

IF to IF Simulation of Wireless Links Using Commercial CAD Software

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This talk focuses on the nuts and bolts level of simulation tools for developing new hardware sub-systems for wireless applications.

Acknowledgements

- + This work was supported in part by separate grants from **Intersil** and **Ansoft** companies.
- + The measurement data was acquired in the WAMI teaching laboratory. This lab was made possible by combined grants from **NSF**, **Agilent**, **USF** and sponsorship of many other companies.
- + The coaxial system hardware examined here is comprised of components donated by the companies **Mini-Circuits**, **Miteq**, and **Piezo-Technologies (PTI)**.
- + The authors also thank **Ansoft** and **Agilent** for making their CAD software available on the USF campus.



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This talk is not intended to endorse any particular software product, but we do appreciate the cooperation of these companies.

Agenda

- **Motivation of Work**
- **Description of Transmitter/Receiver Hardware**
- **Simulation and Measurement Comparisons**
 - Filter Responses
 - Conversion Gain and Bandwidth
 - Gain compression (1-dBc Point)
 - Third-Order Intercept (TOI)
 - Receiver Noise Figure
 - Spectral Content (Mixer products, etc.)
- **Conclusions**



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Motivation and Goals

- + **This work explores, by way of example, the application of modern CAD software to the simulation of RF communication system hardware.**
- + **A 915 MHz transmitter/receiver system is used in a series of measurement and simulation comparisons.**
- + **This effort is part of a longer range effort that involves students in system level studies that are building greater understanding of how to effectively model communication system hardware.**
- + **Two different simulators – Agilent ADS and Ansoft Serenade are exemplified to varying degrees.**



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This is a work in progress.

Direct comparison of the products is not our goal.

Motivation and Goals (cont'd)

- + Considered are various RF/IF performance metrics for receiver and transmitter sub-systems.
- + Antennas/channel modeling not studied here.
- + Goals:
 - Illustrate modern CAD solutions to system hardware simulation.
 - Explore which measures and simulations make sense to compare at sub-system level.
 - Determine where problems arise in system hardware simulations, or answer the question: **what works / what doesn't?**



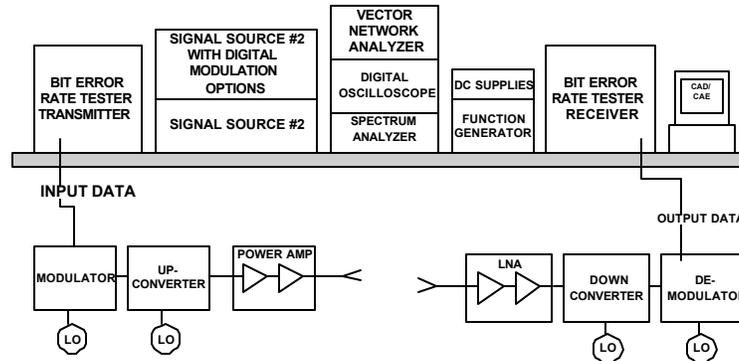
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We know of no better way to understand the capabilities and limitations of simulation software than conducting extensive measurement and simulation comparisons.... though we are quite open to hearing of alternatives!

Wireless Communications Test-Bed (In-development)



Project-based learning in a complete communications system context



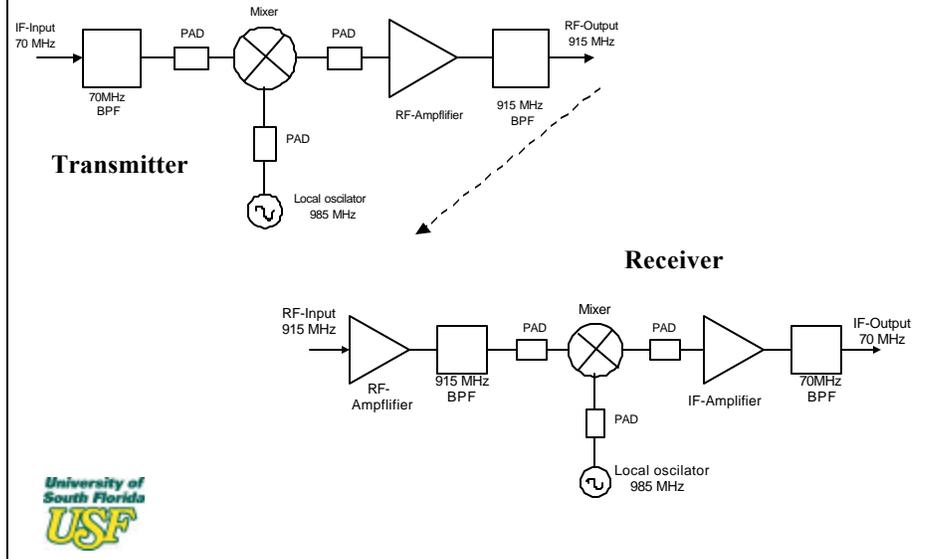
- Test-bed at 915 MHz – generic transmit receive pair ← Today's focus
- Test-bed at 2400 MHz – Intersil PRISM Wireless LAN hardware
- Bits-to-bits treatment as goal
- Simulation and measurement comparisons reveal and validate needed improvements for system hardware simulations

There are many many things we can study with this generic test-bed approach.

One goal is to better understand the effect of RF performance issues on overall communication system quality. We want to understand how to properly model sub-system components to enable reliable simulations of overall bits-to-bits performance.

We are teaming graduate and undergraduate students in various projects using this test-bed as a platform philosophy.

Simulation and Measurements of Wireless Transmitter and Receiver Hardware

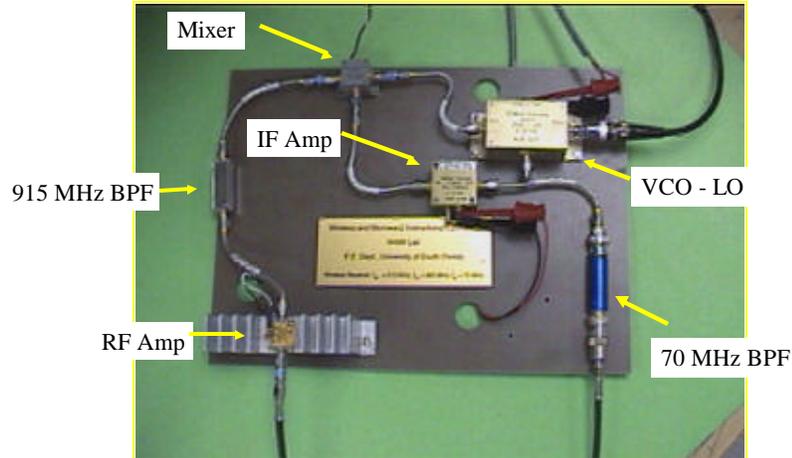


The present work is limited to IF/RF and RF/IF consideration.

Continuing work is adding mod/de-mod to test-bed and simulations.

Note transmitter has one amplifier receiver has 2 – a quick way to visually see which we are talking about in future slides.

Picture of Receiver Board



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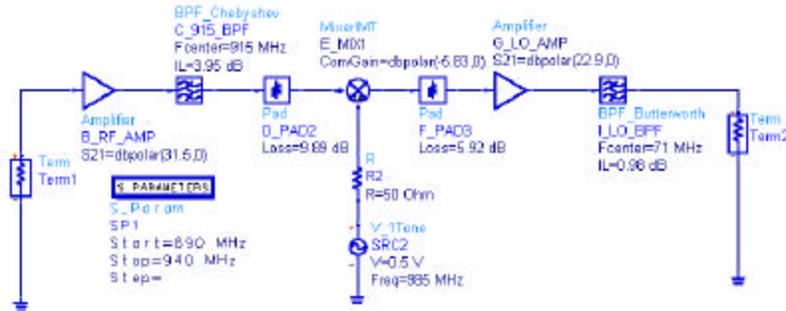
The transmitter looks similar to this.

The advantage of this particular coaxial hardware set is that we can test each component separately.

The goal of our work is to build necessary understanding of the proper simulation approach (and limitations thereof) to allow useful design simulations of surface mount and IC-based sub-systems.

Receiver Simulation

ADS



System components are modeled with functional models selected from the CAD simulator library. This is a small signal sweep bench.

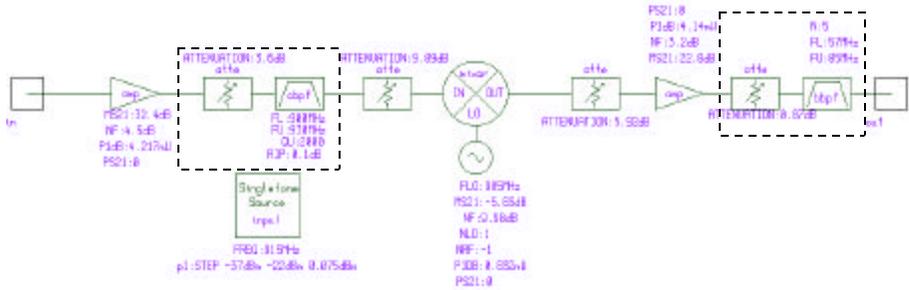


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The simulations ADS are made for both the transmitter and the receiver. In ADS it is necessary make different benches to do be able to simulate the different parameters. This schematic, however, shows the main structure of the receiver.

Serenade

Receiver

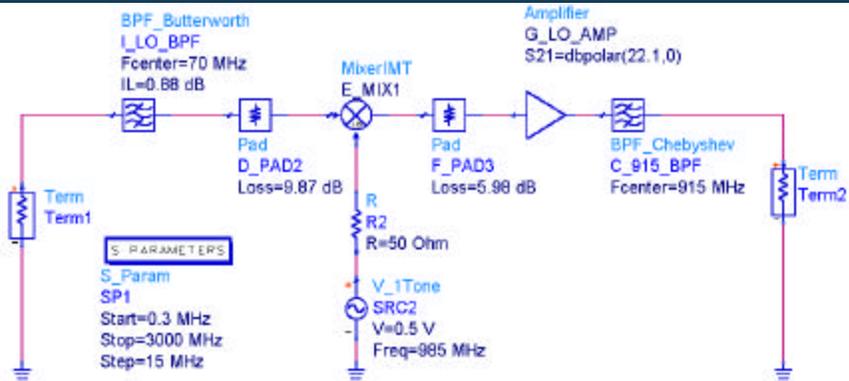


Similar schematic representations are used to define the sub-systems in the two simulators.



Transmitter Simulation

ADS

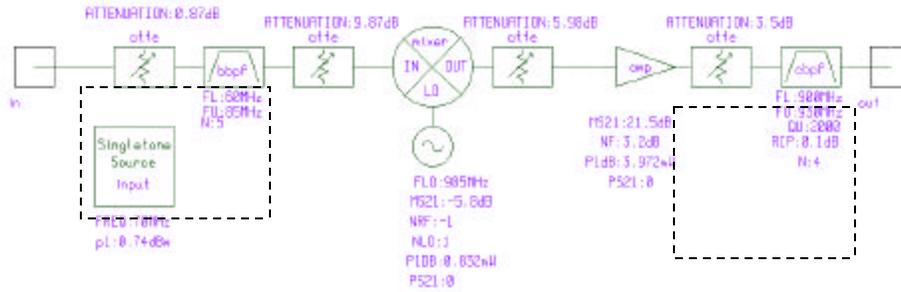


Parameters used to define the components are selected initially from component specifications, then “calibrated” using measured component data.



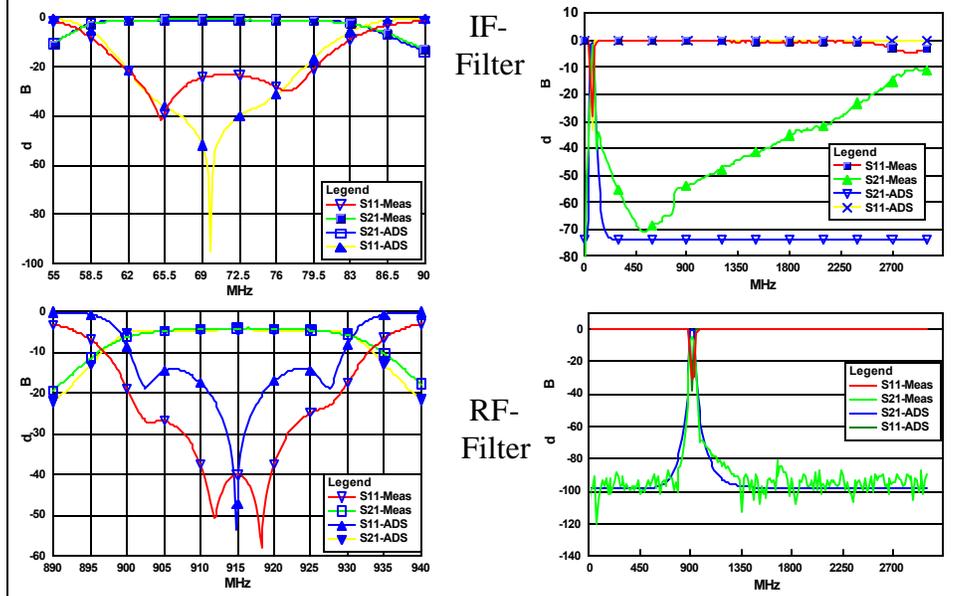
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Serenade *Transmitter*



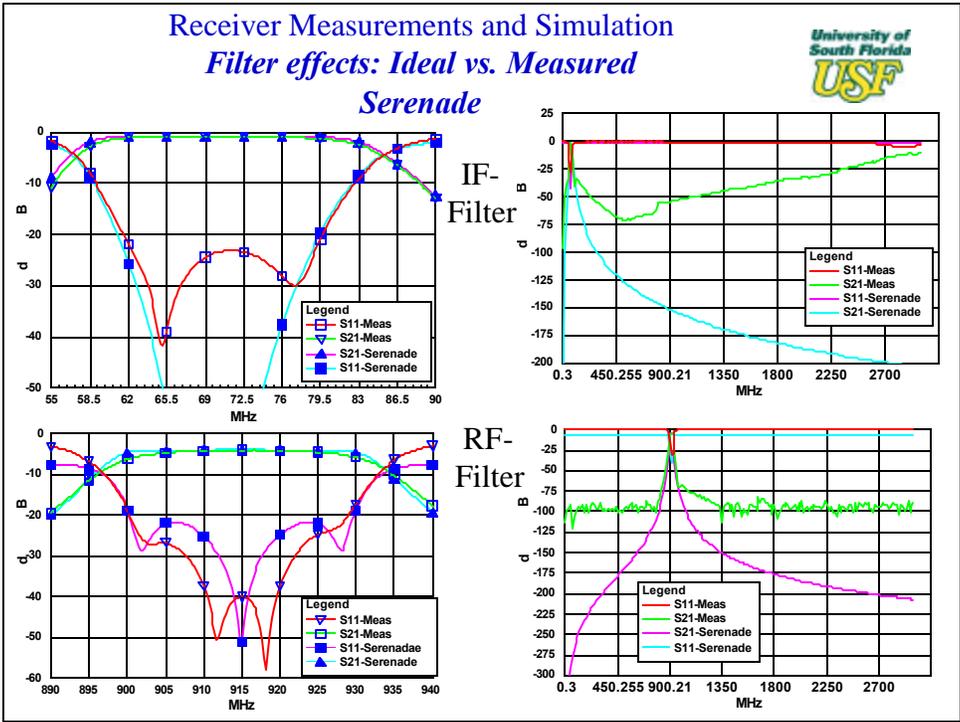
In Serenade one bench template can be used for all simulations, with suitable modifications.

Receiver Measurements and Simulation
 Filter effects: Ideal vs. Measured
 ADS



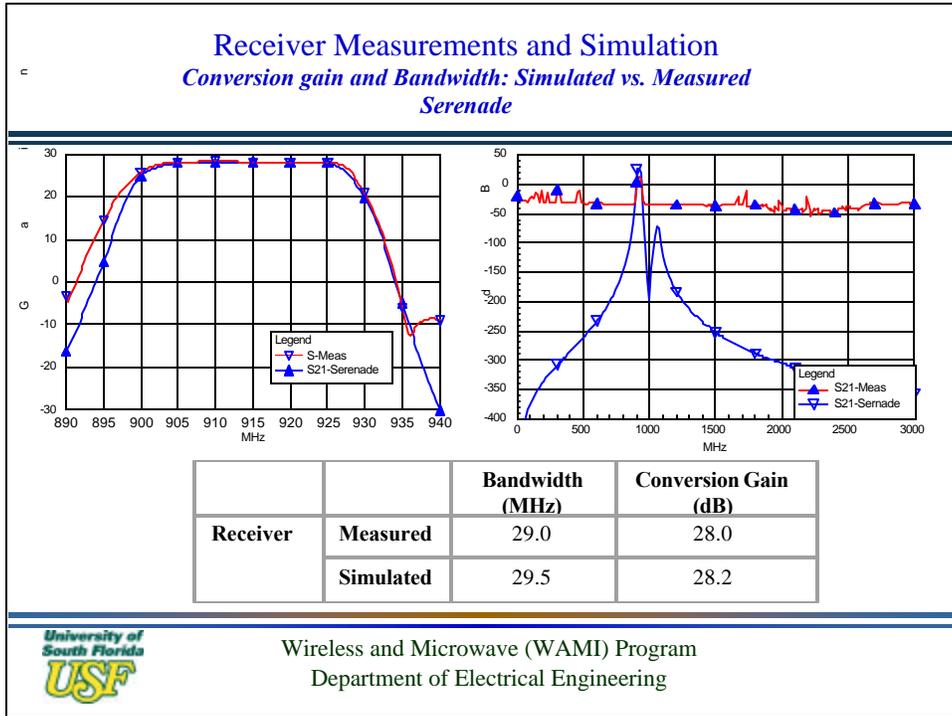
With more effort we may be able to get a better representation of the reflection response. However, reflections are neglected in our simulation approach.

More importantly, note the problems with the out-of-band response of the IF filter. Although not considered here, the phase response may also be important and should be examined as well.



Just an observation – we did not see a way to limit the out-of-band rejection in Serenade.

The transmitter filters are very similar so will not be examined separately.



This measurement is made by using a VNA that provides a swept signal to input and a broad-band detection mode at the output. The noise floor is set by the broad-band detector limitations.

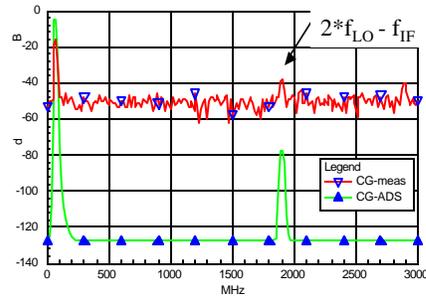
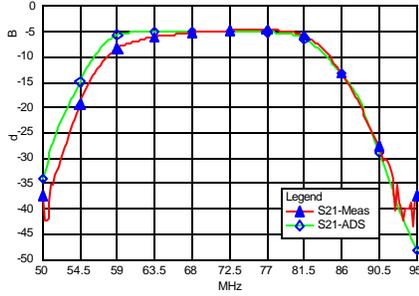
Note the image frequency shows up in the simulation.

The input and output frequencies are different at each point in the measurement.

Transmitter Measurements and Simulation

Conversion gain and Bandwidth: Simulated vs. Measured

ADS

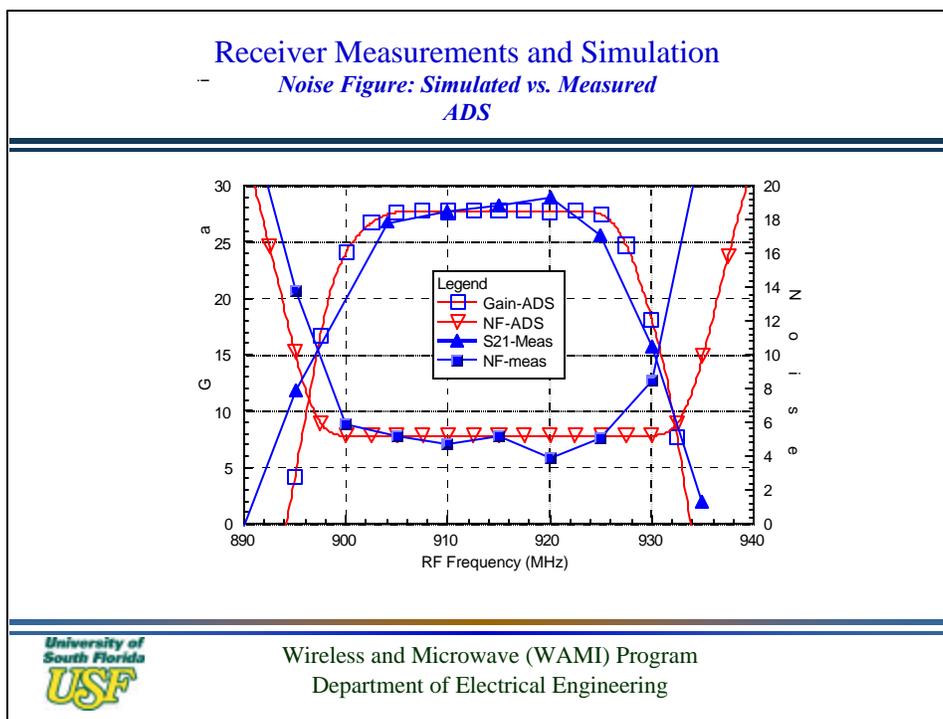


		Bandwidth (MHz)	Conversion Gain (dB)
Transmitter	Measured	24.1	-5.1
	Simulated	25.8	-5.2



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The apparent discrepancy in the in-band gain of the broad-band response is only due to using too large of a frequency step for the measurement across this range.

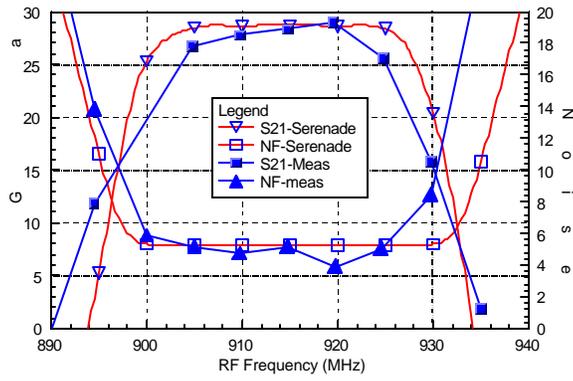


The measurement of noise figure and conversion gain was made using a spectrum analyzer. Somewhat better tracking with simulations may be achieved by using a smaller frequency step for this measurement.

Still, a somewhat narrower low noise bandwidth is apparent in the measurement as compared to the simulation.

Receiver Measurements and Simulation

*Noise Figure: Simulated vs. Measured
Serenade*

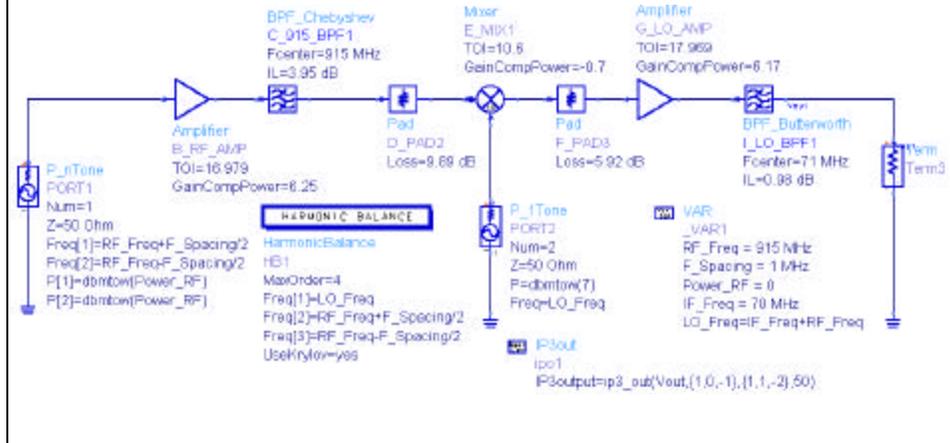


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Receiver and Transmitter Measurements and Simulation

P1dB and *TOI*: Simulated vs. Measured

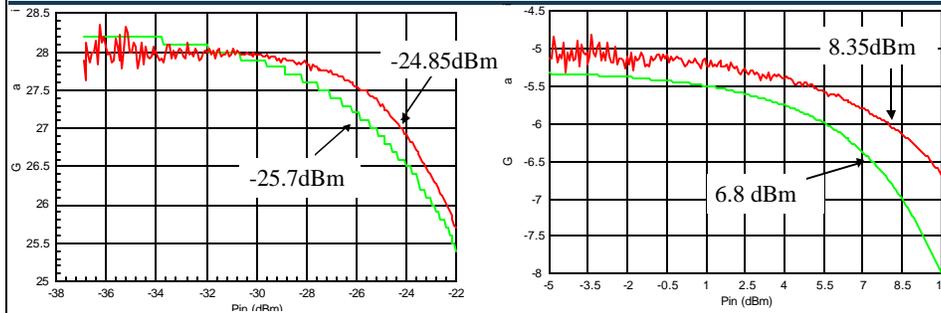
ADS



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A harmonic balance simulation is used in ADS to simulate the 1 dB gain compression and the third-order-intercept point. Note that the signal source used here has 2 tones.

Receiver and Transmitter, Measurements and Simulation
1- dB Compression point
ADS



Receiver (referenced to input)

Transmitter (referenced to input)

• Harmonic Bench

• Conditions:

IF Frequency 70MHz, LO Frequency
985MHz, RF Frequency 915 MHz

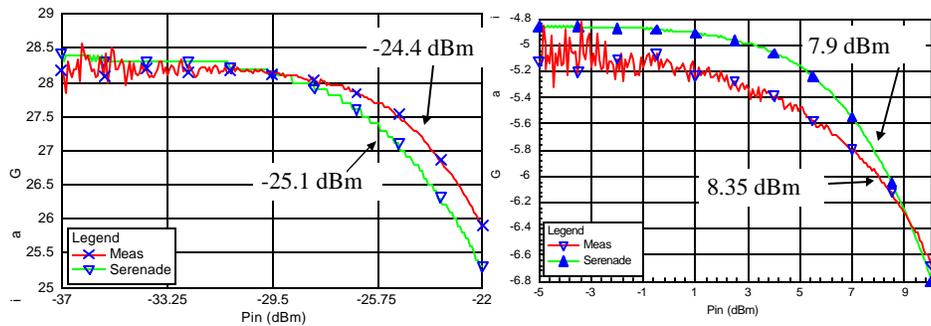


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The measurement was made here using an HP8714 vector network analyzer. The input frequency was set in each case to the center frequency of intended operation (915 MHz for receiver and 70 MHz for transmitter) then a power sweep was setup on the input signal. The output is processed using a broadband detector to deal with the fact that the input and output signals for each sub-system are at different frequencies. Calibration is done by normalization to a measurement made with a thru connection.

Receiver and Transmitter, Measurements and Simulation

*1-dB Compression point: Simulated vs. Measured
Serenade*



Receiver (referenced to input)

Transmitter (referenced to input)

•Conditions: IF Frequency 70MHz, LO Frequency 985MHz, RF Frequency 915 MHz



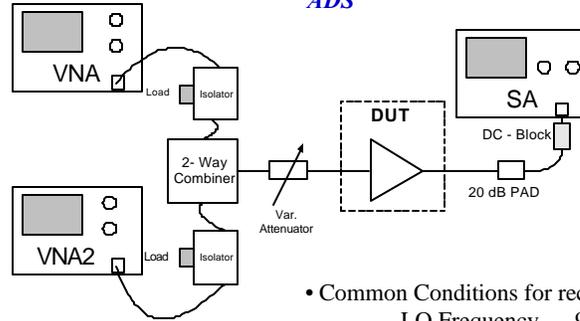
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The transmitter output is around 2 mW

Receiver and Transmitter Measurements and Simulation

TOI: Simulated vs. Measured

ADS



- Common Conditions for receiver/transmitter:
LO Frequency 985MHz, + 7 dBm

TOI Measurements referenced to **output** of receiver/transmitter sub-systems

	2-Tone Frequencies (MHz)	Measured TOI (dBm)	Simulated TOI with ADS (dBm)
Receiver	915, 916	9.65	8.79
Transmitter	70, 71	11.78	11.05

For the transmitter TOI measurement isolators were not available for the 70/71 MHz input signals.

Receiver and Transmitter, Measurements and Simulation
*TOI Compression point: Simulated vs. Measured
Serenade*

TOI Measurements referenced to **output** of receiver/transmitter sub-systems

	Measured (dBm)	Simulated (Serenade) (dBm)
Receiver	9.65	9.41
Transmitter	11.78	12.2



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Reasonable agreement is obtained with both simulators for TOI.

Receiver Measurements and Simulation
Spectral Content Simulations – Mixer Product Simulation
 Enabled by Use of IMT Table

Default Intermodulation Table

```

† DLB2.INT
† H( # ) $Source: /cus/sr/src/genintui/templates/dbl2.int,u $ $Revision: 1.2 $ $Date: 1997/06/27 11:28:47 $
† Intermodulation table for double balanced mixer #2
† Signal level (dBm) LO level (dBm)
  -10      7
† H x LO ( Horizontal )  N x Signal (Vertical )
†\ 0  1  2  3  4  5  6  7  8  9  10  11  12  13  14  15
†
99  39  42  46  58  37  65  49  75  62  72  61  70  57  87  60
25  8  39  11  50  16  59  19  59  43  63  52  70  57  73
60  67  76  67  80  66  82  66  83  72  84  72  82  70
63  58  65  60  65  55  64  54  66  57  85  54  70
96  80  96  80  95  82  98  78  98  95  95  95
93  78  87  72  88  66  85  64  82  75  95
99  99  99  99  99  99  99  99  99  99
99  79  99  78  99  78  99  81  99
99  95  99  95  99  95  99  95
90  95  98  90  90  99  90
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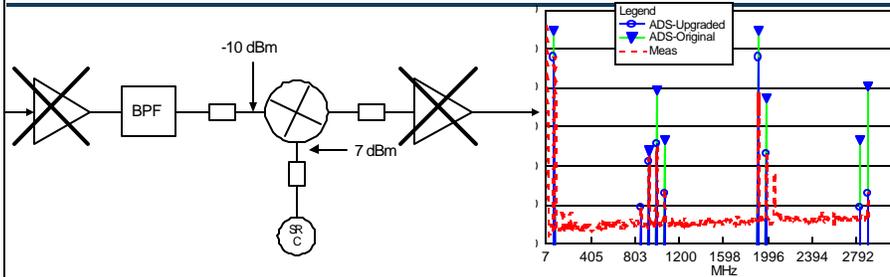
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The prior simulations, use mixer models that only provide the desired up-converted RF or down-converted IF signal at its output. In order to more properly represent the spectral content at the output of the mixer, a more complex mixer model is needed.

The test bench is similar to that shown before for each simulator, however, the mixer block model is replaced with a model that allows (or requires) as input data an intermodulation table (IMT) file. The IMT file is a 2 dimensional table that represents the amplitude level, relative to the desired IF frequency (in the case of a down converting mixer) of various mixer products. This type of information is sometimes called a “spur table”.

Shown is a default intermodulation table that would be used in ADS for an IMT related simulation if the user does not take additional steps to modify what is used for the IMT table.

Receiver Measurements and Simulation
Spectral Content (IMT): Simulated vs. Measured
ADS



Frequency (MHz)	70	915	985	1055	1900	1970
Original (dBm)	-15.2	-46.2	-30.8	-43.2	-15.2	-32.8
Measured (dBm)	-22.6	-49.2	-44.9	-57.0	-31.9	-47.0
Upgraded (dBm)	-22.2	-48.8	-44.1	-56.6	-22.2	-46.2



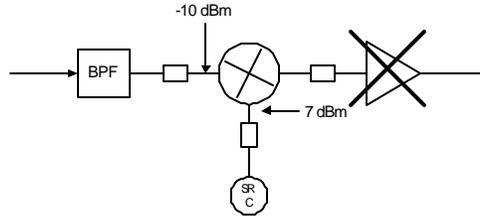
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In this first simulation / measurement comparison related to IMT-based simulations, the receiver is examined in the absence of amplifiers and IF filters. The original simulation was performed using the default IMT file. The upgraded simulation was performed using a IMT file with the help of measured data on the same mixer using the same test conditions as to be used in the verification measurements. Note that the signal component is at 70 MHz.

Clearly a marked improvement in agreement with measurements was obtained, however, there still are some problems. Most notable in this comparison is the remaining discrepancy at 1900 MHz.

Transmitter Measurements and Simulation

IMT: Simulated vs. Measured
ADS



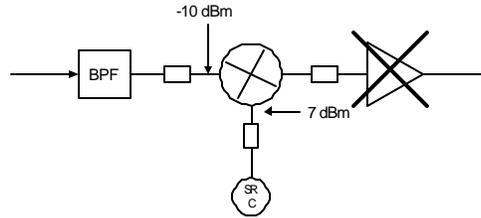
Frequency (MHz)	70	915	985	1055	1900	1970
Original (dBm)	-45.8	-14.8	-30.8	-14.8	-42.8	-32.8
Measured (dBm)	-63.3	-22.4	-32.1	-33.1	-60.0	-36.5
Upgraded (dBm)	-47.6	-21.6	-33.0	-21.6	-59.5	-49.6



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The transmitter mixer IMT file was upgraded in a similar way as in the case of the receiver mixer. At the desired output signal component is at 915 MHz good agreement is seen. For the other components, several discrepancies remain between measured and simulated frequency component amplitudes. At this point we do not sufficiently understand the algorithms embedded in the software to explain the discrepancies. We have noted that the simulator, for one, fixes the amplitude of the image frequency component at 1055 MHz to be the same as the amplitude of the 915 MHz component for the up converter simulation. This was surprising to us as the IMT file used assigns different amplitude values for the 2 components.

Transmitter Measurements and Simulation
IMT: Simulated vs. Measured
Serenade



Frequency (MHz)	70	915	985	1055	1900	1970
Original (dBm)	-51.8	-21.8	-39.8	-21.8	-61.8	-53.8
Measured (dBm)	-63.3	-22.4	-32.1	-33.1	-60.0	-36.5
Upgraded (dBm)	-47.9	-21.8	-33.1	-21.8	-59.8	-49.7



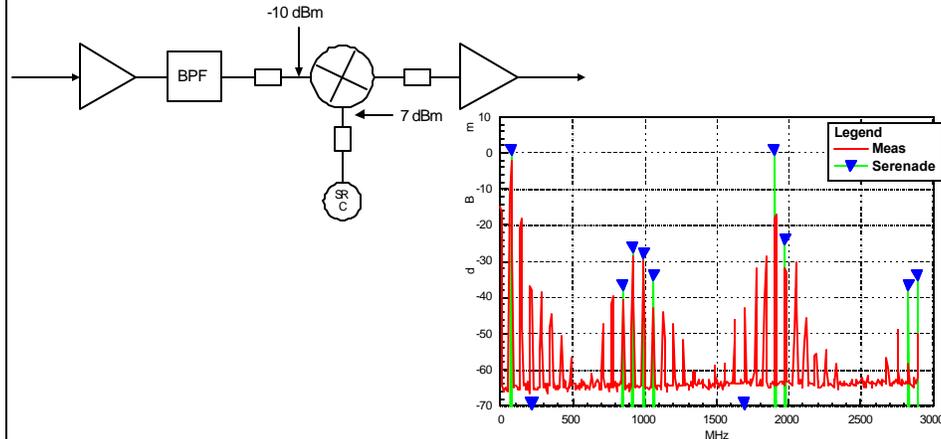
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It appears that the same type of discrepancies appear in either simulator. Again, we see some improvement with the upgraded IMT file use.

Receiver Measurements and Simulation

IMT: Simulated vs. Measured

Serenade



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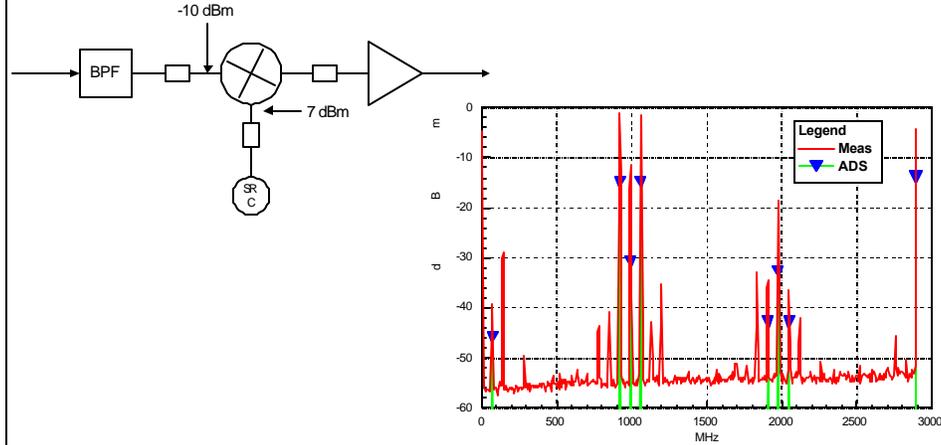
This is probably the most dramatic demonstrations of revealing problems presented in this talk. Here the amplifiers have been added back into the simulation, and it is clear that the non-linear representations we utilized in representing the amplifiers are not sufficient for predicting the spectral content added by harmonic and intermodulation distortion within the amplifiers.

This problem showed up in our simulations using both simulators.

It is possible that there exist built-in non-linear modeling options within the simulators examined that will allow us to reproduce this additional spectral content.

Transmitter Measurements and Simulation

IMT: Simulated vs. Measured
ADS



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The transmitter shows less additional spectral content as compared to the simulator. This is likely caused by the fact that there are two amplifiers in the receiver, with one occurring prior to mixing. Still, there are several spectral lines present in the transmitter output spectrum measurement (with RF filter removed) that are not predicted by the simulator.

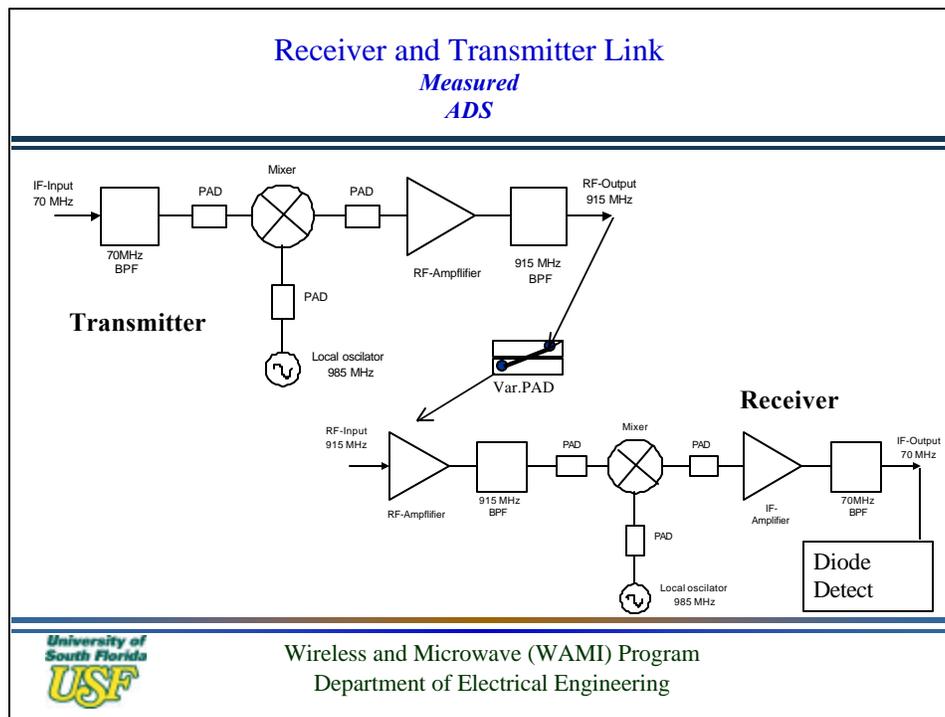
Summary

- + Good predictions of in-band performance can be achieved for all parameters examined.
- + The differences between CAD library (ideal) filters and measured filters can cause significant out-band discrepancies.
- + Mixer product (spur) simulations are much improved after using custom intermodulation tables; unexplained discrepancies remain for some frequencies.
- + The lack of non-linear representation of amplifiers was evident when amplifiers were included in mixer spur analysis and measurement. Many frequency components not predicted in output.
- + See <http://ee.eng.usf.edu/WAMI> for related MS Project Report
- + Future work will study 2.4 GHz “Prism” WLAN hardware, extend consideration to “modulation domain”, and time domain, and include antenna/channel considerations.



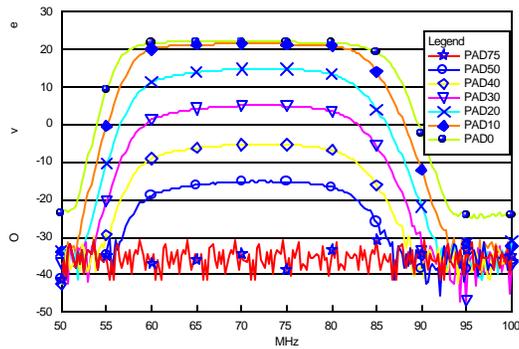
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A suggestion of the first author is that companies who plan to utilize system-level CAD software in designing new systems may benefit from having their engineers perform similar measurement/simulation comparisons. The simple sub-systems comprised of coaxial components examined here are particularly conducive to these types of comparisons.



Though not part of the formal presentation, we did conduct one experiment that combined the transmitter and receiver utilizing a variable attenuator as the “channel”. The input signal was taken from a network analyzer at a swept frequency and constant amplitude.

Receiver and Transmitter Link
Measured
ADS



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The various curves were obtained by changing the attenuation value of the variable attenuator connected between transmitter and receiver. The noise floor is dominated by the limitations of the broad-band detector used on the receiver output. The saturation effects of the receiver is also apparent at low values of attenuation.

A corresponding simulation is in preparation.