Agilent Technologies

Advanced Design System 2002

RF System DesignGuide

February 2002

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Agilent Technologies
395 Page Mill Road
Palo Alto, CA 94304 U.S.A.

Contents

Chapter 1: RF System QuickStart Guide

This *QuickStart Guide* is intended to help you get started using the RF System Design Guide effectively. For detailed reference information, refer to Chapter 2, RF System DesignGuide Reference/

The *RF System DesignGuide* has many simulation set-ups and data displays that are very useful for designing a communication system. The simulation setups are categorized by the System configuration, simulation technique, and type of topology. This DesignGuide is not a complete solution for all types of measurements and topologies, but covers the most common approaches. Subsequent releases of this DesignGuide will include an expanded range of features.

Note This manual is written describing and showing access through the cascading menu preference. If you are running the program through the selection dialog box method, the appearance and interface will be slightly different.

Using DesignGuides

All DesignGuides can be accessed in the Schematic window through either cascading menus or dialog boxes. You can configure your preferred method in the Advanced Design System Main window. Select the *DesignGuide* menu.

The commands in this menu are as follows:

DesignGuide Studio Documentation > **Developer Studio Documentation** is only available on this menu if you have installed the DesignGuide Developer Studio. It brings up the DesignGuide Developer Studio documentation. Another way to access the Developer Studio documentation is by selecting *Help* > *Topics and Index* > *DesignGuides* > *DesignGuide Developer Studio* (from any ADS program window).

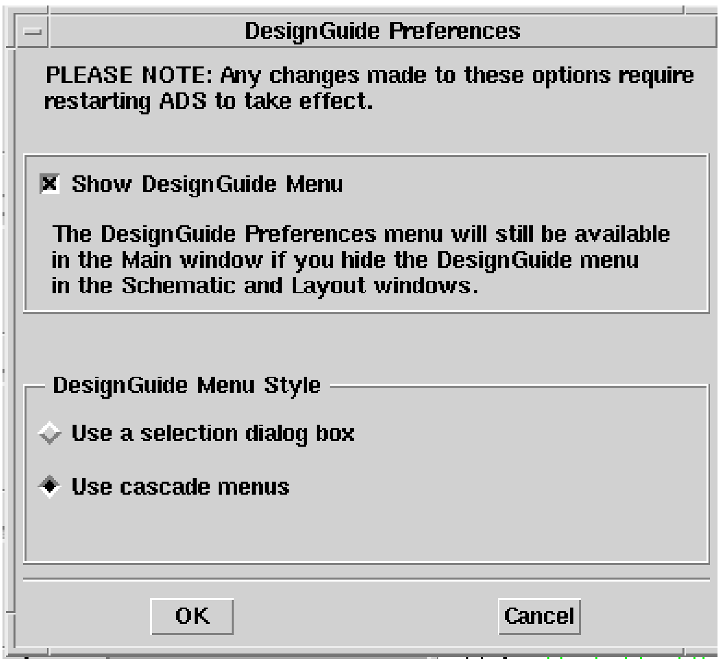
DesignGuide Developer Studio > **Start DesignGuide Studio** is only available on this menu if you have installed the DesignGuide Developer Studio. It launches the initial Developer Studio dialog box.

Add DesignGuide brings up a directory browser in which you can add a DesignGuide to your installation. This is primarily intended for use with DesignGuides that are custom-built through the Developer Studio.

List/Remove DesignGuide brings up a list of your installed DesignGuides. Select any that you would like to uninstall and choose the *Remove* button.

Preferences brings up a dialog box that allows you to:

- Disable the DesignGuide menu commands (all except Preferences) in the Main window by unchecking this box. In the Schematic and Layout windows, the complete DesignGuide menu and all of its commands will be removed if this box is unchecked.
- Select your preferred interface method (cascading menus vs. dialog boxes).



Close and restart the program for your preference changes to take effect.

Note On PC systems, Windows resource issues might limit the use of cascading menus. When multiple windows are open, your system could become destabilized. Thus the dialog box menu style might be best for these situations.

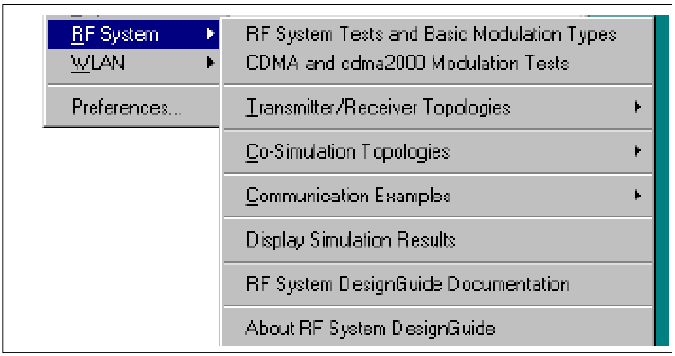
Accessing the Documentation

To access the documentation for the DesignGuide, select either of the following:

- **DesignGuide** > **RF System** > **RF System DesignGuide Documentation** (from ADS Schematic window)
- **Help** > **Topics and Index** > **DesignGuides** > **RF System** (from any ADS program window)

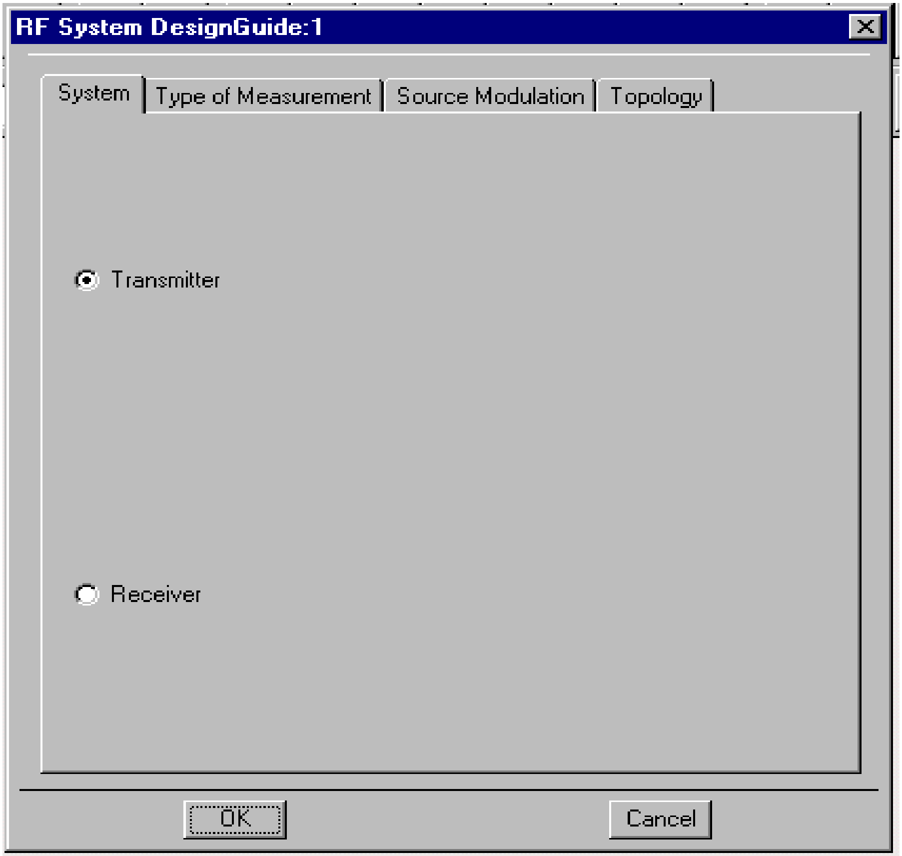
Basic Procedures

The features and content of the *RF System DesignGuide* are accessible from the *DesignGuide* menu found in the ADS Schematic window.



Transmitter/Receiver Design

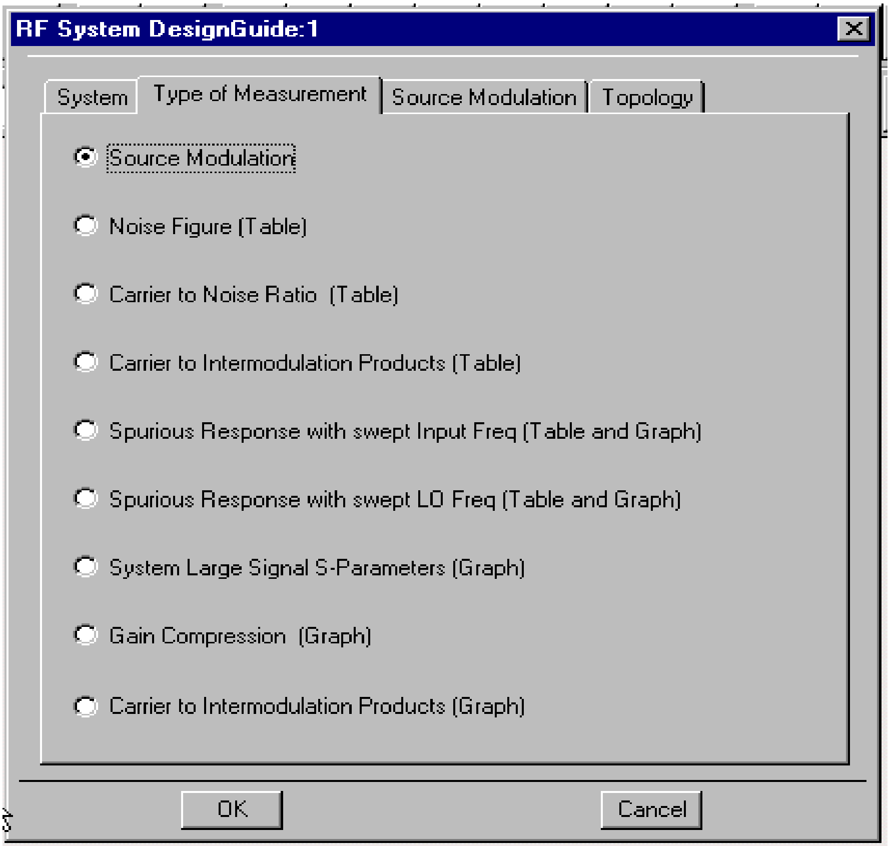
Using a dialog box labeled Transmitter/Receiver Design on the menu, you select your desired communication configuration, as shown here.The first step is to select one of the two available system configurations from the RF System tab of the dialogue box.



Having identified the type of communication system, you then select one of the nine simulations available from the Simulation tab, as shown in the illustration that follows. The simulations include

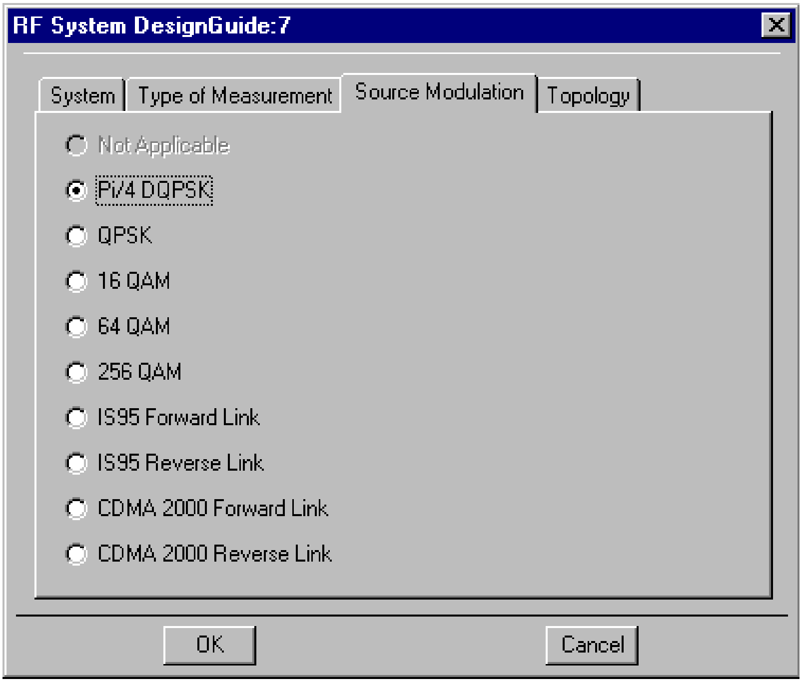
- Source Modulation (you choose the type of modulation on the next tab)
- Noise Figure (Tabular Format)

- Carrier to Noise Ratio (Tabular Format)
- Carrier to Intermodulation Distortion (Tabular Format)
- Spurious Response (Table and Graph)
- Spurious Response as a function of the LO frequency (Table and Graph)
- S Parameters (Graphical Format)
- Gain Compression (Graphical Format)
- Carrier to Intermodulation Distortion with swept RF input power (Graphical Format)

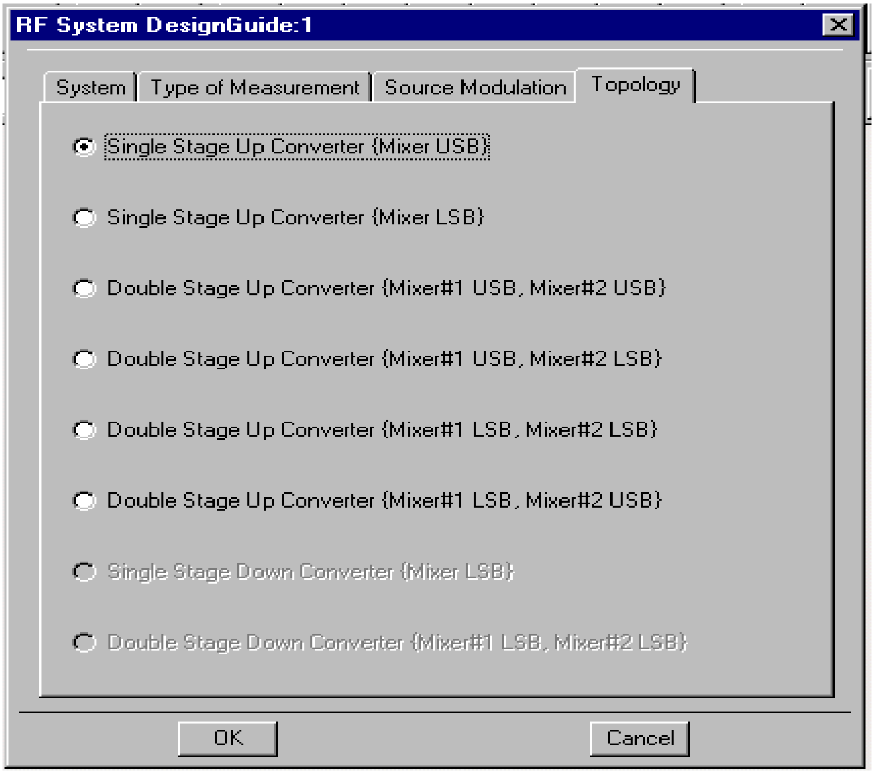


Having selected Source Modulation on the previous tab, you then have a choice of modulations. If you have developed your own source modulation, you can replace the source on the schematic. The *Not Applicable* box will be highlighted if you have not chosen source modulation on the previous tab.

The selection box for source modulations is shown here.



Shown here is the selection box for system topology. The grayed-out selections are not available with the previous tab selections. Click one of the available selections. For a detailed description of the topology selections, refer to the RF System DesignGuide user manual. If the communication system is a transmitter, you have a choice of 6 topologies. If the communication system is a receiver, then you have a choice of 2 topologies. The topologies are functions of whether the upper sideband or lower sideband is used for each mixer.



Transmitter/Receiver Topologies

The first step in most system designs is to select a topology. Typically a receiver uses either one or two stages of frequency conversion. Most receiver systems use the lower sideband of the mixer output at each frequency translation and therefore there are only two topologies. Whereas, for transmitters, the configurations are more varied, this DesignGuide has topologies for each of the four double stage up converters, as well as the two possible single stage up converters. There is a Transmitter example included to demonstrate how the pre-defined topology can be modified to your configuration

From the Schematic window, select *DesignGuide* > *RF System Design Guide* > *Transmitter / Receiver Topologies*.

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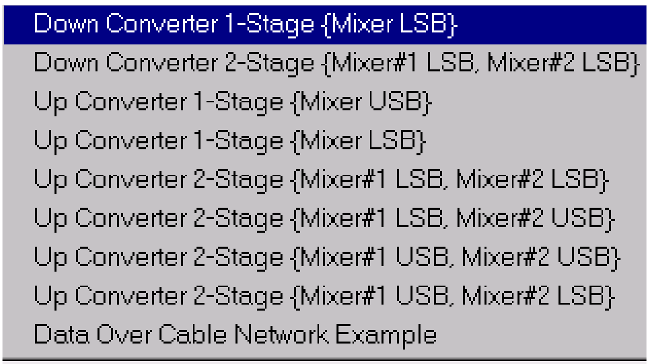

Co-Simulation Topologies

To use the system topology within a Ptolemy simulation, there are co-simulation topology modules to facilitate the process. The topology that has been designed and tested with the Type of Measurement schematics can then be entered into these modules for further testing in the Ptolemy environment.

From the Schematic window, select *DesignGuide* > *RF System Design Guide* > *Co-Simulation Topologies*.

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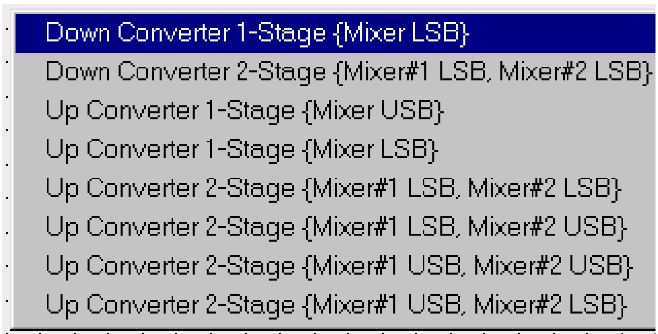

Communication Examples

Some example files show how the co-simulation modules are inserted into the Ptolemy schematics. From the Schematic window, select *DesignGuide* > *RF System DesignGuide* > *Comunication Examples*.

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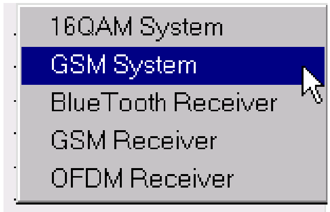


Display Simulation Results

The Display Simulation results menu selection is only present as a means of opening secondary data displays that correspond to a particular schematic. Most of the simulations with modulated signals have a second data display that shows the spectrum, power, and ACPR calculations. This secondary data display can only be opened via this menu selection. However, if you rename the schematic, the menu selection will not work anymore. For this reason, we recommend that you open the corresponding data display before renaming a schematic. After renaming schematics, you must open data displays using one of the standard ADS methods.

Chapter 2: RF System DesignGuide Reference

The RF System DesignGuide is integrated into Agilent EEsof's Advanced Design System environment, working as an interactive handbook for the creation of useful designs. The Guide contains many templates to be used in the ADS software environment. These templates can assist the system developer in designing a transmitter/receiver to meet performance specifications.

You can use the Transmitter/Receiver Topologies templates to define a system configuration, then proceed to characterize the performance with respect to quantities such as Noise Figure, Carrier-to-Noise Ratio, Carrier-to-Intermodulation Distortion, etc. The final performance measurement is then observed as the given modulation is applied and quantities such as ACPR and EVM are measured. If more sophisticated sources are required, the Co-Simulation Topologies can be used to easily interface with either a user-defined Ptolemy source or one of the available libraries. The DesignGuide provides a complete tool kit to interactively explore Transmitter/Receiver systems at the top level as part of an integrated design process.

In addition to the requirements of theAgilent EEsof ADS software, the RF System DesignGuide requires approximately 60 MBytes of additional storage space.

Note This manual assumes that you are familiar with all of the basic ADS program operations. For additional information, refer to the ADS User's Guide. For access to the complete set of ADS online documents, select *Help >Topics and Index* from an ADS program window.

Using the RF System DesignGuide

The key features of the RF System DesignGuide follow.

- Predefined system characterization templates and data displays:
- Noise Figure
- Carrier to Noise Ratio
- Carrier to Intermodulation Distortion
- Spurious Response
- Spurious Response as a function of the LO frequency
- S Parameters
- Gain Compression
- Carrier to Intermodulation Distortion with swept RF input power

Predefined templates and data displays for various modulation sources:

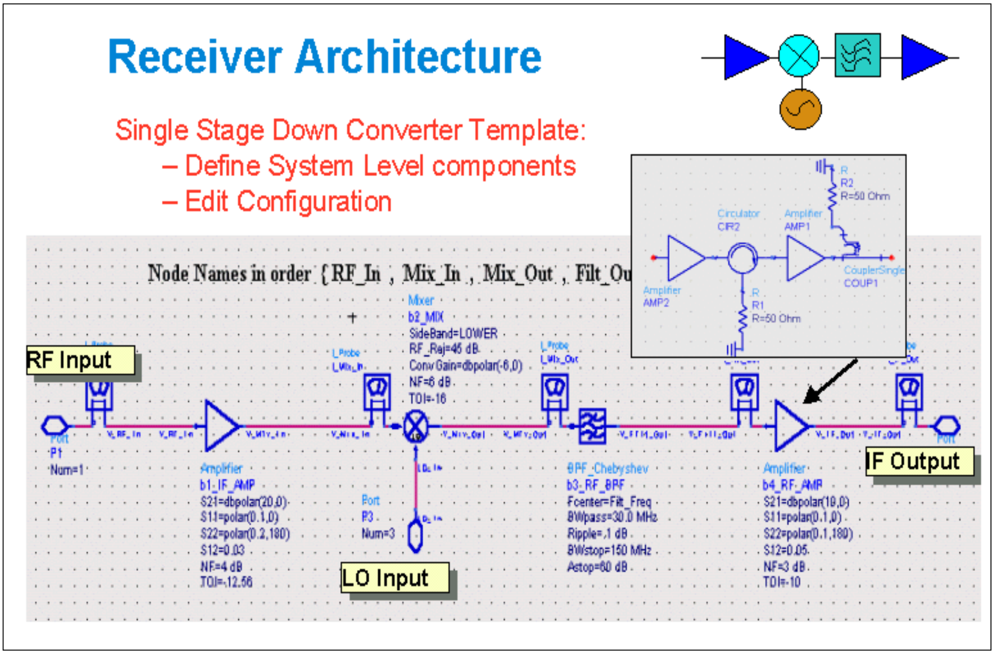
- pi/4 DQPSK
- QPSK
- 16 QAM, 64 QAM, 256 QAM
- IS95 and CDMA2000 (reverse and forward link)
- Co-Simulation Links to Ptolemy Libraries
- GSM, OFDM and BlueTooth Ptolemy examples
- Predefined Transmitter and Receiver Topologies:
  - Single Stage Down Converter (mixer LSB)
  - Double Stage Down Converter (mixer #1 LSB, mixer #2 LSB)
  - Single Stage Up Converter (mixer LSB)
  - Single Stage Up Converter (mixer USB)
  - Double Stage Up Converter (mixer #1 LSB, mixer #2 LSB)
  - Double Stage Up Converter (mixer #1 LSB, mixer #2 USB)
  - Double Stage Up Converter (mixer #1 USB, mixer #2 LSB)
  - Double Stage Up Converter (mixer #1 USB, mixer #2 USB)

- Co-Simulation Topologies:
    - Single Stage Down Converter (mixer LSB)
    - Double Stage Down Converter (mixer #1 LSB, mixer #2 LSB)
    - Single Stage Up Converter (mixer LSB)
    - Single Stage Up Converter (mixer USB)
    - Double Stage Up Converter (mixer #1 LSB, mixer #2 LSB)
    - Double Stage Up Converter (mixer #1 LSB, mixer #2 USB)
    - Double Stage Up Converter (mixer #1 USB, mixer #2 LSB)
    - Double Stage Up Converter (mixer #1 USB, mixer #2 USB)
- Communication Examples:
    - 16 QAM complete with Transmitter, Receiver and LOS Link
    - GSM complete with Transmitter, Receiver and LOS Link and co-simulator
    - BlueTooth Ptolemy example with Receiver and co-simulator
    - GSM Ptolemy example with Receiver and co-simulator
    - OFDM Ptolemy example with Receiver and co-simulator

Transmitter/Receiver Design

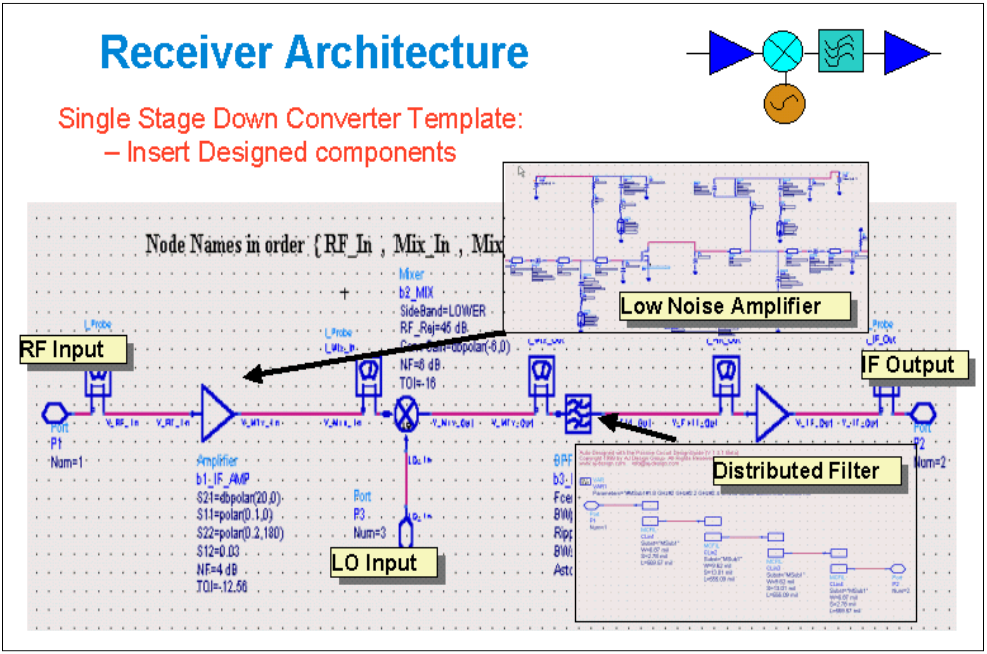
The general design flow for a transmitter or receiver consists of a three-step process before a prototype is developed. The first step is the creation of the frequency converter topology; this is followed by performing system measurements to ensure that the specifications can be met. The system tests usually involve Carrier to Noise Ratio, Carrier to Intermodulation, Noise Figure, Spurious Response, and others. This initiates an iterative process between the choice of system architecture and the system measurements. Once a candidate design has been optimized, measurements can be performed using the required signal modulation. These tests may involve Adjacent Channel Power Ratio, Error Vector Magnitude, Peak to Average ratio and others.

The system designer identifies a candidate topology from which he then proceeds to define the individual component specifications. Many designers focus initially on the mixers and filter requirements. The mixers can play a significant role in setting the system Dynamic range and reducing costs. Minimizing the number of components at the higher frequencies will typically reduce the system costs. Filters are placed at strategic points in the line-up to eliminate spurious signals and control the CNR. Attention is given to the filters to ensure that their individual order is not excessive, which would increase the loss and size. The gain stages can then be placed throughout the receiver to minimize the system Noise Figure (increase sensitivity) and maintain a good CNR throughout the chain. As one gets closer to a candidate topology, the individual component specifications can be filled out. This is an iterative process in which the system designer converges on a suitable transmitter/receiver design that meets all his criteria.



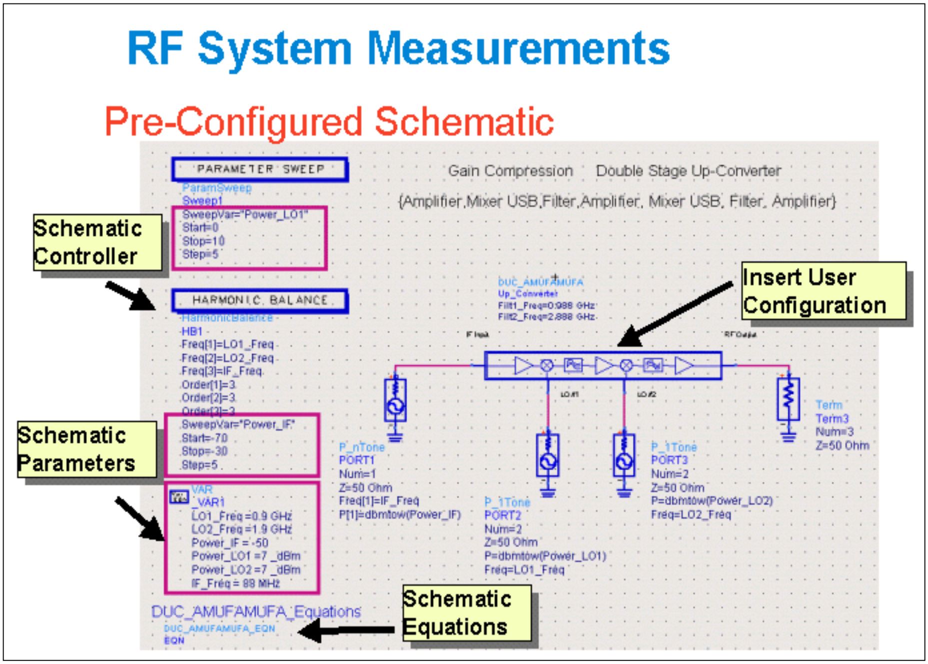
Having pre-configured topologies that can be readily modified to user configurations will aid the designer. Nodes and probe components are identified to facilitate the measurement process. The topologies all have assigned node and probe names that need to be maintained for the simulation to work properly. The nodes and probe names can be placed at various points along the chain, but all names must be included. (Be careful with the syntax). The more advanced user can alter the names as well as add additional names but the schematics as well as the data displays will need to be modified.

After a suitable review, the system designer then passes the individual component specifications on to the component designers. The component designers then proceed to develop a CAD representation of the individual components. These designs can be inserted in place of the system level building blocks to investigate their overall impact on the performance. This allows the assembly of a complete CAD transmitter/receiver design, which can be further tested.

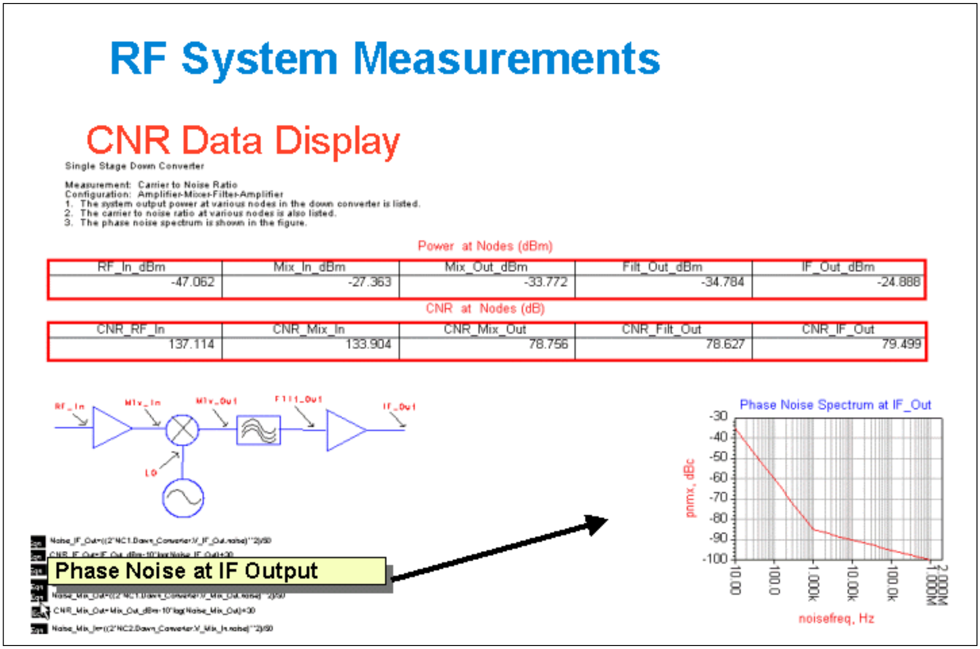


The designed transmitter/receiver performance then needs to be evaluated. Pre-configured schematics and data displays that you can readily modify for your system will speed up the design process. Replace the place-holder with your candidate transmitter or receiver design. The pre-configured schematics are constructed for a particular system measurement. Then edit the schematic parameters and parameter sweep ranges to reflect the desired system. Schematic equations are included to aid the extraction of key measurements such as power, noise, spurious levels, gain, ripple, etc.

Various schematic controllers are used wherever appropriate to reduce the simulation time. Some Schematic Controllers have sweep variables that allow you to observe the sensitivity to various parameters. The Schematic Parameters are central to the design. The Frequencies and Powers of the various sources are typical. These parameters need to be adjusted for your design. The user-designed transmitter/receiver topology needs to be inserted in place of the existing preassigned topology (Insert User Configuration). The Schematic Equations are used to extract measurements pertinent to the simulation.



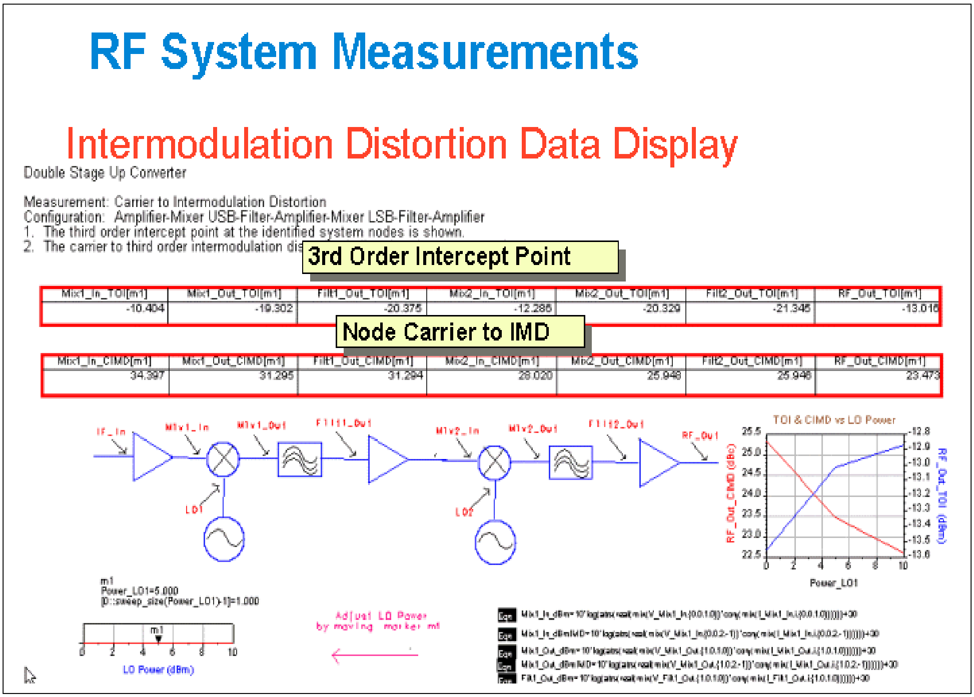
An example of an important measurement is the carrier to noise ratio. The noise limitations may arise from the noise floor of the individual components or it could be from the excessive phase noise of the local oscillators. You also have the flexibility of entering an input noise source.



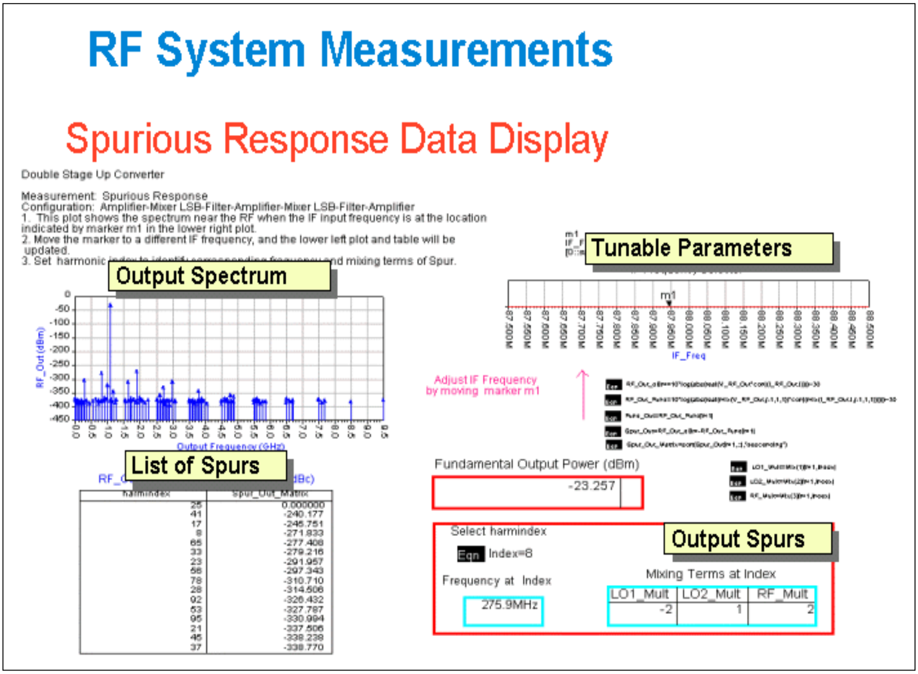
There are two factors that limit the transceiver system dynamic range:

- Carrier-to-Noise Floor Ratio
- Carrier-to- Intermodulation Level

The C/IMD performance is limited by the third order intercept point (TOI) of the individual components. The TOI at various nodes in the chain can be estimated as a function of the power levels of the fundamental and intermodulation signals. Or the actual C/IMD levels can be plotted as a function of the input power level. This is a useful means for determining the dynamic range limiting components.

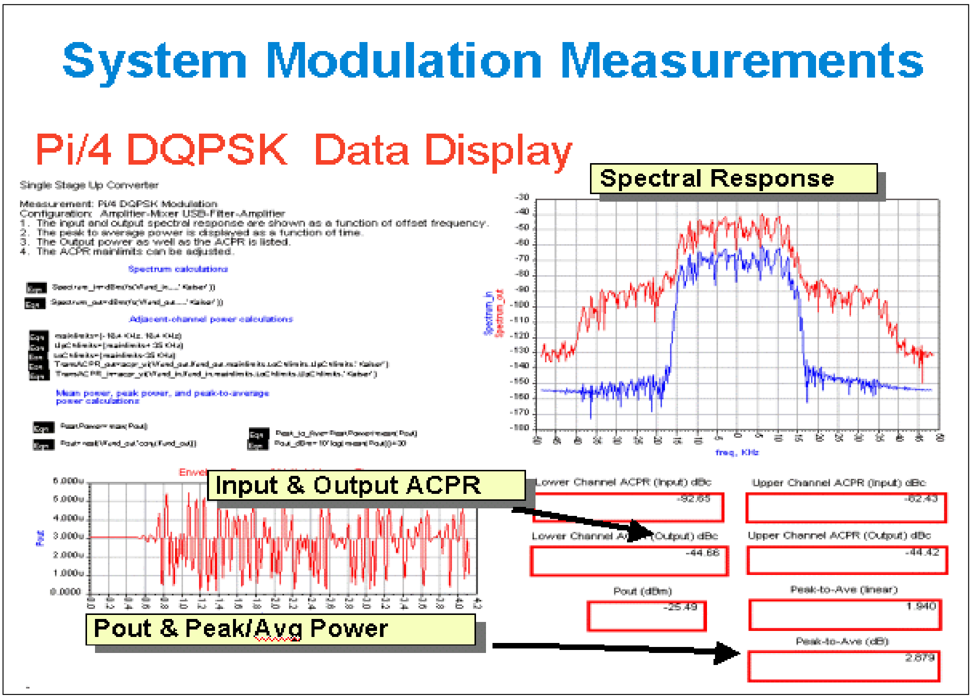


The introduction of nonlinear components into the transmitter/receiver generates unwanted spurious signals that need to be controlled. Spurious signals that fall in-band will degrade the BER performance for the given channel. Spurs that fall out-of-band may contaminate other channels or they may be aliased into the given channel. The data display below is useful for identifying the levels of the various spurs as well as assisting in tracking the component from which they originate. The data display can have variable parameters such as the RF input frequency, power levels, LO frequencies, etc. This can aid in the optimization of the system chain.

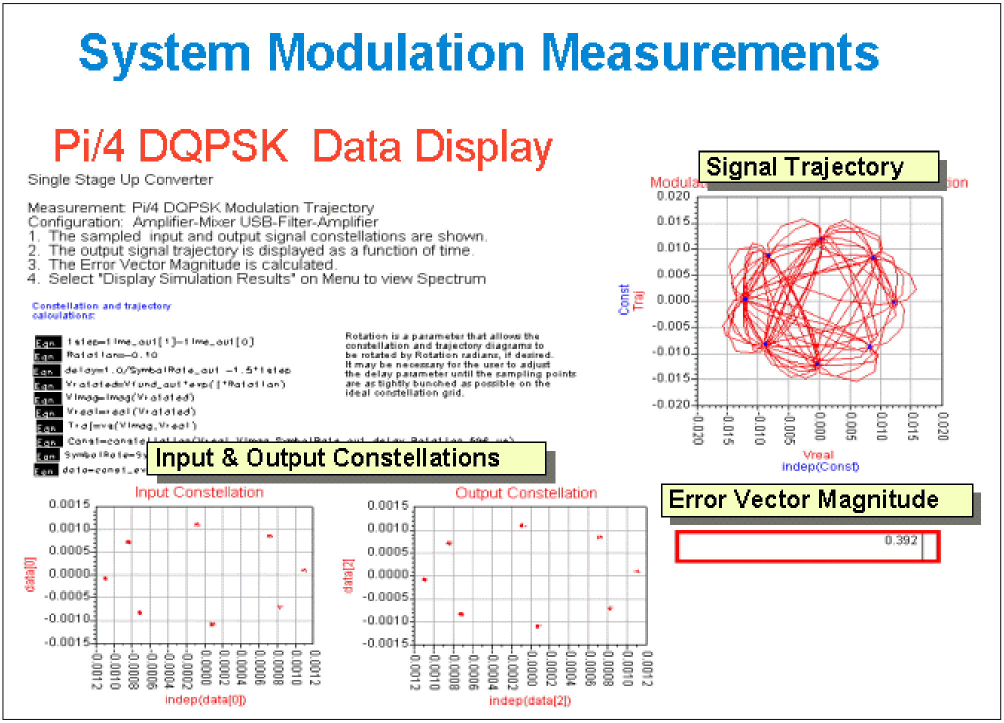


Once a candidate design has been developed and has been tested against the standard system level specifications, you can introduce a modulated source. The modulated signal can either be created using the Analog/RF components or in Ptolemy, with a co-simulation used to translate between Ptolemy and the Analog/RF transmitter or receiver.

Applying the modulated source to the transmitter/receiver will allow for more fundamental measurements such as BER,EVM, Average Power Output, Peak to Average Ratio, ACPR, etc. The testing based on a two tone (3dB Peak/Average Ratio) will not give the appropriate measurement of the ACPR when, for example, a CDMA signal is applied. The BER measurement can take a significant amount of time to simulate. Therefore, a measurement of the Error Vector Magnitude can serve as an intermediate evaluation of the performance of the system. The ultimate goal would be to run a Ptolemy simulation for a long enough period of time to evaluate the BER.



The Error Vector Magnitude measurement would provide you with an initial indication of the performance achievable by the transmitter/receiver. The constellation diagrams help in giving insight into the contribution of the distortion. As an example, if compression and phase rotation were observed on the constellation, this could be traced back to the overdriving of a particular stage in the chain.

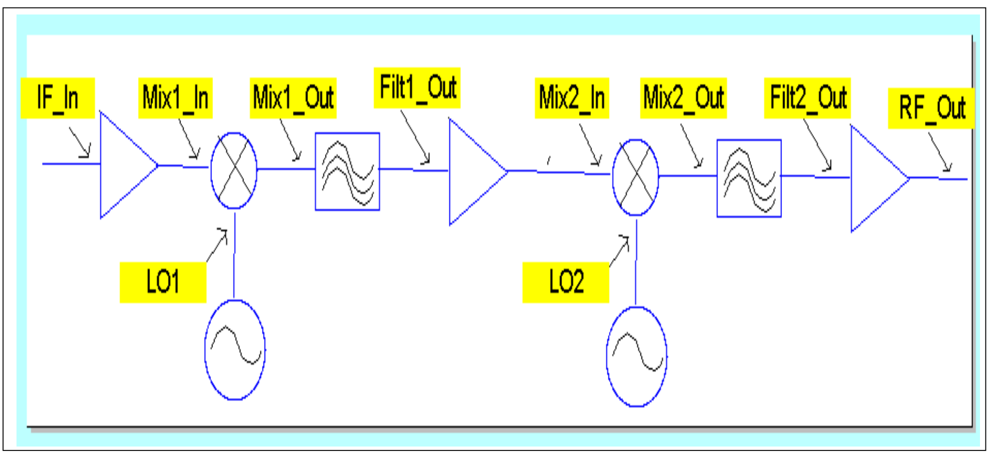


Transmitter/Receiver Topologies

There are 8 predefined topologies that have corresponding measurement Schematics and Data Displays. They are listed below:

- Single Stage Down Converter (mixer LSB)
- Double Stage Down Converter (mixer #1 LSB, mixer #2 LSB)
- Single Stage Up Converter (mixer LSB)
- Single Stage Up Converter (mixer USB)
- Double Stage Up Converter (mixer #1 LSB, mixer #2 LSB)
- Double Stage Up Converter (mixer #1 LSB, mixer #2 USB)
- Double Stage Up Converter (mixer #1 USB, mixer #2 LSB)
- Double Stage Up Converter (mixer #1 USB, mixer #2 USB)

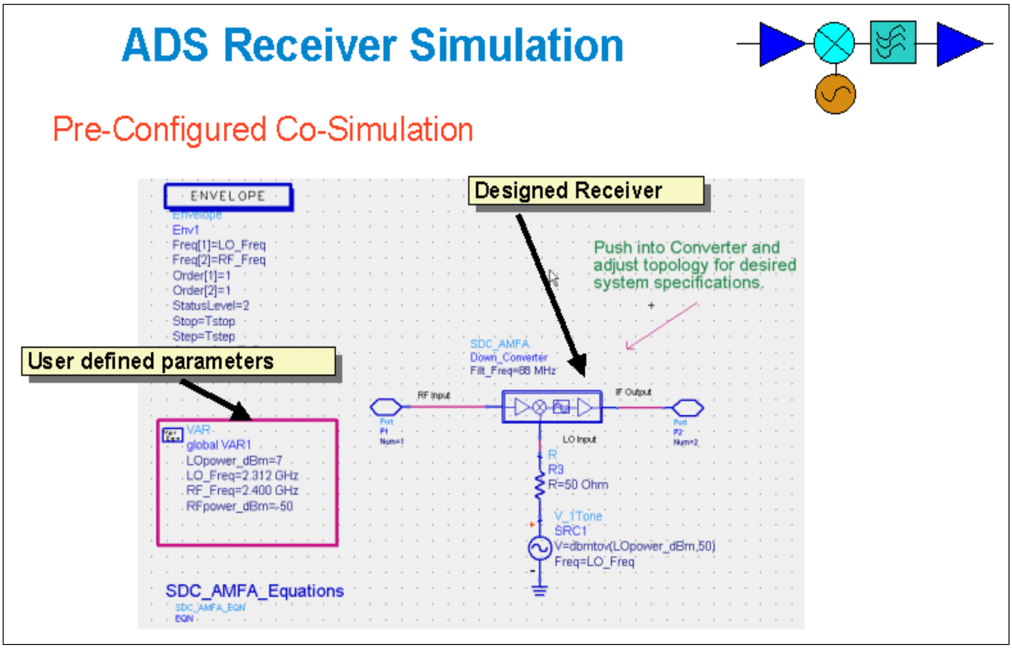
You would select one of the given topologies, then proceed to modify it for your system requirements. The components in the schematic are just placeholders and you can replace, add, or expand on the given configurations. The important elements are the node and probe names and the frequency conversion of the mixers (ie whether it is LSB or USB). The identification of the LSB (lower sideband) or USB (upper sideband) is important for insuring that the simulation and data displays will give the correct results.



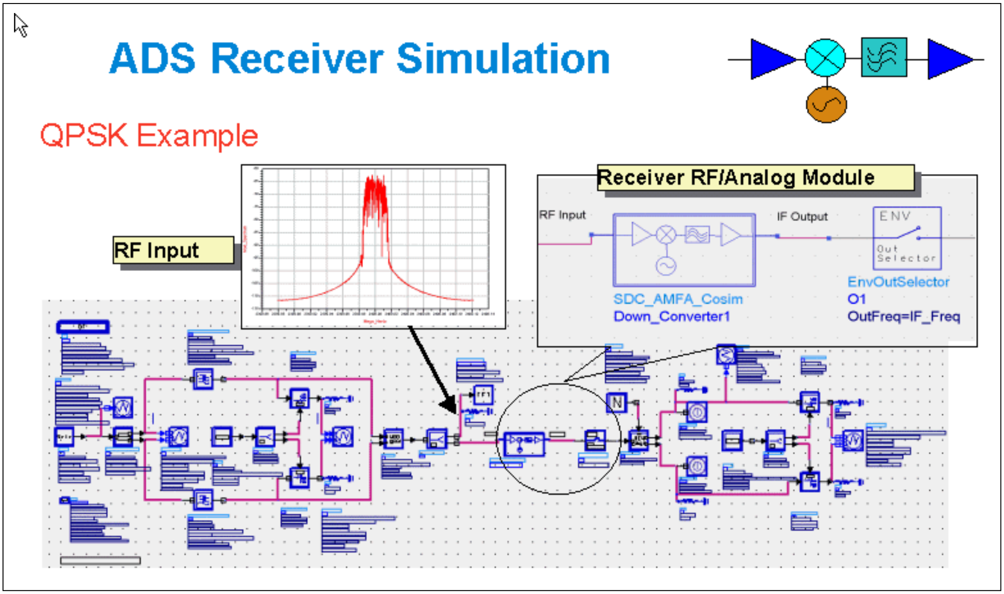
Co-Simulation Topologies

Ultimately, you would like to integrate the transmitter or receiver with the DSP portion of the communication system. Ptolemy can be used to generate a wide variety of baseband modulation signals. This allows you to perform more extensive tests on the system. The designed transmitter/receiver can then be integrated into Ptolemy using the co-simulator, allowing efficient translation between the DSP world and the Analog/RF world.

This figure shows a template for integrating your receiver design into the Ptolemy simulation. Again, the user-defined parameters would be inserted into the schematic. Notice that the envelope simulator has been used.

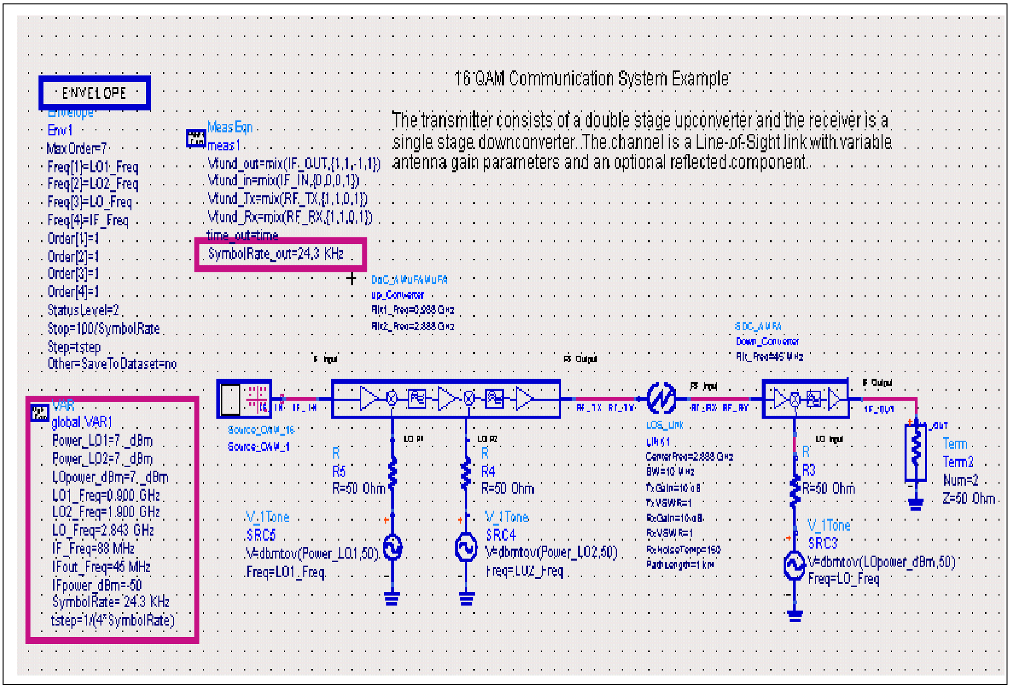


An example of the insertion of the receiver schematic template from the one created appears in the preceding figure. Also we have added the co-simulation block for translation from Analog/RF to Ptolemy.

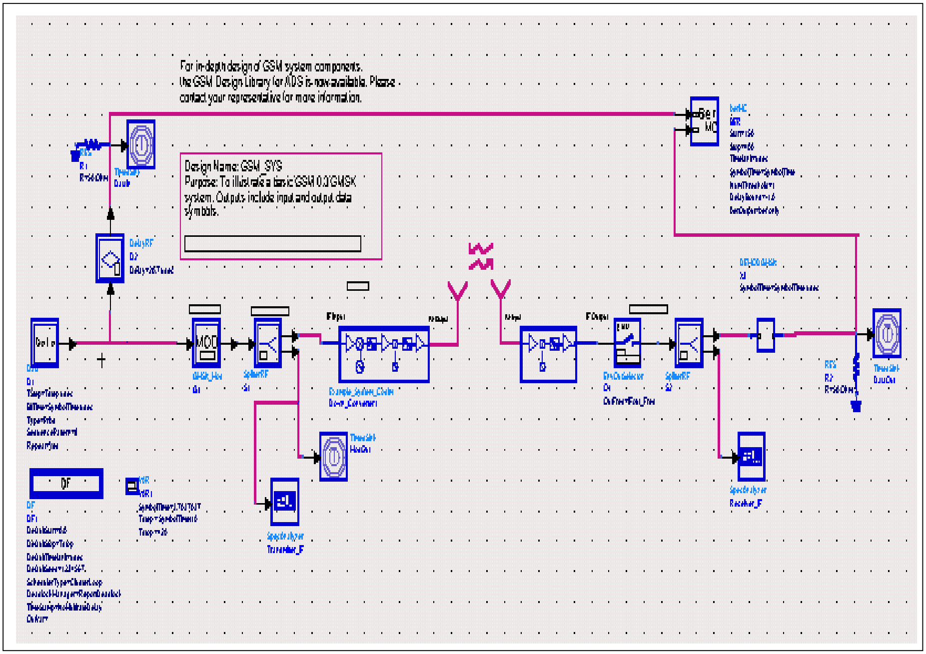


Communication Examples

The transmitter/receiver design dialog box assists you in creating up and down converters. The example below shows how the designed Transmitter and Receiver can be used in a communication system. This example uses a Line-of-Sight Link where the antenna gains, vswrs, distance, etcetera can be specified. The example is simulated in the Analog/RF environment using a 16 QAM source.



Another example of a GSM communication system is shown here. The transmitter and receiver were created using the Transmitter/Receiver Design dialog box. These topologies were then inserted into a schematic set up for simulation, along with the identified channel and are identified via the up and down converter symbol. The schematic set up for simulation was then placed in the Ptolemy environment along with the GSM modulator and demodulator for a complete DSP to Analog/RF to DSP simulation.



Reference

[1] W.P.Robins, *Phase Noise in Signal Sources*, IEE Telecommunications Series 9, 1982,Peter Peregrinus Ltd.

[2] *Digital Modulation in Communications Systems*, Agilent Application Note 1298, literature number 5965-7160E.

[3] *Testing and Troubleshooting Digital RF Communications Transmitter Design*, HP Agilent Application note number 1313.

[4] *Testing and Troubleshooting Digital RF Communications Receiver Designs*, HP Agilent Application note number 1314, literature number 5968-3579E.

[5] *Using Vector Modulation Analysis in the Integration, Troubleshooting and Design of Digital RF Communications Systems*, Agilent Product Note 89400-8, literature number 5091-8687E.

[6] *Understanding CDMA Measurements for Base Stations and Their Components*, Agilent Application Note 1312, literature number 5968-0953E.

[7] Voelker, Kenneth M. "*Apply Error Vector Measurements in Communication Design*", Microwaves & RF, December 1995, pp. 143-152.

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