with an antenna attached?

Swept Port Power

MIXER Automatically Sweeps And Plots LO and RF Power (User Selectable)



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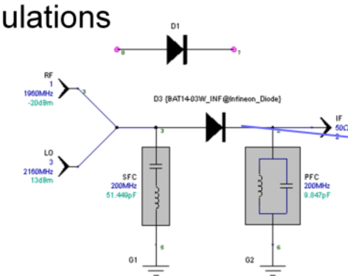
For the LO sweep the RF power is held constant at -20dBm. Note that a minimum LO power of approximately +10dBm is required to keep the mixer from starving. Keeping the LO power at 13dBm and sweeping the RF power we see a decline in conversion efficiency at +7.5dBm.

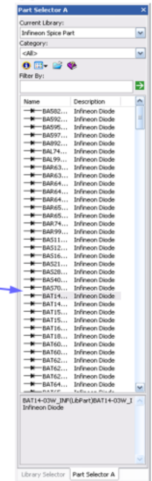
Substituting Commercial Part

Substitute Default Diode With Vendor Model From Parts Selector

Check-Mark Graphs For Comparison

Rerun Simulations





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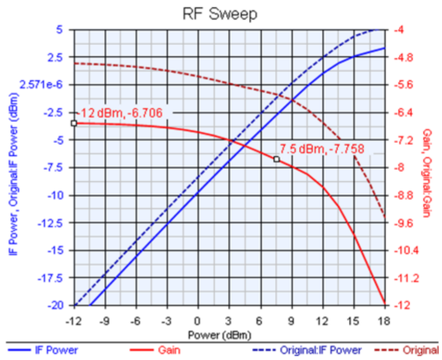
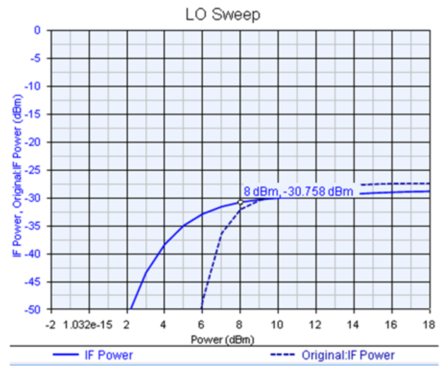
While an default diode helps us start our design, ultimately a known measured diode is required to predict performance accurately. GENESYS offers numerous non-linear models in SPICE and VerilogA format. We have selected an Infineon schottky for this example.

Comparing Model Differences

Note Changes In Loss, Compression And Harmonics, etc.





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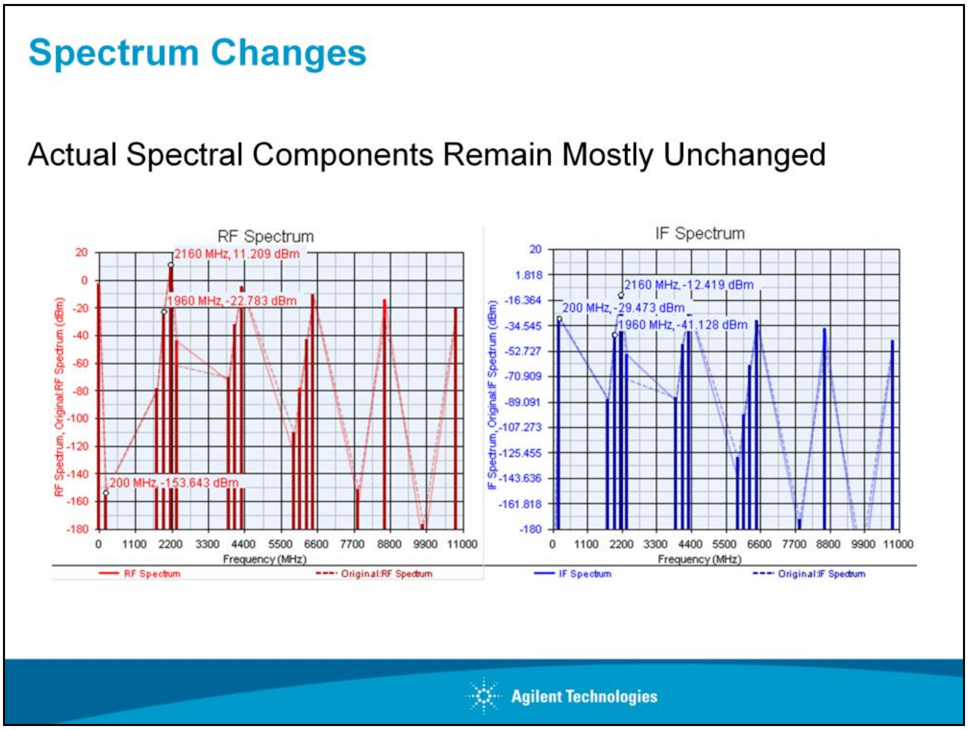
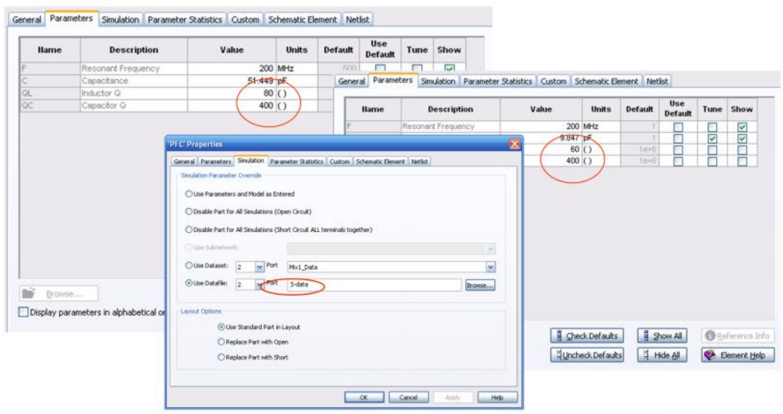
Note the changes in loss due to parasitics and parameters of our diode. With this diode selection the range of LO power over which our mixer will operate successfully is extended.



Spectral components remain relatively unchanged other than an increase in conversion loss.

The Effect Of Q

We Modify The Ideal Resonators With Realistic Q, Estimated Or Measured



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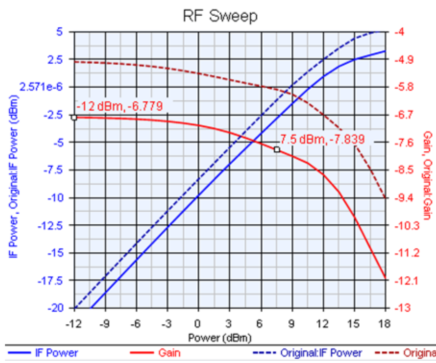
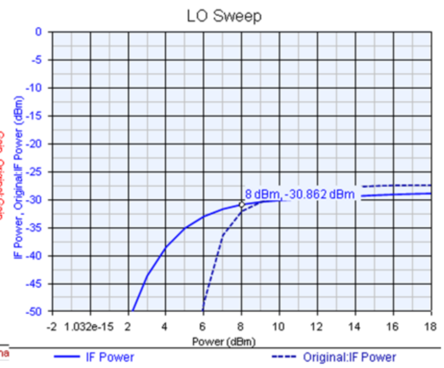
We can enter estimated values for element Qs for our resonators or use measured S-parameter data from the resonator manufacturer or individual values if discrete components are used.

Changes In Conversion

Small Increases In Conversion Loss Due To Changes In Resonator Q





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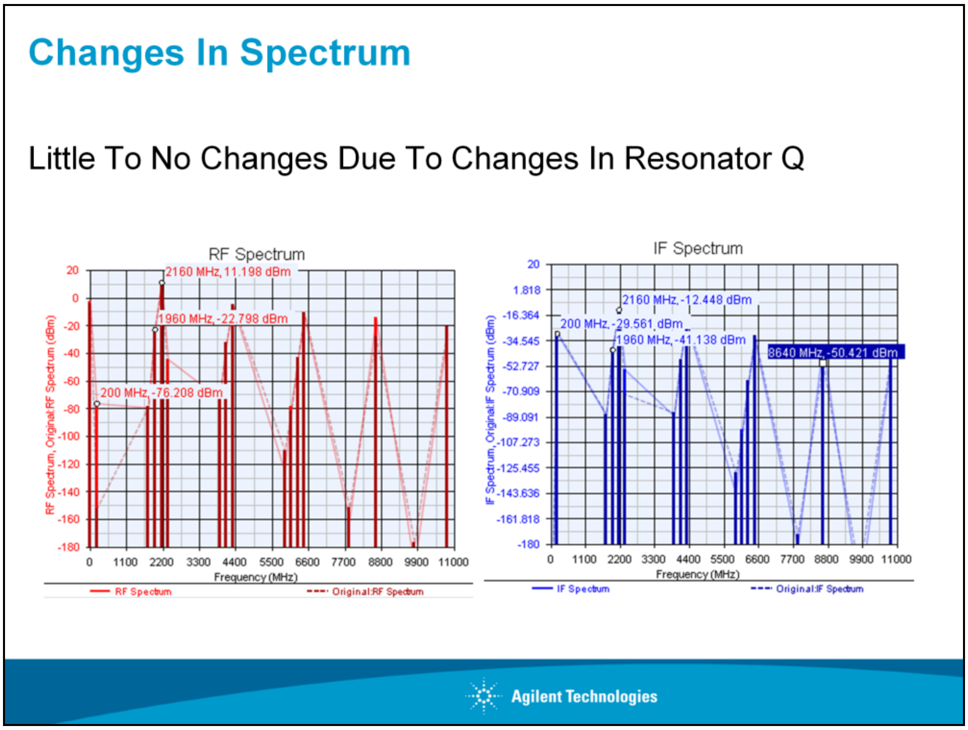
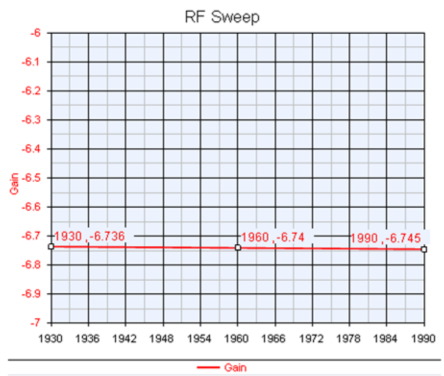
Low resonator Qs have a small effect on the conversion loss. This allows us to be less selective in the resonator elements that we employ.



The changes in component Q’s have little to no effect on the relationship of the harmonics and spurious spectral content.

Frequency Response

How Well Does This Mixer Operate Over The LTE Receiving Band?



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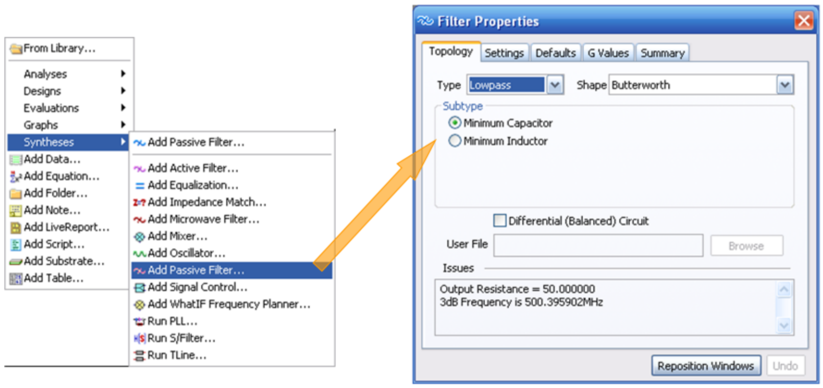
The only frequency selective elements, beside the diode parasitics, are the IF resonators. Since our IF is fixed there is little to no effect verses frequency.

Adding IF Filtering

Use GENESYS PASSIVE FILTER For Rapid Design And Implementation



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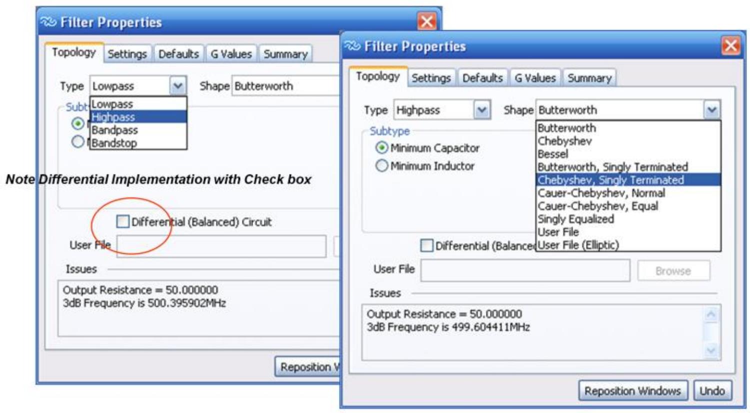
We will now add an IF filter to our mixer to reduce harmonics and unwanted mixing products from our signal. Using the Passive Filter tool makes this addition effortless.

Selecting Filter Type And Shape

Select From Numerous Topologies



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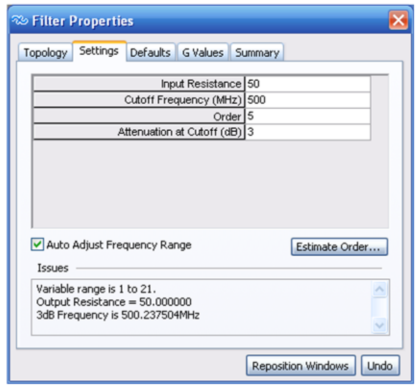
The filter function is defined by the *Type* and *Shape* selection. This determines the roll-off and in band response. Note, with the addition of singly terminated shapes, diplexer filter design is possible also known as constant return loss filters.

Selection Of Parameters

Next

- Number Of Sections Or Order
- Cutoff Frequency



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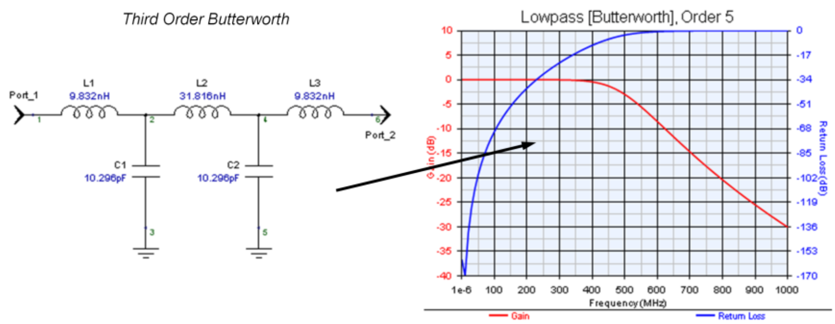
Under the Settings tab we specify the filter's impedance as well as the number of filter sections, cutoff frequency and attenuation at cutoff for non-Butterworth filters. We select 500 MHz as our cutoff frequency to attenuate unwanted harmonics and spurious while minimizing the in band loss at 200 MHz.

Automatic Generation

Schematic And Response Graph



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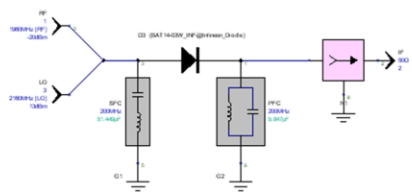
Passive Filter automatically generates a schematic and response curve. Changes made in the definition dialog are instantly updated in these graphs

Reuse Of Subnet

Hierarchical Design Using Filter Subnet

- Incorporate Filter In Original Schematic
- Rerun Simulation To Compare IF Signal Levels



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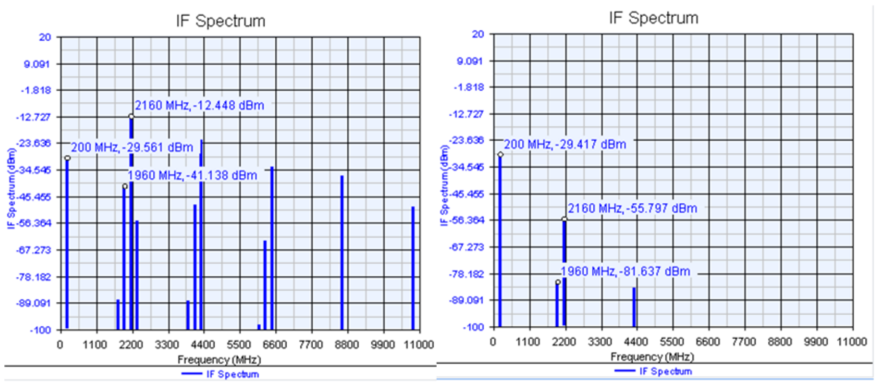
Instead of copying the filter directly into our mixer schematic we use the filter sub-net as packaged component shown to the right of our mixer.

IF Output Comparison

Note Reduction In RF, LO And Harmonics

RF Port Power =~-23dBm



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Note the reduction in spurious IF output. Conversion loss remains constant. To Improve the LO suppression, a higher filter order may be implemented.

Single Ended Mixer Performance

Let's Review The Performance Of Our First Design

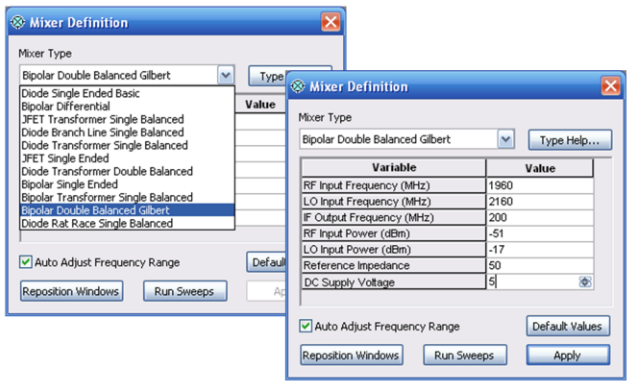
- Improvement in LO-RF isolation is difficult (filtering) since the LO and RF frequencies are close
- Limited to fixed IF frequency with limited dynamic range
- Moderately high LO power is required

RF-LO Isolation	Poor	3dB
Conversion Loss	Moderate	-7 dB
Compression Point	Moderate	+7.5 dBm
LO Drive	High	+13 dBm

LO to RF port leakage limits the applications of this mixer. If we spread the separation with the LO frequency so that an appropriate RF filter can dissipate the LO signal, the resulting image frequency appearing at the IF output is more difficult to filter out. This type of mixer is more suitable for second or third mixer in a chain. The higher power required increases the opportunity for interference into other networks in our system.

Alternative Mixer Design

Returning To Our MIXER Synthesis Tool



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Let’s try a different mixer. We use the same settings as in the single ended mixer but with the addition of operating voltage since this is an active mixer. The additional complexity results in better performance. While other double balance configurations are simpler the Gilbert allows us to implement a mixer with high dynamic range, higher power capacity and inherent isolation due to the balance in LO and RF driven ports

Schematic Generation

Components Are Selected Base Upon Our Parameter Selection

Note that transformers and their parameters are used for coupling

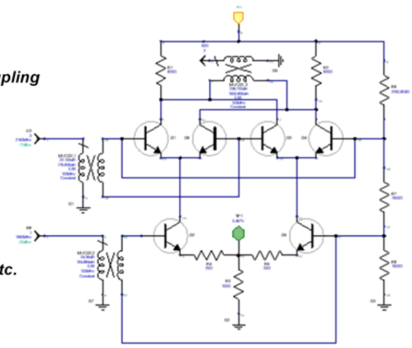
LO drive requirements are much lower ~-17dBm

Conversion gain instead of loss

Increased Linearity

Improved Noise Figure

Can be implemented in various technologies, e.g. MOSFET etc.



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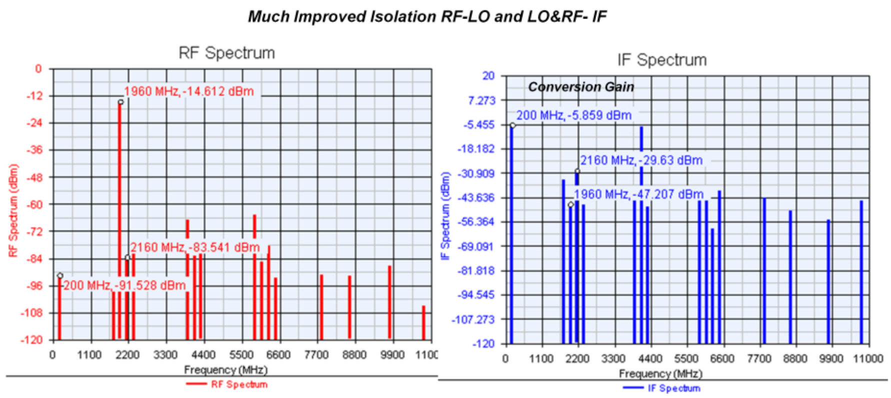
MIXER automatically selects the bias and frequency related components to ease our implementation. We note that the LO drive requirements are much lower which allow un-amplified synthesizer output for driving mixer. In addition we achieve conversion gain as opposed to a loss. Noise figure is generally improved. The active components may be substituted with alternate semiconductor technologies

Spectrum Graphs

GENESYS MIXER Automatically Generates Spectrums At The RF And LO Ports



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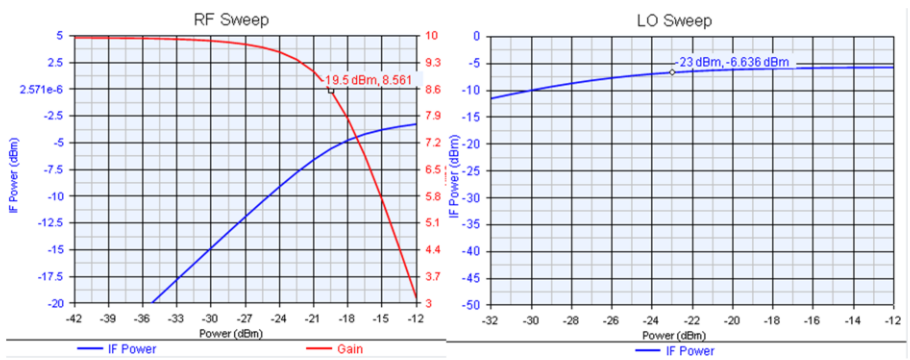
The most notable observation of the port spectra is that there is a marked decrease in unwanted energy at the RF port. This is achieved by the balanced design. In fact little to no filtering would be required at the RF port. In addition, note the reduction in RF and LO signal at the IF port. This reduces the amount of post IF filtering. This design is inherently broadband.

Compression And LO Power

A 10dB Gain With Minimum IF/LO Slope



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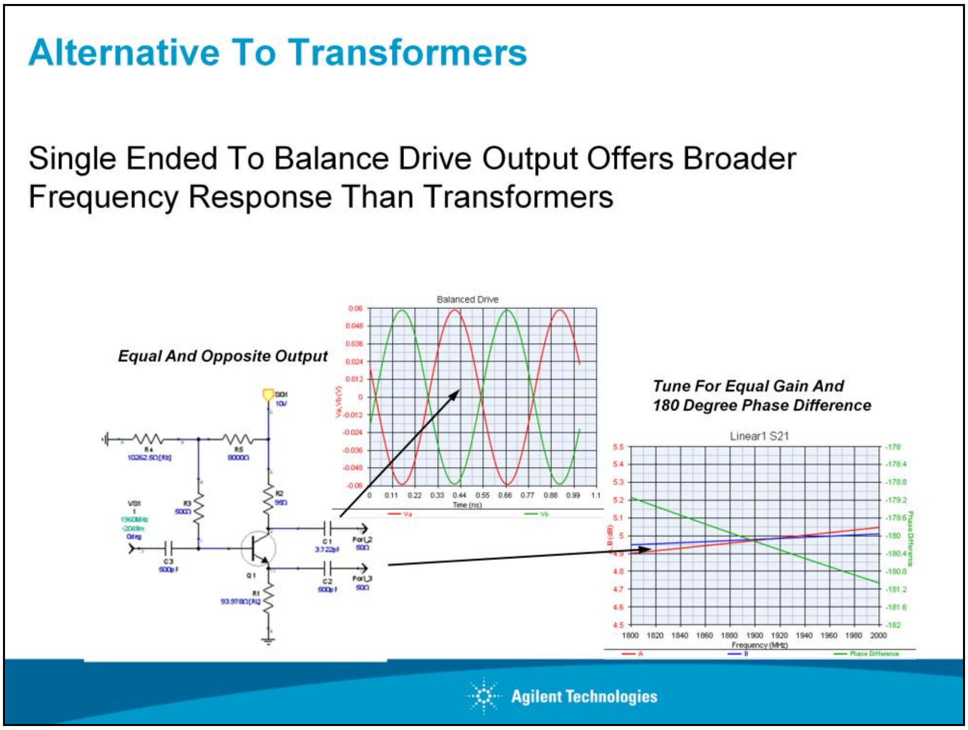
The 1dB compression point occurs at approximately -21dBm input. Note that the IF output is constant over a wide range of LO drive level, approximately 10dB.



Single to Balanced conversion is difficult over a broad frequency range. While transformers work well up to about 1GHz, using them above this frequency requires tuning of the transformer over a limited band. To overcome this at the cost of additional circuitry we may implement the balanced drive using the circuit shown. In a separate workspace we tune and optimize the performance of the network to meet the performance of a transformer. We tune the circuit for equal drive levels which are 180 degrees apart. For this simple design we achieve a few degree shift over the entire LTE band. We additional effort we can extend the performance to cover multiple octaves up to and including WiMax.

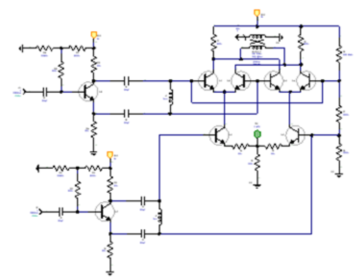
Active Transformer

Benefits

- Broadband Response For RF And LO Ports
- Improved Isolation At RF Port
- Lower LO Drive Requirements

High Frequency Broadband Transformers Are Difficult To Realize

An Optimized Mixer Can Be Used Over Multiple Bands, i.e. LTE To WiMax



Note That GENESYS HARBEC Handles Large Number Of Non-Linear Nodes

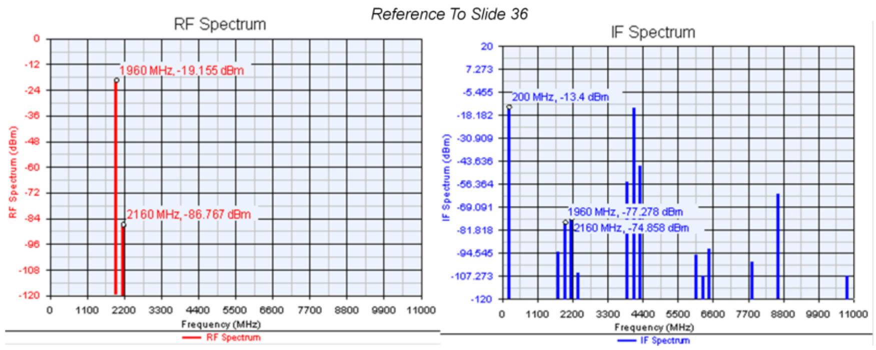
Agilent Technologies

The resulting schematic after substitution. Note, we could also reduce the active transformer network into hierarchical representations which helps to reduce schematic clutter. We retain a transformer output for the 200 MHz IF for simplicity and broadband performance. Note that GENESYS' HARBEC engine is capable of multi-device Harmonic Balance simulations.

Spectral Comparison

Note The Improved Rejection At The IF And Virtual Elimination Of Spurious At The RF Port

- What Improved The RF Port Spectrum?



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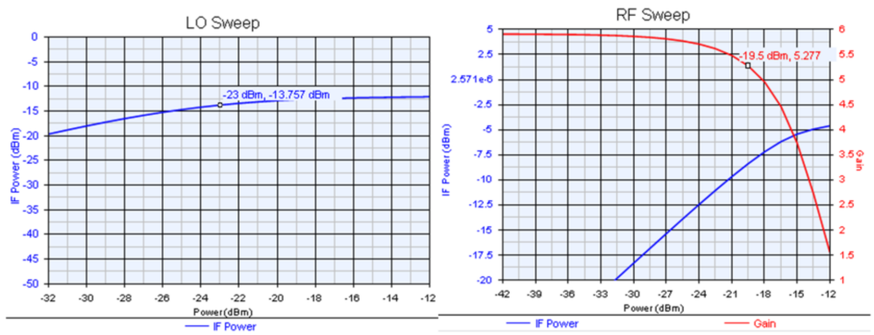
Note the excellent port spectrums. At the RF port all spurious signals below -120dB have disappeared and the LO appears -66dB below our RF signal. The inherent reverse isolation of our active transformer has provided the isolation. In addition the RF and LO feed through has be reduced from -23dB to approximately -65dB. IF filtering is easier since the largest IF signal next to the difference frequency is the sum frequency at 4120 MHz. This is an inherently broadband design that may be used over multiple octaves.

Compression And LO Drive

IF Power Is Insensitive To LO Power

Compression Point Is Slightly Higher

Optimization Required To Improve Gain



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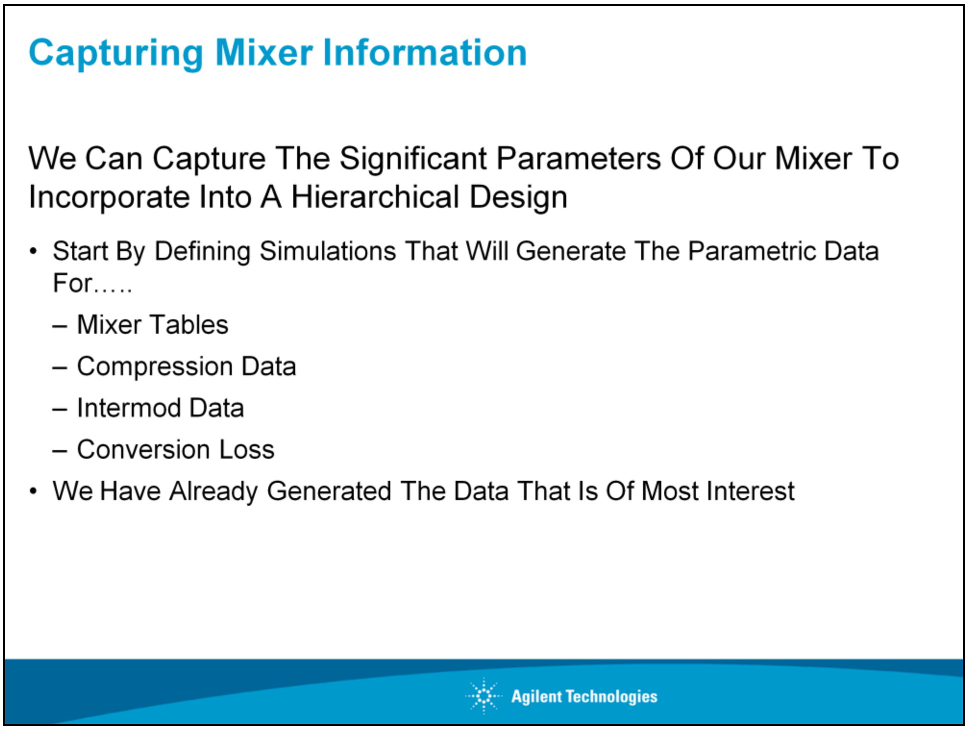
While having slightly lower gain, the compression and LO sensitivity plots are the same. To improve gain performance some optimization between the active transformer and mixer is desired.



Having a base design, we can capture the data generated by GENESYS simulations to use in additional simulation and design scenarios.

Generating A Mixer Table

Difference Frequencies For Mixer IF Table

- Build Difference Table For Up To N Order

N=5 For Our Example

RF \ LO	2160	4320	6480	8640	10800
1960	200	2360	4520	6680	8840
3920	1760	400	2560	4720	6880
5880	3720	1560	600	2760	4920
7840	5680	3520	1360	800	2960
9800	7640	5480	3320	1160	1000

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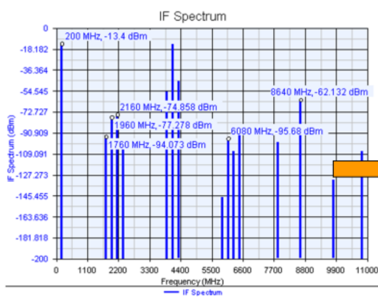
This 5th order mixer table will be used for defining a table mixer parameter entry. The table represents the difference frequencies given the RF and LO frequencies. The first entry represents the base or harmonic 1 for each.

Extracting Data From Circuit

Copy Data From Graph

- Normalize To 200 MHz IF Frequency



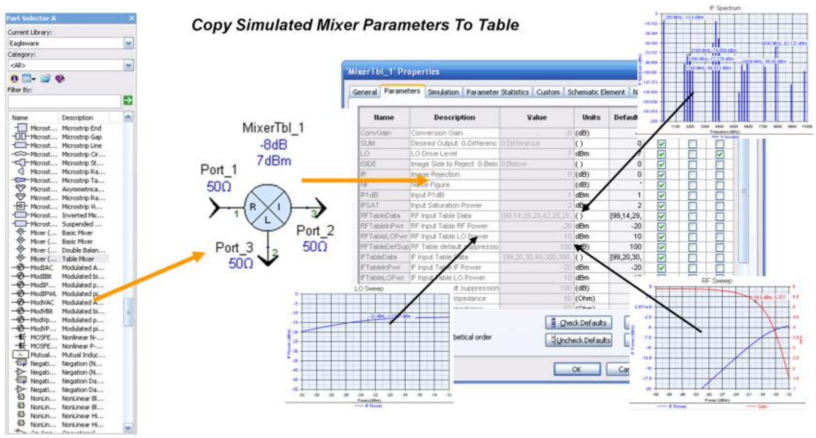
Darkened Data Is Essentially Zero

RF \ LO	-62	-33	-80	-48	-94
-64	0	-92	-200	-200	-200
-42	-80	-200	-200	-200	-200
-134	-200	-200	-200	-200	-200
-86	-200	-200	-200	-200	-200
-118	-200	-200	-200	-200	-200

Using the spectrum data from our simulation we enter the values normalized to the primary difference frequency at 200 MHz, as well as the RF and LO frequencies and their harmonics.

Creating A Table Mixer

Use GENESYS *Mixer Table* Model



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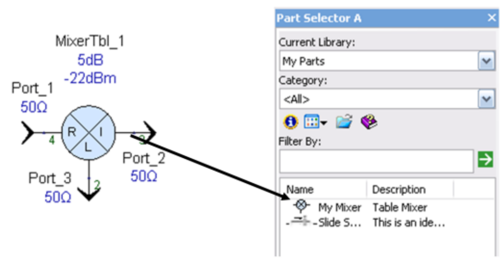
From the parts selector we choose the *Table Mixer* model to place on a schematic. Accessing it’s properties we manually enter the data taken from our various simulations. Table data from our spectral data, compression data, LO power, RF power, impedance etc.

Save Mixer Table To User Model

Having Copied The Mixer Parameters, Save The Table To A New Model i.e. “My-Mixer”

Mixer Can Then Be Used On Subsequent System Level Designs Such As WhatIF And SPECTRASYS



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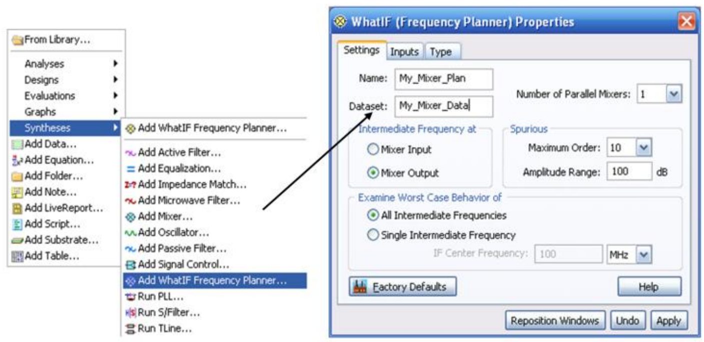
Having defined the pertinent parameters for our new mixer, save this mixer to a library. Above we save it to a library call ‘My Parts’. The mixer is now available for use in other designs.

Using Our New Mixer

WHATIF Helps Us To Determine The Spurious Free Ranges For System IF And Subsequent LO



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We select the number of mixers, whether or not this will be used for up-conversion or down-conversion as well as the spurious mixing order and dynamic range that we are interested in. We can focus on just one IF frequency or all IF's that may be available.

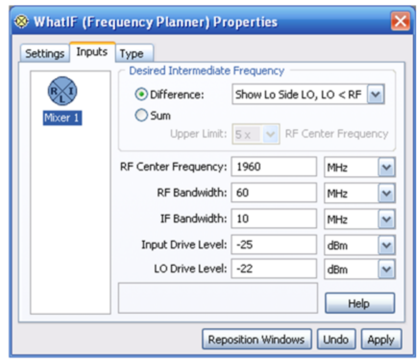
Setting Up The Frequency Plan

We Select A Difference Frequency

Note The Center Frequency And RF Bandwidth

We Have Selected A 10 MHz IF Bandwidth

Input Drive Level Reflects Our Device As Measured And Saved In Our Model Table



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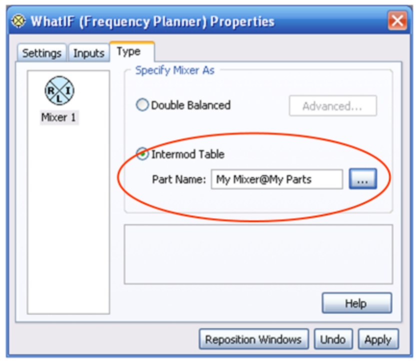
At the input tab we select the RF operating frequency as well as the expected bandwidth, which for our example is 60 MHz. The RF and LO drive levels are consistent with the nominal values as used in Gilbert simulation as well as the model entries. The IF bandwidth is set to what is required for LTE, e.g. 1, 2, 3 MHz etc.

Using Our Mixer Model

Import *My Mixer* From Dialog Selection

- WhatIF Uses Our Model Parameters



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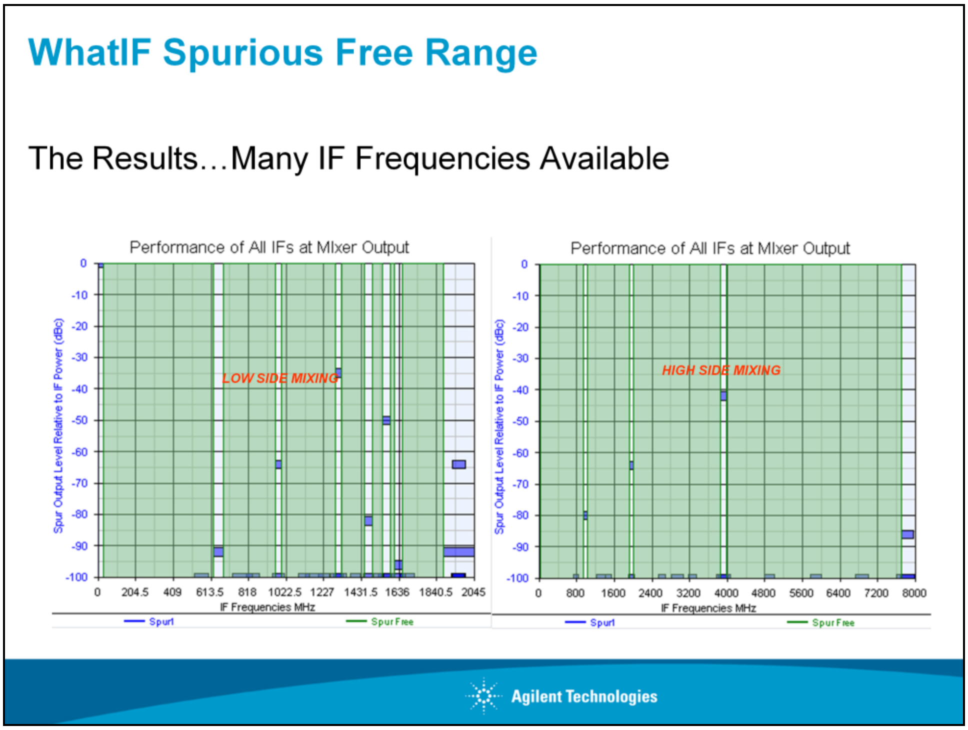
The type tab allows us to select from a variety of mixer types. There is a built in double balance model as well as supplier defined models. In our example we will select our own design via the Mixer-Table model.

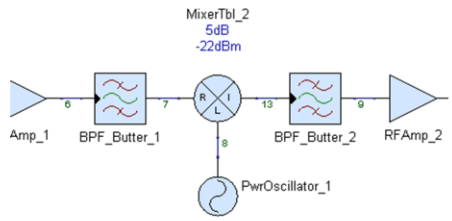


The results for our mixer are impressive. Since the spurious response of our mixer is excellent, the range of spurious free bands is almost unlimited. From the Inputs tab from the dialog box we alternately select between a high side mix (LO>RF) and low side mix (LO<RF) and review the best IF offerings for each.

Using Mixer In Spectrasys

Build Up Design Workspace Using The Mixer We Have Designed And Built

Determine What Parameters Require Improvement At A System Level And Amend Design



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For a system architecture tool, such as SPECTRASYS, we incorporate our *Mixer Table* model for design and review. Should it deem necessary to improve gain, intercept, spurious levels, or VSWR of our mixer these system level parameters can then be used to improve specific performance at the circuit level and then re-incorporated into our mixer model.

Summary

We Have Reviewed The Role Of A Mixer

We Have Synthesize A Basic Single Ended Mixer And Viewed It's Performance

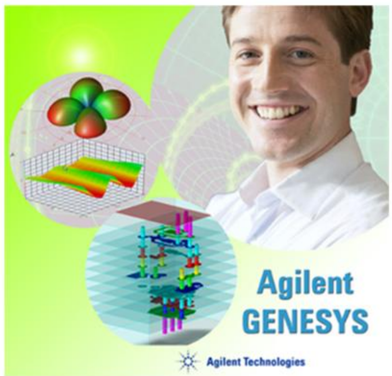
We Chose An Alternate Gilbert Cell Topology Viewed And Modified It's Performance

Incorporated A Mixer's Performance Parameters Into A Hierarchical Model

Used WHATIF To View Mixer Performance

Thank You

Additional Information-
Just Google search "Agilent Genesys"



1. **Register for the 4th "How-To-Design" seminar on LTE Power Amplifier design**
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References

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Microwave Solid State Design, Inder Bahl, Prakash Bhartia, Wiley Interscience 1988

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