Creating Measurement-Based RFIC Models

Product Note E4600-8

Overview

This product note describes a technique for modeling RF Integrated Circuits (RFICs) in the Series IV OmniSys Design Suite. Using the steps demonstrated in this note, a variety of RFIC devices can easily be incorporated into OmniSys's system-level simulation by using measured S-parameters. This modeling technique uses the multi-dimensional linear interpolation of S-parameter measurement. Creating models of complex RFICs based on their S-parameter measurements offers several benefits: the designer doesn't have to acquire detail knowledge of the device's internal topology; the difficulty of applying physical phenomena to internal components such as transistors can be avoided; models based on measured data offer a high degree of accuracy as they reflect actual observed behavior including frequency dependency, rather than mathematical approximations. In addition, with the use of multi-dimensional interpolation, the process of curve-fitting that is often very tedious and inaccurate can be eliminated. These benefits allow communication systems designers to expand the capability of OmniSys and design better products.

The process of creating an OmniSys RFIC model starts with measuring S-parameters. The user must first determine a set of parameters characterizing the device. These characterization parameters include input port stimuli specifiers, bias conditions, and control lines. For each parameter, the user must decide on the specific values at which measurement will be taken, while remembering that the data set should be enough to accurately describe the behavior. Measuring S-parameters at a few values with large intervals won't capture the behavior of the device, while too much data will result in redundancy and slow simulation time.

The measured S-parameters are read into OmniSys by using data files with the Measurement Data Interchange Format (MDIF). An MDIF file can be used to store S-parameters measured over 11 different parameters, one of which is designated for input sweep frequency. After the MDIF files are created, a schematic symbol and subnetworks are built in OmniSys. The subnetworks consist of elements that indicate the names of the MDIF files used. Once the schematics are done, the model can be added to an OmniSys library and used for simulation. When this model is simulated, multi-dimensional linear interpolation of the S-parameter lookup tables emulates the device behavior.

The process is summarized as follows:
1. Determine characterization parameters and values for the device at which S-parameters are measured
2. Measure S-parameters for every combination of parameters and their values
3. Create MDIF files by listing measured S-parameters in the correct format
4. Build Schematics and add the symbol to an OmniSys library
5. Customize dialog boxes for the schematics

HEWLETT PACKARD

Introduction

The RFIC Library in OmniSys currently has 25 RFICs from three different vendors, National Semiconductors, NEC, and Triquint. These models are developed based on S-parameter measurements. In this product note National Semiconductor's LMX2216B Low Noise Amplifier and Mixer is used to demonstrate the methodology. The model is named *ic60_nat_LMX2216B* in OmniSys and is available in the *National Semiconductor RFIC* library. The function of this RFIC is to downconvert a signal through its LNA and mixer.

The schematic symbol of this model is shown in Fig. 1. The behavior of the model is determined by five user-specified model parameters in OmniSys, which are:

> *TYPE* = mixing type.
> *PLO* = power of mixer's LO
> *FLO* = frequency of mixer's LO
> *VCCM* = bias voltage of the mixer
> *VCCA* = bias voltage of the LNA

The model also has several ports for input and output signals. Although the real device has 16 pins, only four of them are needed for the OmniSys model — LNAin, LNAout, RFin, and IFout.
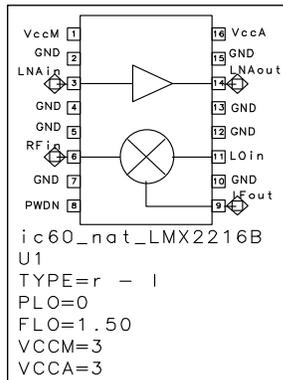

Figure 1. LMX2216B Schematic Symbol

More information regarding the operation of this model is included on page 3-14 of the Series IV *Model Libraries* manual.

Determining Parameters and Values

Before measuring S-parameters, the user must identify characterization parameters that affect the performance of the device and determine values for each parameter that produce a sufficient set of S-parameter data. Since S-parameters must be measured for every combination of parameters and their values, the resulting S-parameter set can be quite substantial. For example, if a device is modeled with input power, bias voltage, input frequency, and temperature as parameters, and 5 different values are chosen for each parameter, then 5^4, (or 625), S-parameter sets are required. Simply doubling the number of measurement values for each parameter escalates the total number of measurements to 10^4.

For the LMX2216B mixer, S-parameters were measured for 3 values of bias voltage, 2 values of mixing type, 3 values of LO power, 3 values of LO frequency, and 24 values of input RF frequency, which produced 1296 sets of S-parameters (real and imaginary values of S_{11}, S_{12}, S_{21}, S_{22}). The user must measure enough data to characterize the device completely without having redundant and unmanageable data.

The LNA and the mixer of the LMX2216B have independent input and output ports. Therefore, these components are characterized separately, and two different sets of parameters are determined for S-parameter measurement. For the LNA part of the model, the parameters are bias voltage (VCCA), input power (LNAin Power), and input frequency (LNAin Freq.), whereas the mixer has mixing type, LO power, LO frequency, bias voltage, and input RF frequency. These parameters and their values at which S-parameters are measured are summarized in Tables 1 and 2.

Table 1. LNA S-parameter Variables

Amplifier			
Parameters	VCCA	LNAin Power	LNAin Frequency
Values	2.7, 3.0, 3.3V	-20, -16, -14, -12, -8 dB	11 frequency values

Table 2. Mixer S-parameter Variables

Mixer					
Parameters	VCCM	TYPE	RFin Frequency	LO Power	LO Frequency
Values	2.7, 3.0, 3.3V	r-l (RF - LO), l-r (LO - RF)	24 frequency values	3.0, 0.0, -5.0 dB	0.5, 1.5, 2.0 GHz

Measuring S-parameter Data

Once the characterization parameters and their values are determined, the user can measure S-parameters for each combination of the values. In general, S-parameters can be measured with network analyzers, such as the HP 8753D with the HP 85046 S-parameter test set or the HP 8510 Microwave Network Analyzer with the HP 8514B S-parameter test set.

Note that, in measuring S-parameters for a mixer, a problem of ambiguity arises in defining S-parameters due to frequency conversion between the input and the output. Specifically, defining a phase shift between the RF port and the IF port (angle of S_{21}) is not possible given that the two are at different frequencies. Therefore, for the LMX2216B mixer certain S-parameters are arbitrarily defined: all S_{12} parameters, real and imaginary, are assumed to be zero, and the imaginary values of S_{21} are assumed to be zero as well (angle of S_{21} set to zero).

Creating MDIF Files

The measured S-parameters can now be organized according to MDIF so that they can be read into OmniSys simulation. Using a text editor the user has to list the measured data in the correct format explained in this section and save the file with appropriate extension. In order to facilitate formatting, the user can use UNIX, Awk, or Pearl scripts, or C or some other programming language translators as well.

MDIF files are saved with extensions depending on the type of S-parameters used and the number of ports. Note that in Table 1 the LNA has its incident input power as a parameter. Due to this power dependence, the LNA's MDIF file contains large signal power-dependent data and has the extension .p2d. For the mixer, however, only small signal S-parameters are needed, thus the MDIF file is named with the extension .s2d. Refer to Table 3 for different types of MDIF files and their applications.

Table 3. MDIF File Types

MDIF File	Type of Data	Applications
.s2p	2-port data without incident power dependence or frequency translation	Passive devices
.s2d	2-port data with frequency translation	Mixers, multipliers, amplifiers (no harmonics)
.p2d	2-port data with power dependence or frequency translation	Same as .s2d but with power-dependent parameters

In addition to S-parameters, the user can include a variety of other pertinent data in the MDIF file such as noise data or intermodulation data. For the LMX2216B, only the S-parameter measurements are considered. More information on MDIF files is available in Chapter 9 of the Series IV *System Network Items* manual.

In general, an MDIF file has the following guidelines and format:
- Comments in the file are initiated with an exclamation mark (!).
- A space or any number of spaces delimits each data column entry.
- VAR statements are used to indicate different variable values used in measuring frequency versus S-parameter data.
- BEGIN signals the beginning of a data block and specifies the type of data
  - BEGIN ACDATA for alternating current data
  - BEGIN NDATA for optional noise data
- The # line, called an option line, specifies various options. The general format is:
  #AC(HZ/KHZ/MHZ/GHZ   S/Z/Y/H/G   MA/DB/RI   R   n   FC $f1$ $f2$) for ACDATA
  #AC(HZ/KHZ/MHZ/GHZ   MA/DB/RI   R   n) for NDATA.
  - HZ/KHZ/MHZ/GHZ for choosing Hertz, kilohertz, megahertz, or gigahertz.
  - S/Z/Y/H/G for choosing scattering, impedance, admittance, hybrid-h, or hybrid-g parameters
  - MA/DB/RI for choosing magnitude-angle, dB, or real-imaginary data
  - R is a reserved word indicating reference resistance
  - n is reference resistance value in ohms and is normally set to 50
  - FC is a reserved word indicating frequency conversion
  - $f1$ $f2$ define input and output frequency relationship
  - Based on the values of FC, $f1$, and $f2$, the output frequency is calculated as
    $Fout = f1 * Fin + f2$
- % line is for setting the order in which the parameter values are entered in the data block.
- The ACDATA data block is required; the NDATA data block is optional.
- Each data block ends with END.

Mixer .s2d File

Shown below is a small portion of the .s2d file for the mixer section of the LMX2216B. The data blocks in this file containing frequency vs. S-parameter data are preceded with four VAR lines, each representing the parameter value used in measuring the S-parameters. When this file is called by OmniSys during simulation, a set of parameter values are passed to the file. If these values do not match the VAR values listed in the file, the simulator selects the data blocks with the closest VAR values and performs a multi-dimensional interpolation to determine the correct S-parameters. Having multiple VAR line is the reason multi-dimensional interpolation is performed to calculate S-parameters between the discrete measured data points.

```
REM 11106 6.000
! SCCS @(#) /wlv/src/syslib_600/ic/nat ic60_nat_LMX2216B-M.s2d_src 1.13 date: 03/20/95
!
```

These VAR lines indicate different variables and the values used to measure S-parameters in the subsequent data block.

These S-parameter values are arbitrarily set to zeros due to frequency-conversion related ambiguity.

```
VAR TYPE = -1
VAR _FLO = -0.5
VAR PLO = 3.0
VAR VCC = 2.7

BEGIN ACDATA
```

Option Line

```
#  AC( GHZ   S   RI   R 50.0   FC   1   -0.5 )
%  F          n11x          n11y         n21x      n21y  n12x  n12y      n22x          n22y
   0.510    0.01208       -0.0699        0.5855      0     0     0      0.5933       0.02365
   0.520    0.01064       -0.06962       0.5721      0     0     0      0.5965       0.001702
   0.530    0.009096      -0.06941       0.5598      0     0     0      0.6          -0.0206
   0.540    0.007466      -0.06924       0.547       0     0     0      0.6015       -0.04088
   0.550    0.005777      -0.06911       0.5346      0     0     0      0.5997       -0.05817
   0.560    0.00405       -0.069         1.912       0     0     0      0.5958       -0.07454
   0.570    0.002308      -0.0689        0.5111      0     0     0      0.5907       -0.09033
   0.580    0.0005738      0.0688        0.514       0     0     0      0.5852       -0.1044
   0.590    -0.001131     -0.06868       0.4819      0     0     0      0.5827       -0.1182
   0.600    -0.002783     -0.06853       0.4508      0     0     0      0.5799       -0.1341
   0.610    -0.00436      -0.06833       0.431       0     0     0      0.5603       -0.1537
   0.620    -0.005841     -0.06808       0.4406      0     0     0      0.5393       -0.166
   0.630    -0.007201     -0.06775       0.4597      0     0     0      0.545        -0.1612
   0.640    -0.008423     -0.06734       0.487       0     0     0      0.5451       -0.1804
   0.650    -0.009533     -0.06686       0.496       0     0     0      0.5189       -0.2202
   0.660    -0.01059      -0.06632       0.4831      0     0     0      0.4946       -0.188
   0.670    -0.01164      -0.06574       0.4592      0     0     0      0.4924       -0.1273
   0.680    -0.01276      -0.06515       0.4576      0     0     0      0.5159       -0.1407
   0.690    -0.01399      -0.06455       0.4748      0     0     0      0.5333       -0.178
   0.700    -0.01539      -0.06398       0.5012      0     0     0      0.5291       -0.1941
   0.710    -0.017        -0.06343       0.5339      0     0     0      0.5227       -0.2071
   0.720    -0.01883      -0.06291       0.5464      0     0     0      0.5185       -0.2218
   0.730    -0.02084      -0.06241       0.5451      0     0     0      0.512        -0.2335
   0.740    -0.02301      -0.0619        0.5297      0     0     0      0.5054       -0.2439
END

VAR TYPE = -1
VAR _FLO = -0.5
VAR PLO = 3.0
VAR VCC = 3.0

BEGIN ACDATA
```

Note that the value for VCC is now changed to 3.0 for the next data block.

<Data block continues>
⋮
⋮
⋮

Another important part of an MDIF file is the option line. In the file shown above, the option line indicates that:

GHZ = frequency is given in units of gigahertz,
S = S-parameter data is included in the ensuing data block
RI = S-parameter data is expressed in term of real and imaginary values
R 50.0 = reference impedance is 50 ohms
FC 1 -0.5 = frequency conversion factors are 1 and -0.5

An MDIF file is formatted such that the values in the option line are used to calculate the output frequency according to the equation, Fout = $f1$*Fin + $f2$ where:

$f1$ = negative value of TYPE
Fin = RF input frequencies specified in the data block
$f2$ = value of _FLO is mapped to $f2$

Depending on the mixing type, the variable TYPE can be either -1 or 1. For example, if the input RF frequency to the mixer is higher than the LO frequency, the mixing type is r-l and TYPE is indicated with -1. Conversely, for LO higher than RF, the mixing type is l-r and the TYPE value is 1. The _FLO variable is a reserved word that overrides $f2$ in the equation. The value is derived from an equation, _FLO = TYPE * FLO, where FLO is the LO frequency value. The _FLO variable is defined with the equation because the output frequency of the mixer is dependent both on the LO frequency and the mixing type. Now, the new variable _FLO conveys information about both the LO frequency and the mixing type.

With _FLO and TYPE clearly defined, the output frequency can be calculated as illustrated in the following examples.

- For conditions $f_{RF} > f_{LO}$ and FLO = 0.5 GHz, the correct values are:
  TYPE = -1, _FLO = -0.5, f1 = 1, f2 = -0.5
  Option Line = # AC(GHZ S RI R 50.0 FC 1 -0.5).

  The output frequency is then calculated as,
  Fout = f1*Fin + f2 = 1*Fin + -0.5.
  Note that Fout is indeed Fin - 0.5 or f_{RF}-f_{LO} as it should be for RF > LO.

- For conditions: $f_{RF} < f_{LO}$ and FLO = 0.5 GHz, the correct values are:
  TYPE= 1, _FLO = 0.5, f1 = -1, f2 = 0.5
  Option Line = # AC(GHZ S RI R 50.0 FC -1 0.5)

  The output frequency is Fout = -1*FC + 0.5.
  Fout is calculated as 0.5 - Fin or f_{LO} -f_{RF}, since LO > RF.

In order to create a functional MDIF file for a frequency converting device, such as a mixer or a multiplier, it is important that the user enter all the correct values of VAR and $f1$ and $f2$ values as well as the associated S-parameters. Refer to Table 4 for a summary of these variables and their values.

Table 4. Summary of Frequency Translation Relationship

	Condition 1: RF>LO	Condition 2: RF<LO
Mixing Type	r-l	l-r
TYPE	-1	1
f1	1	-1
_FLO (and *f2*)	-1 * FLO	1 * FLO
Fout	f_{RF} - FLO	FLO - f_{RF}

Amplifier .p2d File

The following is an excerpt from the .p2d file for the LNA of the LMX2216B. A .p2d file is different from an .s2d file in that it could contain both small-signal and large-signal data. With the LMX2216B LNA, only the large-signal S-parameters are measured to capture the the gain compression characteristics. Therefore, only the power-dependent large-signal data are listed in the file below without small-signal data. If small-signal data blocks are used in a .p2d file they must precede large-signal data.

```
!sample file

VAR  VCCA = 3.3
BEGIN ACDATA
# AC( GHZ  S  RI  R  50  FC  1  0 )

%  F
  0.500
%  P1    P2     n11x    n11y    n21x   n21y   n12x    n12y     n22x    n22y
  -20   -30    0.0287  0.0422  -4.7   3.22   0.0878  -0.028   0.112   0.145
  -16   -30    0.19    -0.18   -4.34  3.54   0.0873  -0.0282  0.125   0.14
  -14   -30    0.219   -0.195  -4.1   3.51   0.088   -0.0278  0.113   0.142
  -12   -30    0.285   -0.24   -3.6   3.32   0.0874  -0.0279  0.12    0.14
   -8   -30    0.397   -0.295  -2.68  2.7    0.086   -0.0268  0.129   0.133

%  F
  0.700
%  P1    P2     n11x    n11y    n21x   n21y   n12x    n12y     n22x    n22y
  -20   -30    0.0372  0.0191  -3.85  3.79   0.078   -0.035   0.185   0.156
  -16   -30    0.112   -0.222  -3.5   4.11   0.0772  -0.035   0.192   0.153
  -14   -30    0.142   -0.245  -3.43  4.17   0.0784  -0.0339  0.183   0.153
  -12   -30    0.188   -0.293  -2.73  3.7    0.077   -0.0341  0.185   0.153
   -8   -30    0.279   -0.361  -2.02  2.98   0.0763  -0.0321  0.191   0.148
```

Note that for this particular model, the incident power at the output (P2) is constant at -30dB, and does not enter into interpolation. Also, since the LNA does not involve any frequency conversion, the S-parameters are measured only for VCC, input power, and frequency. The lack of frequency conversion means that *f2* of the option line, which represents LO frequency, is fixed at 0 due to the absence of an LO input — # AC(GHZ S RI R 50 FC 1 0).

The large-signal data block heading line differs slightly compared with the small-signal heading line. It has two additional columns to accomodate power values at the input and output ports.

```
%  F
    input frequency
%  P1    P2     n11x    n11y    n21x     n21y     n12x     n12y     n22x     n22y
```

incident output port power

incident input port power

As explained in this section, the user should remember the following key steps when transferring the measured data to MDIF files:

- Choose appropriate file type according to the type of data measured (.s2d, .s2p, or .p2d)
- Follow the specific format for the file type chosen
- Specify VAR values to indicate the conditions when the S-parameters are measured
- For frequency translating elements, use the correct values of TYPE, _FLO, *f1*, and *f2* to control the output frequency.
- For power dependent large-signal data, enter the input and output power
- Save the files with proper extension in the */data* directory of the project.

Selecting Keywords and Values

Once the MDIF files are created and saved in the */data* directory, the schematics for the model can be built. However, it is important at this point to review the process in which the parameters are passed from the schematics to the MDIF files.

The model requires the user to enter values for its model parameters shown with Figure 1. These values are then passed to the model's subnetwork and sub-subnetwork, and also to the MDIF files. The variables that appear in the VAR lines of MDIF files are called "KeyWords" in OmniSys. In the OmniSys model, the user can associate the user-entered model parameters with proper VAR values by using an MDIFLIST data item as shown in Figure 2--creating this data item is explained in the next sections. The names for KeyWords must match the names that appear with the VAR lines in the MDIF files. The "Values" for KeyWords can be either a value entered by the user or defined by an equation in schematics. The KeyWord values passed to the MDIF files are then used to select the appropriate data blocks for interpolation and calculate S-parameters and output frequency.

```
 ┌─────┐
 │DATA │
 └─────┘
MDIFLIST
MIX
KeyWord="TYPE" "PLO" "_FLO" "VCC"
Value=TYPE PLO FLO_2 VCCM
```

Figure 2. MDIFLIST Element

The next section illustrates the process of defining an equation and assigning the variables while building the model schematics.

Building Schematics

The MDIF files and KeyWords defined in the previous sections are all tied together by building the model schematics. The model for the LMX2216B consists of a main schematic symbol and two subnetworks. The schematic symbol is re-shown below along with the two subnetworks in Figures 3 and 4.
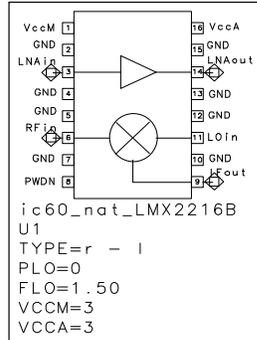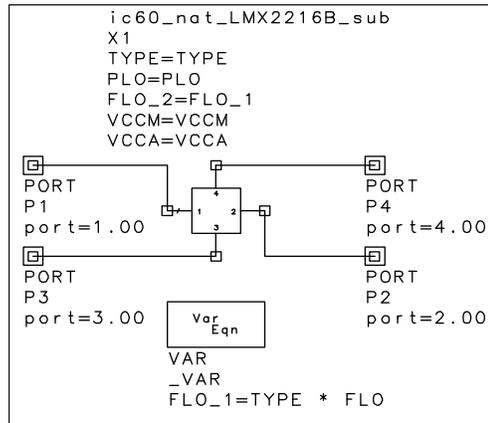

Figure 1. LMX2216B Main Schematic Symbol

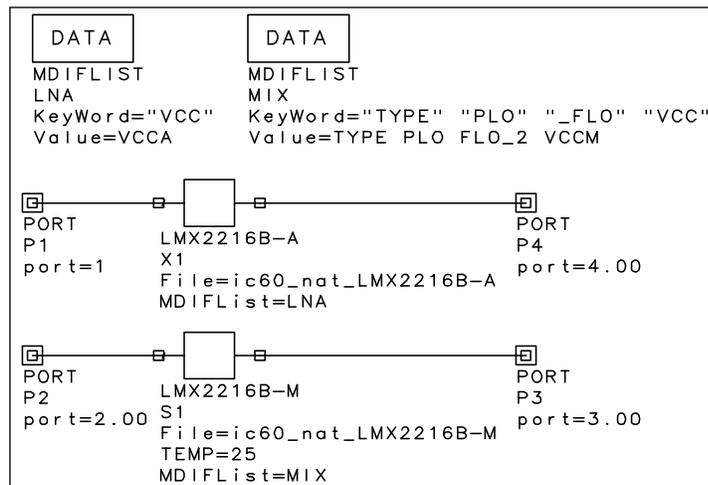

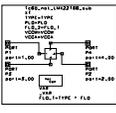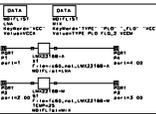**Figure 3. LMX2216B Subnetwork (pushed into `ic60_nat_LMX2216B`)**

Figure 4. LMX2216B Sub-subnetwork (pushed into `ic60_nat_LMX2216B_sub`)

In its most basic level, the sub-subnetwork shown in Figure 4 is used to specify the MDIF files storing the measured S-parameters and to assign proper values to the KeyWords. The user can specify the file names by using one of MDIF file elements named as S2D, P2D, or S2PG depending on the type. Also, the KeyWords and the associated values for the VAR line can be assigned by using the MDIFLIST element.

One of the KeyWords for the mixer, _FLO, has FLO_2 as its value which is defined with an equation. This equation is part of the subnetwork shown in Figure 3. Again, a new variable for _FLO was necessary to combine the mixing type and LO frequency. This new variable is used with the option lines of the .s2d files to calculate correct output frequencies depending on the mixing type. In the subnetwork, FLO_1 is defined as TYPE * FLO, and then FLO_1 is passed to the sub-subnetwork as FLO_2. Once the basic structure and the subnetworks of the model are built, the schematic symbol can be created as displayed in Figure 1. With the symbol complete, the user can use the model with other elements in OmniSys by connecting the ports to other models and entering necessary parameters.

Prior to building schematics, the user must determine how the model is implemented and what and how parameter values are passed from one level of network to its subnetwork. Table 5 outlines the plan.

Table 5. Summary of Schematics and Functions

	Example	Consists of	Functions	Flow of Variables
Main Schematic Symbol		Main symbol, Parameters	Provides a symbol for the model that can be connected to other OmniSys elements. Also, the user can enter the values for the parameters.	User enters values for the mixer as: TYPE = r-l PLO = 0 FLO = 1.5 VCCM = 3 VCCA = 3
Subnetwork		Parameters, Equation	Defines the variable FLO_1 with an equation, and passes all the variables to the sub-subnetwork.	An equation defines: FLO_1=TYPE * FLO The new and other values are passed down to the sub-subnetwork as: TYPE = TYPE PLO = PLO FLO_2 = FLO_1 VCCM = VCCM VCCA = VCCM
Sub-subnetwork		MDIFLIST, S2D, P2D	Specifies the MDIF files used and assigns proper values to KeyWords.	Mixer: KeyWord Values TYPE TYPE PLO PLO _FLO FLO_2 VCC VCCM
MDIF files		VAR lines, Option lines, Data blocks	Lists the measured S-parameters with the associated VAR values and options. Multi-dimensional interpolation is performed.	VAR lines are used to select the correct data block VAR TYPE = VAR PLO = VAR _FLO = VAR VCC =
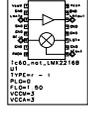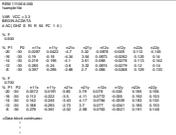
The following key steps illustrate how the LMX2216B model schematics are created:
- specifying KeyWords and Values with MDIFLIST
- placing S-parameter file elements with proper file names
- creating a main schematic symbol
- adding appropriate parameters for user interface.

Creating MDIF File Elements and Specifying KeyWords--Sub-subnetwork (Figure 4)
This sub-subnetwork is used to specify the MDIF files containing the S-parameters and indicate the KeyWords and Values for the files. In OmniSys, there are several S-parameter file elements that can be used to specify MDIF files. Also, a MDIFLIST item is used to match KeyWords and Values. These elements can be accessed from the *Electrical Black Box Elements* library shown in Figure 5.
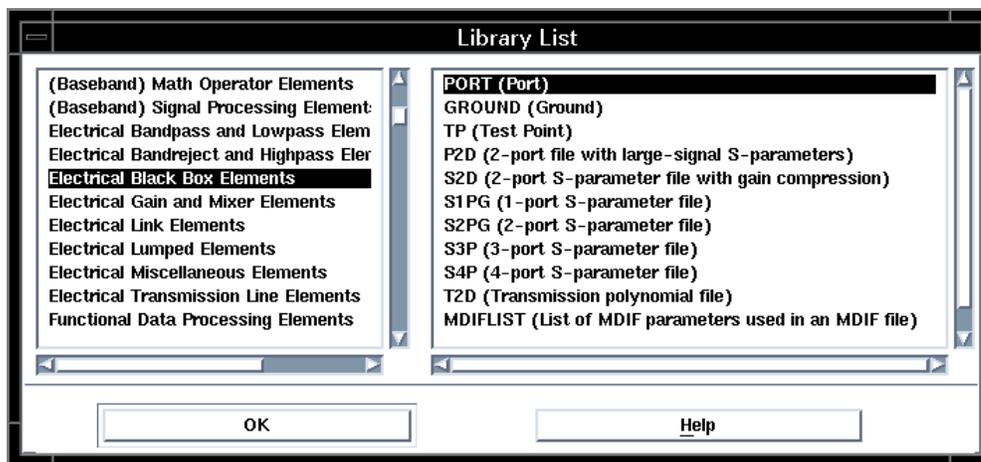
Figure 5. Electrical Black Box Elements

Placing MDIFLIST elements for establishing KeyWords and Values
1. Open an MDIFLIST item from the *Electrical Black Box Elements* library in the OmniSys Schematics window.
2. Add appropriate KeyWords and Values for an MDIF file as shown in Figure 6.
3. Enter the name for the MDIFLIST item. The MDIFLIST item for the LMX2216B mixer shown in Figure 6 is named **MIX**.
4. Choose correct **Value type** for KeyWord and Values. The typical types are **String** for KeyWords and **Variable** for Values.
5. Click **OK** and place the item in the Schematics window. Repeat for any other MDIF files.

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Placing S2D and P2D elements for MDIF files

1. Choose S2D for a .s2d file or P2D for a .p2d file from the *Electrical Black Box Elements* library.

2. Enter the name of the appropriate S-parameter file. Figure 7 shows the S2D file dialog box.

3. Attach ports to the inputs and outputs of S2D and P2D elements. At this point, the schematic should resemble the elements shown in Figure 4.

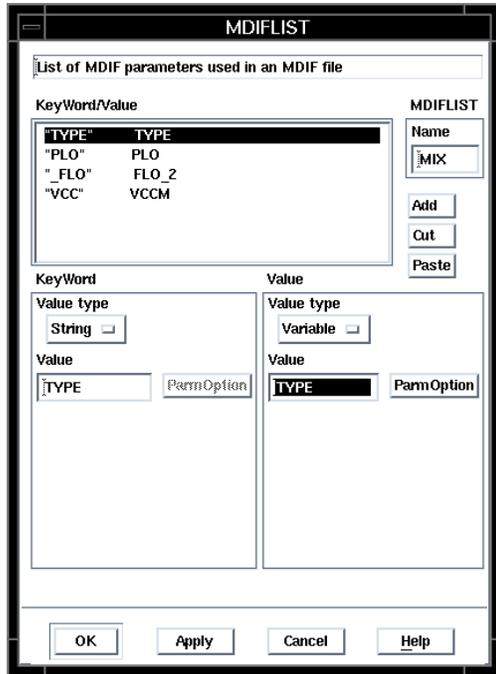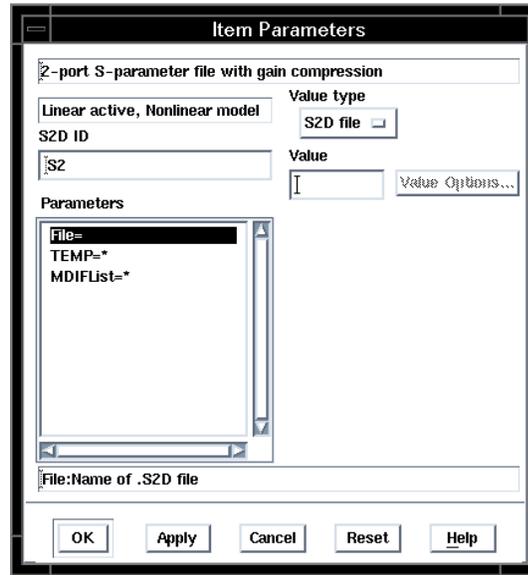4. Save the design with a name for the sub-subnetwork.

Figure 6. MDIFLIST Dialog Box

Figure 7. S2D Dialog Box

Defining Equations and Passing Parameters --Subnetwork (Figure 3)
The purpose of the subnetwork is to define a new variable and pass the values to the sub-subnetwork. The steps below summarize how an equation variable block can be used to define a variable. Also demonstrated in these steps is attaching parameters to a network. These parameters created here are attached to the sub-subnetwork, although they appear in the subnetwork schematic. The schematic in Figure 3 shows that five parameters are attached to the sub-subnetwork *ic60_nat_LMX2216B_sub*.

Attaching parameters to the sub-subnetwork
1. Open a new Schematics window.
2. Open and place the sub-subnetwork created previously from Project System library .
3. Push into the sub-subnetwork to bring back the schematics created in Figure 4.
4. To attach parameters, choose **Parameters** from **File**. The dialog box for this command is shown in Figure 8.
5. Add the necessary parameters while specifying appropriate **Units** and **Value Class**. These parameters correspond to the values that are assigned to KeyWord in Figure 4.
6. For **Value Class**, the most commonly used ones are Optimizable, Real, and Integer.
7. Save the design with the same name.
8. Pop out of the sub-subnetwork.
9. The parameters that were just added do not appear in the schematic yet because it hasn't been updated.
10. Update the schematic by swapping the old sub-subnetwork with the newer version by selecting **Swap Items...**, under **Edit** and **Item**. The updated schematic will now show the parameters under the symbol.
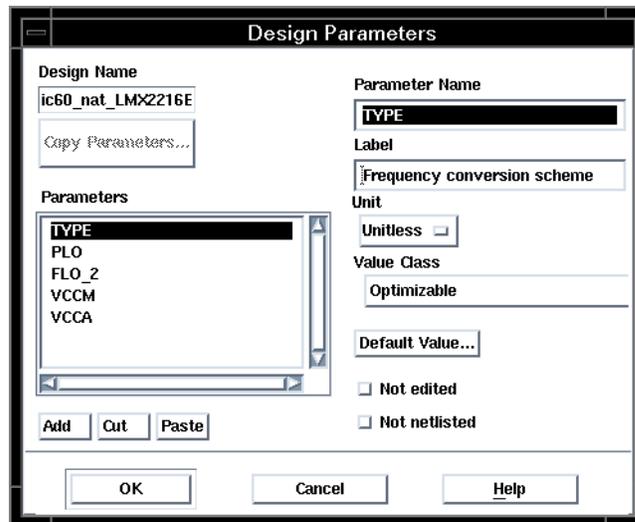

Figure 8. Parameters Dialog Box

Creating a new variable using an equation
1. Now, an equation can be specified with a VAR element, available from *Unit, Variables, and Equations* library.
2. Choose VAR from *Unit, Variables, and Equations* library to see the dialog box in Figure 9.
3. Enter a new variable name and click on the **Add** button.
4. Enter the equation for the variable by clicking on the **EQN Edit...** button.
5. Click on **OK** to close the dialog boxes.
6. The variable and the equation will now appear under the VAR element, as shown in Fig. 10. This new variable and other parameter values can now be assigned to the parameters created above.
7. Double-clicking on the sub-subnetwork element will bring the parameter dialog box so that the parameter values can be entered as shown in Figure 3. Now the necessary parameter values are passed to the sub-subnetwork.
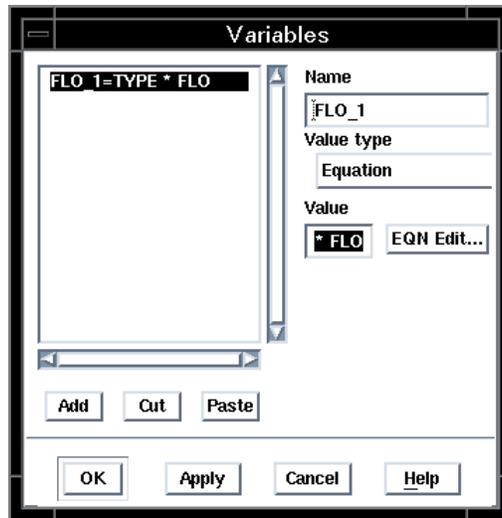8. Save the design with a new name for the subnetwork.
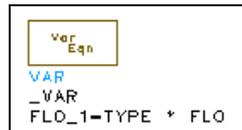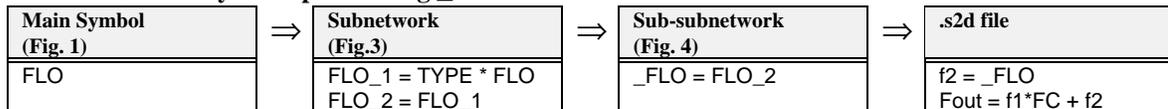

Figure 9. Equation Dialog Box

Figure 10. VAR Element

Table 6. Summary of Steps Defining _FLO

Main Symbol (Fig. 1)	⇒	Subnetwork (Fig.3)	⇒	Sub-subnetwork (Fig. 4)	⇒	.s2d file
FLO		FLO_1 = TYPE * FLO FLO_2 = FLO_1		_FLO = FLO_2		f2 = _FLO Fout = f1*FC + f2

Creating Main Schematic Symbol

1. Open the subnetwork file created previously in a new schematics window.

2. Choose **Switch to Symbol** from **View**.

3. Choose **Generate Symbol...** from **Draw**.

4. Click on **OK** to accept the default values in the Symbol Generator dialog box. This will create a symbol with pins for the ports used in the subnetwork.

6. In order to move the pins, use **Move & Disconnect** under **Edit** and **Move**.

7. In order to embellish the diagram of the symbol graphically, use the commands available under **Draw**.

8. Choose **Design Definition...** from **File** to obtain the dialog box shown in Figure 11.

9. Enter the name of the subnetwork design file under **Symbol Name**. For the LMX2216B, this is ic60_nat_LMX2216B.

10. Specify the library in which the model is going to be located under **Library Name**.

11. Click on **Parameters...** to add parameters for the model, as illustrated in the previous section. For the example used here, these are the five parameters shown in Figure 1.

12. Click on the **OK** buttons to close the dialog boxes.

13. Save the design file with the same name.

14. Choose **New...** from **File**.

15. Select the model from the library specified in Step 10. This should display the symbol just drawn.
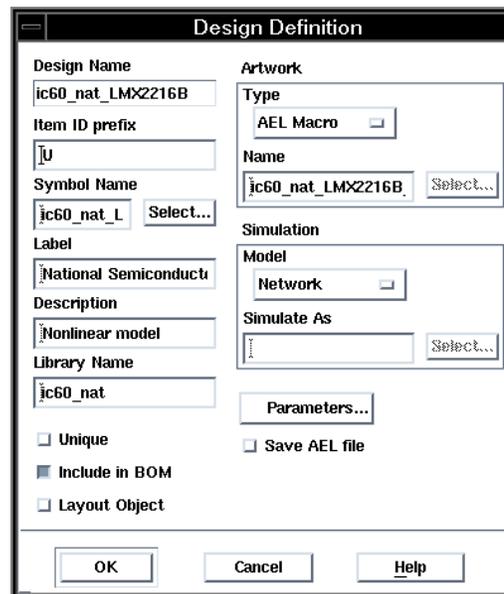

Figure 11. Design Definition

Editing AEL to Customize Value Option

After the model is created and added to the library specified in **Design Definition,** an AEL
(Application Extension Language) file is edited to customize the dialog box for the model. Recall
that for the mixer, the mixing type was indicated with a parameter called TYPE. There were two
values (-1 or 1) for TYPE depending on the mixing type (r-l or l-r). Rather than having the user
remember which value is for what mixing type, the dialog box can be modified so that it displays
the two mixing types and assigns the correct value.

The **Value type** of TYPE in the dialog box without customization (Figure 12) is set to "Real"
where the user has to remember to enter 1 or -1. However, the customized dialog box in Figure
13 offers two options, either "r-l" or "l-r", and assigns the correct numeric value automatically
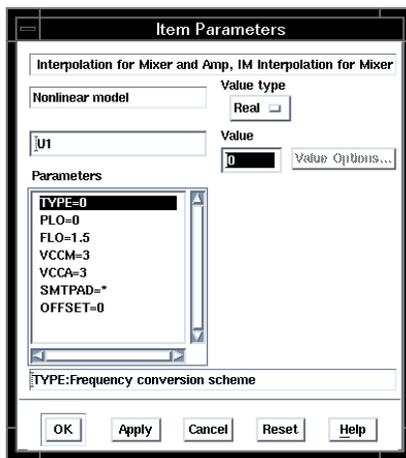for the option chosen.

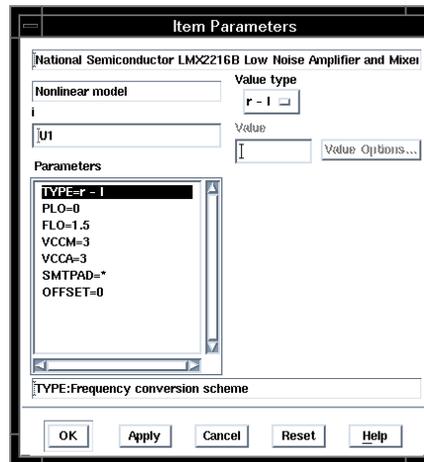**Figure 12. Before Customization**

Figure 13. After Customization

Note: *The parameters for a model are always associated with its subnetwork. In other words,
even though there are five parameters displayed with the main schematic symbol of the model
shown in Figure 1, the user has to push into the model's subnetwork and choose* **Parameters...**
from **File** *to create or modify the parameters.*

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In order to modify the parameter dialog box, locate and open the AEL file with an .ael extension (name_of_subnetwork_design.ael) in a text editor. The .ael files can be found under */networks* directory of the project. For the LMX2216B, the .ael file is named, ic60_nat_LMX2216B.ael. The following is an excerpt from the file, and the modified parts are indicated in bold. For designating the mixing type, the first three lines set the constant values for the two options (r-l or l-r) and the fourth bold line changes the appearance of the dialog box. For the scope of this app note these AEL commands are sufficient but for more AEL information, refer to the Series IV *AEL Guide* manual.

```
set_simulator_type(2);

create_constant_form ("LminusR","l-r",0,"1","l-r");
create_constant_form ("RminusL","r-l",0,"-1","r-l");
create_form_set ("mixtype", "LminusR", "RminusL");


create_item("ddd","National Semiconductor LMX2216B Low Noise Amplifier and Mixer, SO-16N
package, Fin=0.1-2.0GHz, Pin= -23  - -13dBm, VCC=2.7-3.3V, TEMP=25C, NF=4.8dB, Gain=10dB,
Po1dB=-3dBm, Model Features: SP and NP Interpolation for Mixer and Amp, IM Interpolation
for Mixer","U",262160,-1,NULL,100,"Nonlinear model","NETWORK %n %t%# %c%e%b%8?
%k=%p%;%e","","%t%b%4?%:\n%k=%r%s %e%;%e","ic60_nat_LMX2216B",2,"ic60_nat_LMX2216B_l",


create_parm("TYPE","Frequency conversion scheme",0,"mixtype",-1,prm("RminusL")),
create_parm("PLO","Local Oscillator Power, dBm: -5 <= PLO <= 3",0,"rvopt",8,0.0),
create_parm("FLO","Local Oscillator Frequency, GHz: 0.01 <= FIF <= 0.24, Constraint is on
FIF not FLO!",0,"rvopt",0,1.5),
create_parm("VCCM","Mixer Supply Voltage, Volts",0,"rvopt",9,3.0),
create_parm("VCCA","LNA Supply Voltage, Volts",0,"rvopt",9,3.0),
create_parm("SMTPAD","ID of SMTPAD data item (layout only)",8208,"smtpadname",-
2,prm("def*")),
create_parm("OFFSET","Electrical port offset, length units (layout
only)",8208,"real",5,0.0));
set_design_type(31);
library_group("ic60_nat","National Semiconductor RFIC Library v6.0","ddd");
```

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