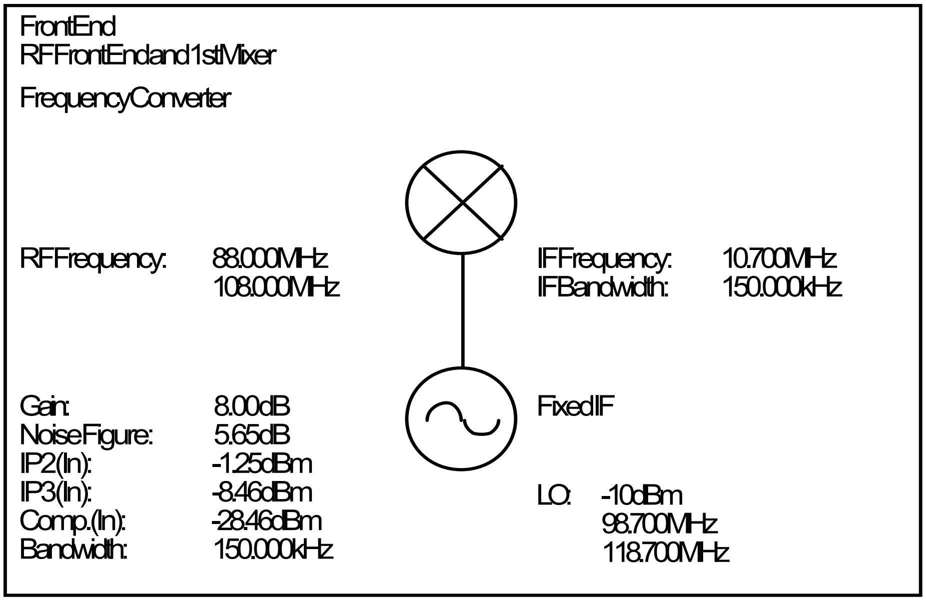

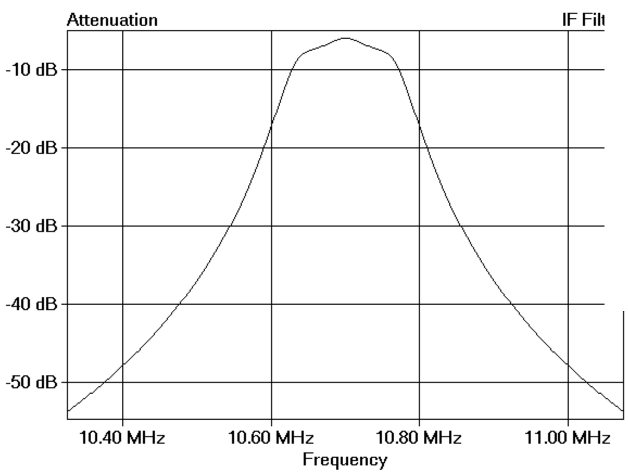

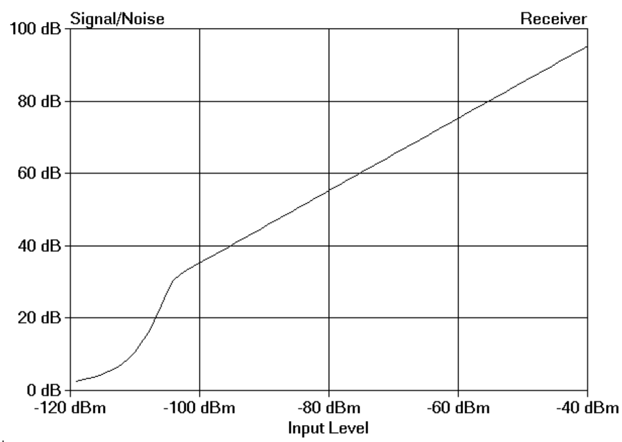

Receiver Toolbox

A simulation tool for the receiver design engineer.

Receiver Toolbox

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by Gary A. Appel

A receiver simulation toolbox

This program simulates many characteristics of a communications receiver. Included are block analysis, spurious analysis of mixers, as well as SNR and BER calculations. Block diagrams may be copied for inclusion in other documentation.

This program is the result of many years of development, for use as an engineering tool in the design of various analog and digital receivers.Additional features are likely to be included in the future. It is a work in process.

Comments and suggestions are appreciated. The author may be contacted at:

garyappel@sbcglobal.net

(at least, this was true at the time this document was prepared.)

Receiver Toolbox

Printed: November 2003.

Special thanks to:

Borland, who offers C++ development environment alternative to the giant in Washington,

Software Development Lohninger, who wrote many of the controls used in the software.

Last not least, we want to thank EC Software who wrote this great help tool called HELP & MANUAL which printed this document. (And also kindly included this final testimonial so I could include it, verbatim, in this document!)

Table of Contents

1 Copyright Statement

This program was created using Borland C++ Builder (Trademark of Borland.)

Some of the components were obtained from Software Development Lohninger (SLD.)

The help files were prepared using Help & Manual (Registered trademark of EC software.)

2 Program Summary

A typical communications receiver contains hundreds of components. These components include active parts, such as diodes and transistors, and passive components such as resistors, capacitors, and inductors. These components are used to build attenuators, amplifiers, mixers, power supplies, and other basic circuits. In addition, the receiver probably contains integrated assemblies, such as IC amplifiers, voltage regulators, mixers, and filters. These have been designed as sub-assemblies, and are included in the receiver having already been designed.

These circuits and assemblies are normally designed using other tools, such as the SPICE circuit simulator. These circuits are analyzed or measured to determine their performance characteristics, such as gain, noise figure, bandwidth, signal handling capability, and so on. It is these "block" characteristics that this program deals with in order to model the performance of a receiver.

For the purposes of modeling a receiver in this program, the receiver is broken up into RF Modules. A typical RF module might be a front end, or a first mixer / IF, or final IF chain. Each module in turn contains blocks, or Elements such as amplifiers, attenuators, and filters. A variable gain element is also available, so the user can analyze an AM receiver as a function of the gain control voltage, or input signal level. In addition, the simulator defines an AGC detector, a signal demodulator, various local oscillator parameters, and input signal characteristics.

The block analysis feature of this program allows the user to cascade the various elements (or blocks) in each module, and cascade multiple modules, defining the receiver. The results of this simulation are system gain, noise figure, intermodulation intercept points, 1 dB compression, and bandwidth. In addition, signal to noise ratio can be calculated as a function of the input signal level. For digital simulations, the bit error rate can be calculated as a function of the input signal level.

If the RF module contains a mixer, the module can be analyzed for the presence of single signal spurious susceptibilities. If there are multiple mixers in the receiver, the user can analyze adjacent converters for the presence of birdies in the tuning range.

The local oscillator leakage can be calculated at either the input to the module containing a mixer, or at the input to the receiver.

Block diagrams, and plots of the receiver performance are available for printing, or inclusion in other documents.

While using the simulator, it will become apparent that information is supplied to the program that is not used in any simulation. In many cases this information has been included to facilitate the later expansion of the capabilities of this program.

In addition to providing a tool for the design of communications receivers, we hope that this program might be useful as a tutorial on some of the aspects of receiver design. As such, we've tried to include explanations and definitions that are probably more detailed than the average user might require.

2.1 Receiver Description

Each receiver simulation contains a similar set of parts. The parameters defining these parts, and the order of in which the parts are cascaded, defines the receiver. Some of the basic parts used to build a receiver simulation are attenuators, amplifiers, mixers, and filters. In this program, these parts are called "Elements".

As Elements are created and defined (by setting their parameters), they are added to the Element Library. Parts contained in the library can be incorporated into the receiver definition by including them in RF modules.

The receiver consists of a cascade of RF Modules. Each RF Module can be defined either by specifying it's block parameters, or by including a cascade of basic Elements in the block. If the module contains a mixer, it's a converter module. Only one mixer may be contained in a converter module.

An AGC detector dialog is available, allowing the user to specify the characteristics of the AGC detector. This will control the AGC response of the receiver, by controlling any gain controlled amplifiers in response to the detected signal level, in order to maintain the correct detector input level. In addition, we hope to add a dynamic simulation in the future, to model the attack and decay characteristics of the receiver.

A demodulator dialog is available, allowing the user to specify the demodulator characteristics. These determine the acceptable input signal types, and the demodulation characteristics of the receiver, including baseband bandwidth.

An input signal dialog is available, allowing the user to specify the amplitude and modulation type of the input signal.

A front panel dialog is available, allowing the user to set the receiver AGC control voltage range, input signal amplitude range, and input signal frequency.

2.2 Features and limitations

This program should run under Windows '95, or later.

This program does not include a graphical interface for defining the receiver. That's because I'm not a professional computer programmer, and I'd rather spend the time writing the simulation, than trying to get a graphical interface working. Instead, I've tried to use a logical format to define the receiver using lists and list boxes to access the elements and RF modules, and define them.

Most plots and tables can be printed directly to the system printer. Plot windows may have to be resized in order to produce a good image on the printer. This results from the simple routines used to print plot windows. Someday, the print routines may improve.

Most plots and tables can also be copied onto the clipboard for inclusion in other documents. In some cases, the plot will be transferred as a bitmap, a limitation of the plot routines obtained from SDL. In other cases the plot will transfer as a metafile, allowing the transferred image to be easily resized, and reducing the final document storage requirements.

Unless expressed otherwise, calculations in this program are not based on pseudo random simulations, but use closed form expressions. In many cases these expressions are generally available. Where this is not the case, we have tried to include the source for the expressions in this help file.

In most cases, the performance calculations take into account only a limited number of items that affect the parameter being analyzed. For example, the noise figure calculation completely ignores any contribution caused by wideband local oscillator noise that might leak into the RF path through the limited mixer isolation. We have seen significant noise figure degradation when using a commercial synthesized signal generator to supply a local oscillator to a receiver. This would not be simulated using this program.

We encourage you to use the program, and contact us with any bug reports or suggested improvements. If there is enough interest in the program, and if we can improve it sufficiently, it may be made available as a commercial product.

2.3 Disclaimer

Parts of this program have been used over the period of several years to analyze receiver performance. However, the program author does not make any warranties that the program includes all required parameters required to calculate receiver performance, or that any calculations performed by this program are correct. In using this program, the user agrees to accept any deficiencies in the program. Checking the results of any simulation is strongly encouraged. In addition, bug reports from users are encouraged.

3 An FM Receiver Example

In this section, we'll introduce the example receiver. We'll develop a monaural receiver for the FM broadcast band.

The FM broadcast band comprises the frequency range of 88 to 108 MHz. The maximum deviation is ±75 kHz, and the maximum audio frequency is 15 kHz. Thus we'll design with an IF bandwidth of 200 kHz, and a baseband bandwidth of 20 kHz, to assure that we aren't introducing frequency distortion in either the IF or baseband filtering.

The IF frequency for the receiver will be selected as 10.7 MHz. It can be shown that a fixed tuned bandpass filter cannot be used at the input for image rejection with this frequency plan. It was common, in days past, to include an RF amplifier with a single tuned resonator at each side - input and output - of this RF amplifier. We'll employ the same configuration in this design.

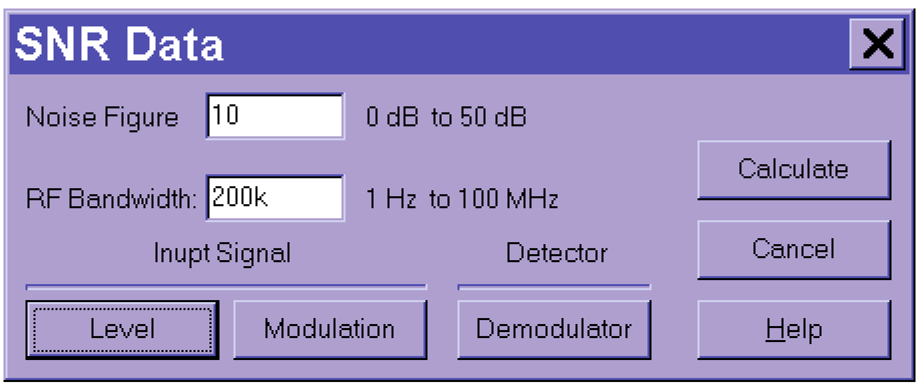
For purposes of this development, we'll partition the receiver into three RF modules. The first module will contain the tuned preselector, including the RF amplifier stage. The second module will contain the mixer circuitry, and IF filter. The final module will contain the IF circuitry, and an additional roofing filter, to control the noise bandwidth prior to the detector.

3.1 Determining the Input Signal Range

At this time, the input signal range is unknown. Without knowing what input range we need to receive, we won't be able to specify the total receiver gain. So our first task will be to determine what the minimum input signal level is that we'll need to receive.

If the simulator program is not yet running, launch it using one of the standard techniques for launching an application under Windows. The program will start up with an empty receiver description. If the simulator is already running, press the New Simulator speed button  in the main simulator window to create an empty receiver description.

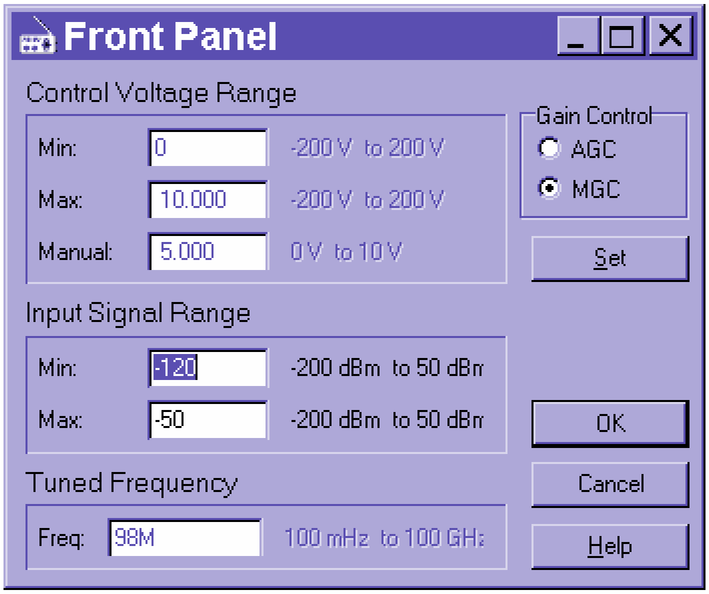
Before we can determine the minimum input signal level, we have to specify the demodulator characteristics. We'll then determine what signal to noise ratio we might expect for a range of input signals. We can determine this by selecting the Tools|System|Calculate SNR menu item from the main simulator window. Selecting this menu item will open the SNR Data dialog:



At this point, we have to specify a receiver system noise figure, and RF bandwidth. Note that the RF bandwidth here refers the the noise bandwidth of the receiver. For our purposes, we'll just assume this is the narrowest bandwidth prior to the detector.

The default noise figure of 10 dB is a reasonable first guess for the receiver noise figure. Leave it at it's default value. Move the cursor to the RF Bandwidth edit box, and enter a value of "200k", for 200 kHz. Finally, press the "Level" button, which will bring up the Front Panel dialog.

3.1.1 Guessing the Input Signal Range

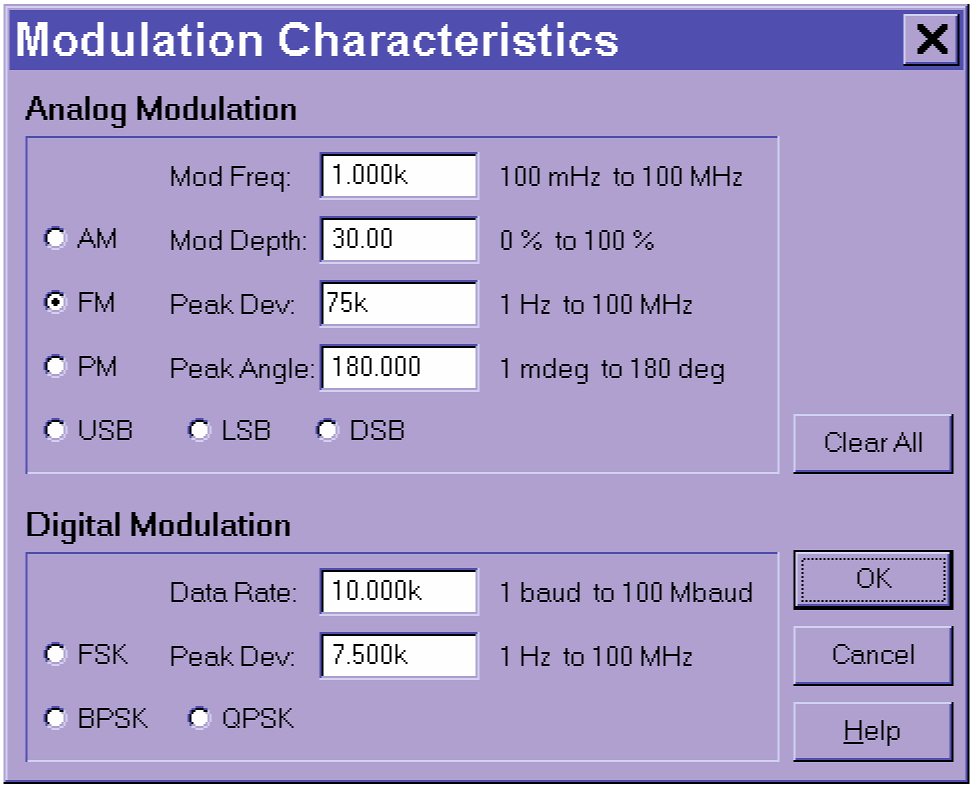


Note that several items on the Front Panel have been disabled. The only items of interest at this time are the minimum and maximum signal levels. The input range specified here will be used for the SNR calculation, so we want to use a first guess with the minimum signal level selected below what we might expect. That way, the SNR plot will include the desired minimum signal level.

Start by defining a minimum signal level of -120 dBm, and a maximum singal level of -80 dBm. Press the "OK" button, to return to the SNR Data dialog.

3.1.2 Specifying the Modulation Characteristics

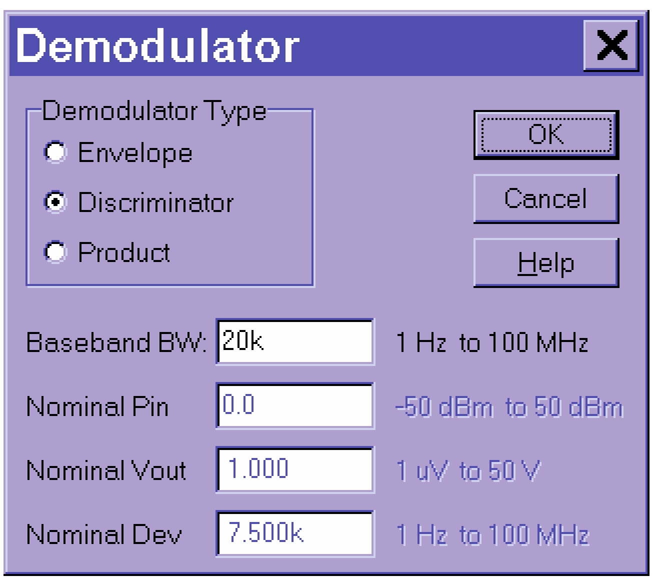
Next, press the "Modulation" button in the SNR Data dialog. This will bring up the Modulation dialog.



Select the FM modulation radio button under the Analog Modulation section, and set the Peak Deviation to 75 kHz, as shown above. Press the "OK" button to close the dialog.

3.1.3 Specifying the Demodulator Characteristics

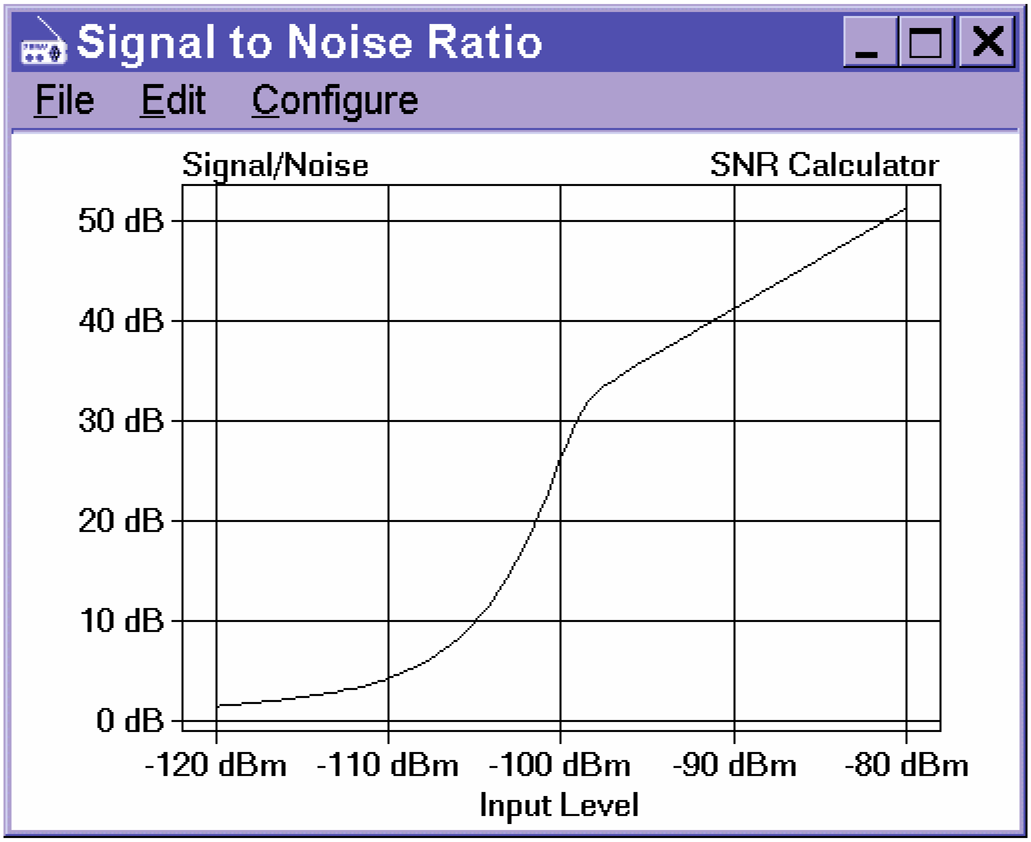
Finally, in the SNR Data dialog, press the "Demodulator" button, bringing up the Demodulator dialog.



As shown above, make sure the Discriminator radio button is selected, and specify a baseband bandwidth of 20 kHz. Press the "OK" button to close the demodulator dialog, and return to the SNR Data dialog.

3.1.4 Calculate Example SNR

At this time press the "Calculate" button in the SNR Data dialog, displaying the calculated signal to noise ratio as a function of the input signal level:



The above signal to noise ratio plot shows that the FM threshold should occur just above -100 dBm for these parameters, with the output signal to noise ratio decreasing rapidly below that input level. We might want to detect signals down to -110 dBm. In order to assure satisfactory performance at low signal levels, we'll include sufficient amplification to bring a -110 dBm signal up to the required demodulator input level.

In an FM receiver, as the signal level increases, the amplifiers go into limiting. Other than damage, and the potential for bias shifts or oscillations as amplifiers are over-driven, there should be no upper end limit to acceptable signal level. As an arbitrary limit to the maximum signal level (for analyses and plotting), we'll chose -50 dB. Extending the high end further will just compress the interesting area of the signal to noise ratio plot.

At this time, close the Signal to Noise Ratio Plot.

3.2 Creating the Receiver Definition

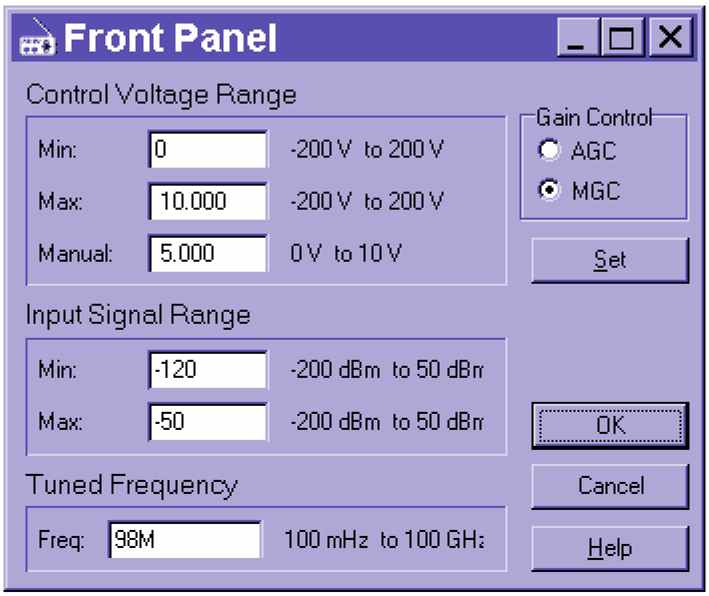
With the input signal power range defined, we can now start to define the receiver. This will be done in two stages. First, the receiver will be defined as a cascade of three modules, with the performance of each module defined. Then the receiver definition will be fleshed out by incorporating various elements into the three receiver modules.

Some systems analyses can be completed with just the three modules defined. Other analyses will require that the receiver be defined in terms of the individual elements, or blocks contained in the each module.

3.2.1 Defining the Receiver Parameters

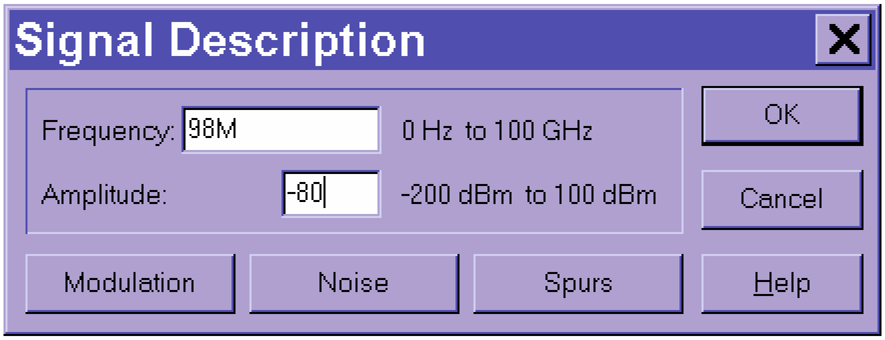
There are three dialog boxes accessible from the main simulator window that are applicable to this FM receiver example. During the parameter specification for the signal to noise calculation, we touched two of these dialog boxes, the Front Panel dialog, and the Demodulator Definition dialog.

Return to the front panel dialog by selecting the Edit|Panel menu item from the simulator main window. Because we have an FM receiver, there will be no gain controlled elements, and the AGC characteristics are meaningless. The input signal range was set to -120 to -80 dBm during the SNR calculation. Change to a range of -110 to -50 dBm. Set the Tuned Frequency to 98 MHz (98M), the center of the broadcast band.

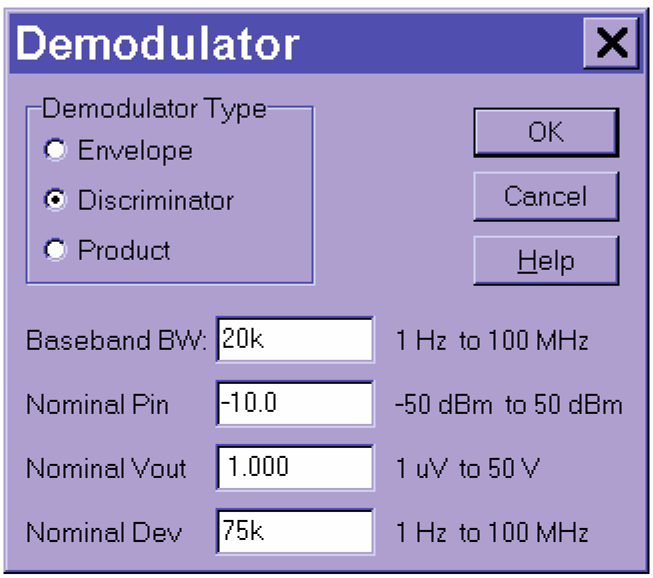


Close the dialog by pressing the "OK" button.

Next, select the Edit|Input Signal menu item, opening up the input signal description dialog. Set the signal frequency to 98 MHz (98M), and the amplitude to -80 dBm. Any analyses that occur at a fixed input level will use the specified signal amplitude. Again, close the dialog by pressing the "OK" button.



Now, select the Edit|Demodulator menu item, opening up the demodulator characteristics dialog. The Demodulator Type has already been selected as a discriminator, and the baseband bandwidth has been set to 20 kHz. The nominal input power should display 0.0 dBm, the default value. This represents the signal level that must be delivered at the output of the receiver cascade, into the demodulator, for nominal operation of the demodulator. We'll set it to -10.0 dBm. Leave the nominal output voltage at 1.0 volts. Finally, set the Nominal deviation to 75 kHz, and close the dialog by pressing the "OK" button.

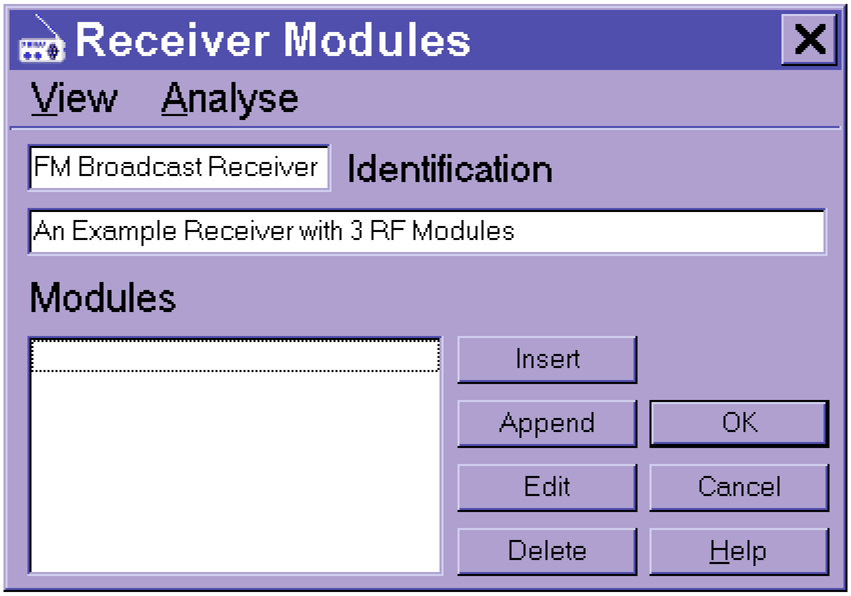


Since this is an FM application, the AGC detector will not be configured.

3.2.2 Creating a Receiver Module

As mentioned earlier, we'll partition the receiver into three RF modules.

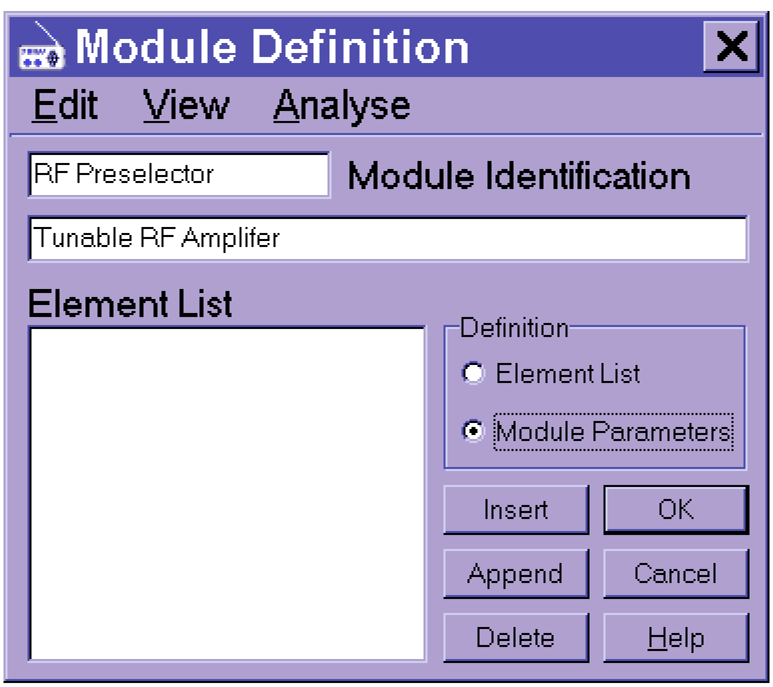
Open the Receiver Modules dialog by selecting the Edit|Receiver menu item on the simulator main window. The Identification edit box presently contains the word "Receiver". Delete this word, and replace it with "FM Broadcast Receiver", or some other title to describe the receiver. The description edit box contains the word "Description". Again, delete this word and replace it with "An Example Receiver with 3 RF Modules", or some other description of the receiver.



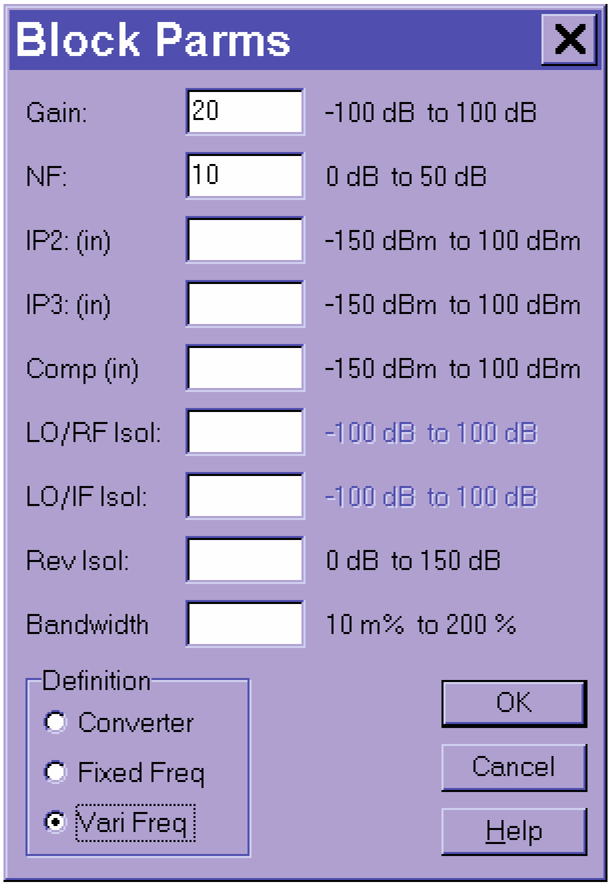
To create the first of the three RF modules, the RF preselector, press the "Insert" button, bringing up the Module Definition dialog.

At this time we won't be defining any elements. Instead we'll define the module performance by specifying the module parameters. This is similar to writing a specification for the module performance, prior to designing the circuitry. We'll begin by defining the module name.

Delete the default module name, "Module", and replace it with "RF Preselector". Similarly, delete the default description, and replace with with "Tunable RF Amplifier", or some other description of the module. Select the "Module Parameters" radio button, to define the module performance in terms specified parameters.

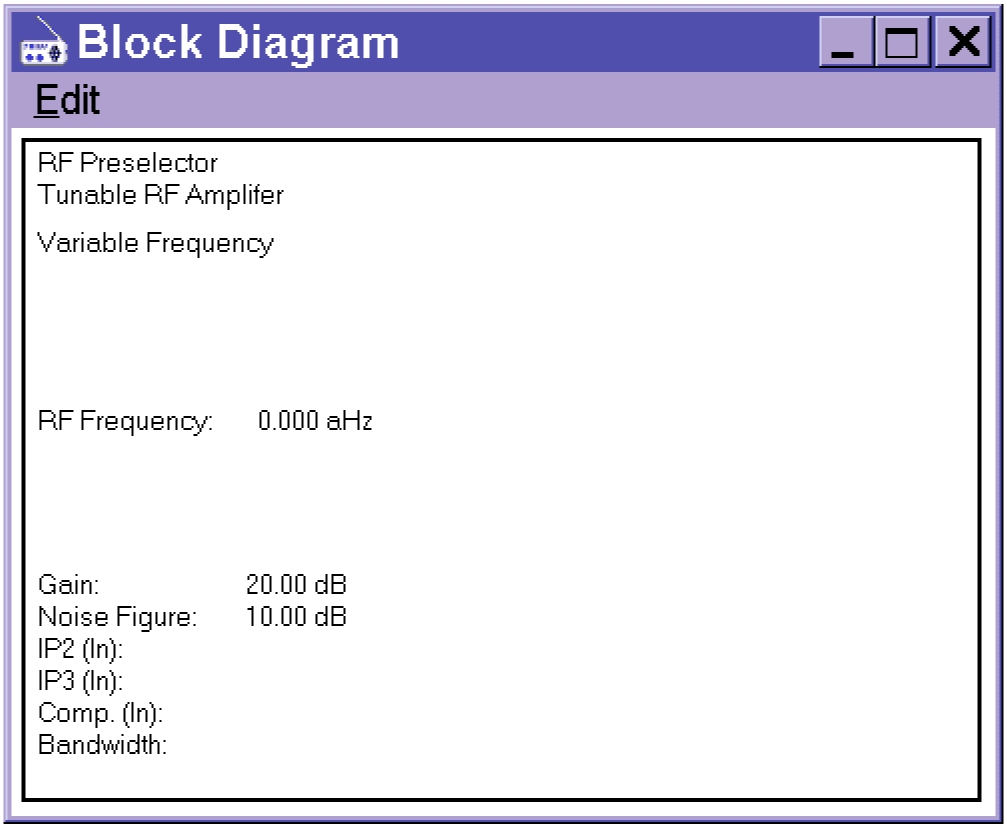


Finally, select the Edit|Module Parameters menu item, to bring up the Module Parameters dialog.



We'll define just the most basic parameters, the Gain and Noise figure for the module. Set the gain to 20 dB, and the noise figure to 10 dB. Finally, select the "Vari Freq" radio button. This specifies that the module is tuned to the desired signal frequency. Close the dialog by pressing the "OK" button.

At this time a summary of the RF Preselector module can be displayed by selecting the View|Module menu item on the RF Module dialog.

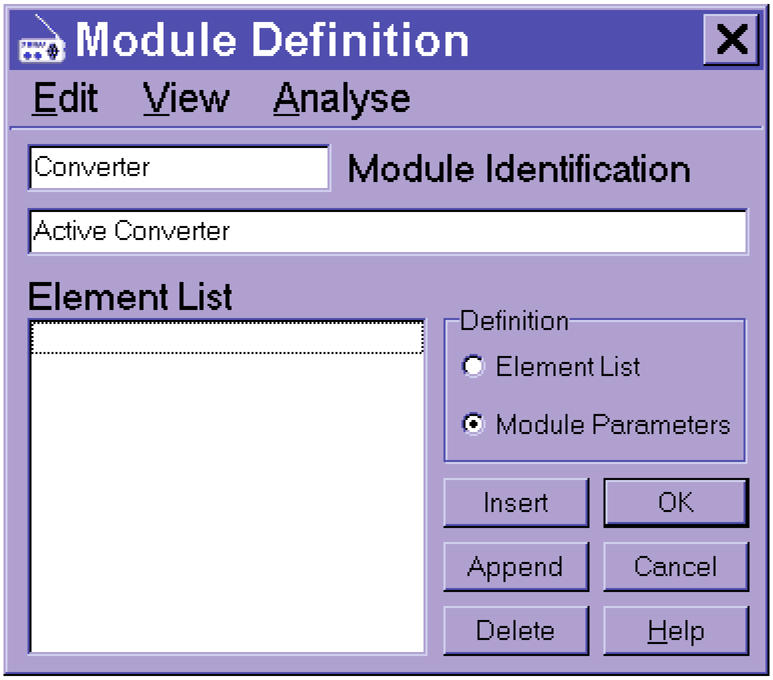


Notice that the RF Preselector gain and noise figure parameters are displayed. The RF frequency is shown as 0.0. This is because no frequency plan has yet been entered into the receiver description, so the program has no way to determine the frequency range of this module.

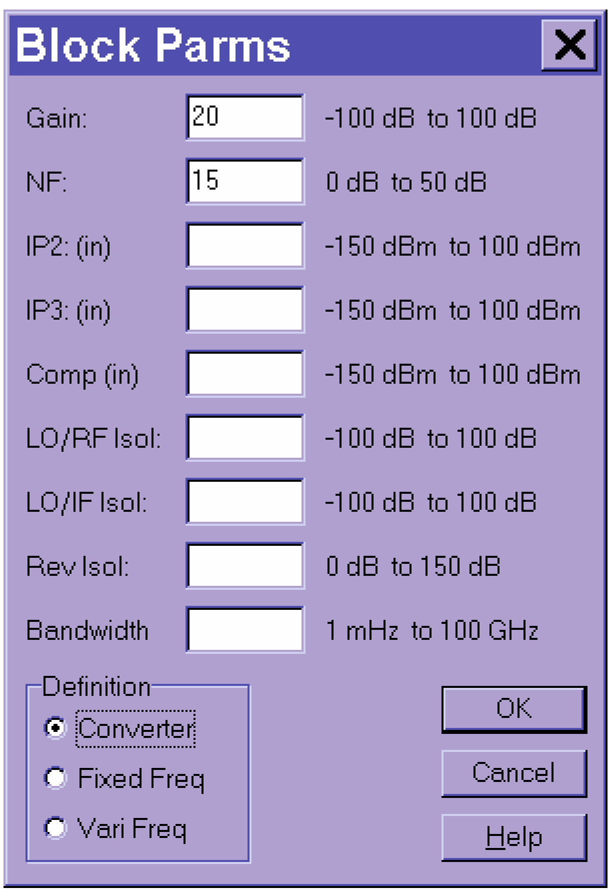
Close this window. Continue by closing the Module Definition dialog, by again pressing it's "OK" button. Note that the Receiver Modules dialog now shows the RF Preselector as only defined receiver module.

3.2.3 Converter Module Definition

At this time press the "Append" button on the Receiver Modules dialog, bringing up another Module Definition dialog. As the module definition below shows, we have changed the name of the second module to "Converter", with "Active Converter" as the description. Again, highlight the Module Parameters radio button.

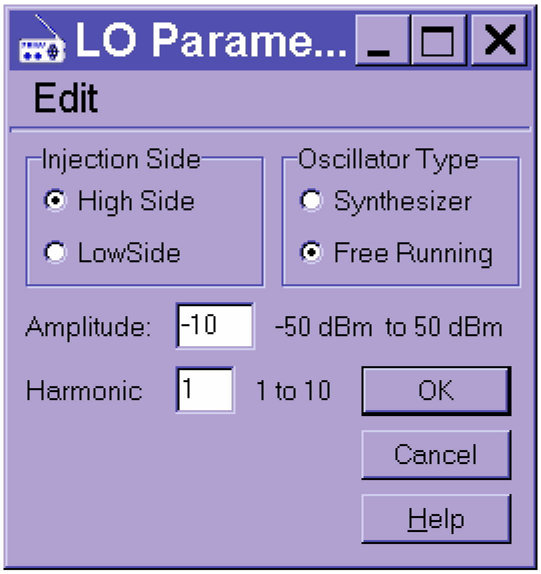


Bring up the Module Parameters dialog, and set the converter module gain to 20 dB, and the noise figure to 15 dB. Select the Converter radio button.



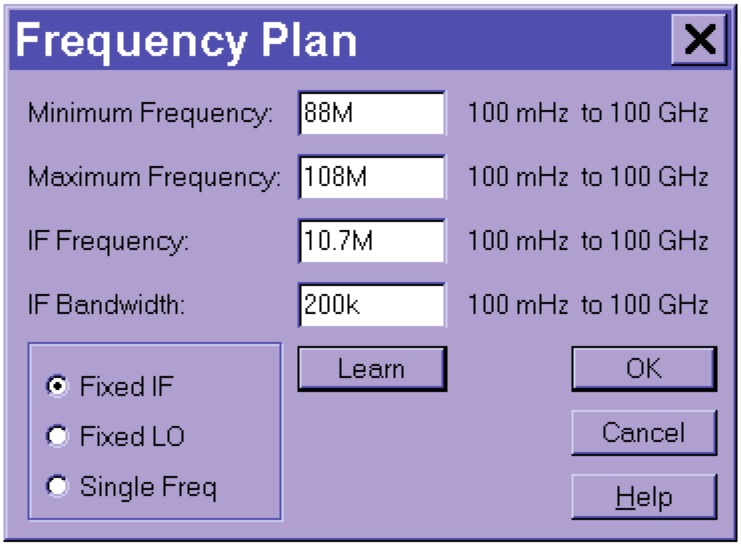
Close the Module Parameters dialog by clicking the "OK" button.

A converter stage needs some additional information regarding the local oscillator. Select the Edit|LO menu item, bringing up the LO Parameters dialog. This receiver will employ high side injection, placing the local oscillator frequency at the sum of the input signal frequency and the intermediate frequency. The oscillator type is not significant at this time, and is not yet incorporated into the program. Set the amplitude to -10 dBm, representing the level of the local oscillator into the mixer element. Again, the Harmonic number is not used at this time, and should be left at 1, representing injection of the fundamental frequency of the oscillator into the mixer.



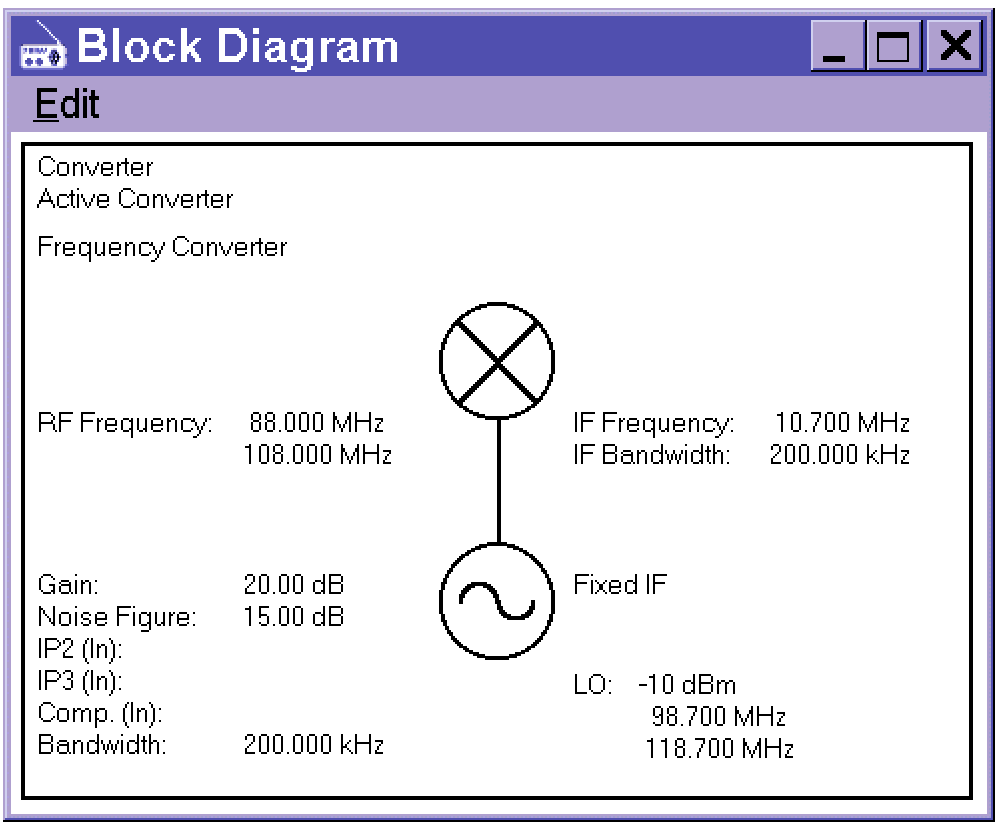
Close the LO Parameter dialog by pressing the "OK" button.

Finally, open the frequency plan dialog by selecting the Edit|Freq Plan button. Set the RF input range by setting the minimum frequency to 88M, and the maximum frequency to 108M. The IF frequency should be set to 10.7M, and the IF bandwidth to 200k. In this converter, the intermediate frequency is fixed while the local oscillator frequency is varied. Select the Fixed IF radio button. If a block conversion was employed, where an RF band is converted to an IF band using a fixed local oscillator frequency, the Fixed LO radio button would be selected. A fixed conversion, typically from one fixed intermediate frequency to another fixed IF frequency, would be indicated by selecting the Single Freq radio button.



Close the Frequency Plan dialog by pressing the "OK" button.

Again, display a diagram of the module by selecting the View|Module menu item in the Module Definition dialog.



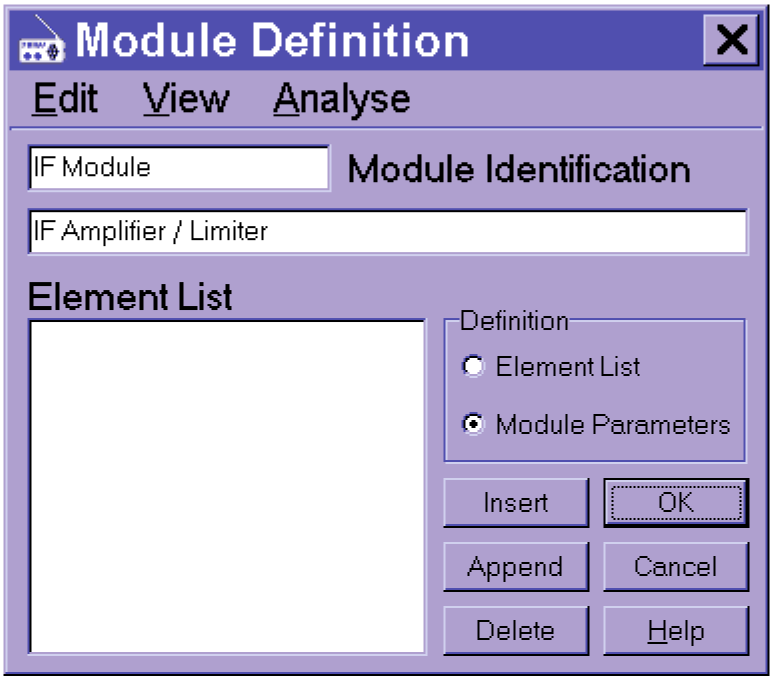
Again we see the gain and noise figure display. In addition, the module bandwidth is displayed, along with the input and output frequency characteristics. The LO frequency range and level are also displayed next to the oscillator signal. Resize the window to see how information is added and removed from the display as the window size changes. Note that the window size responds only to width, with the height automatically readjusted to maintain a constant aspect ratio.

Close the module display. Continue by selecting the "OK" button on the Module Definition dialog.

If you select the RF preselector module, and display it's module diagram again, the RF frequency range of the RF Preselector module will now be shown.

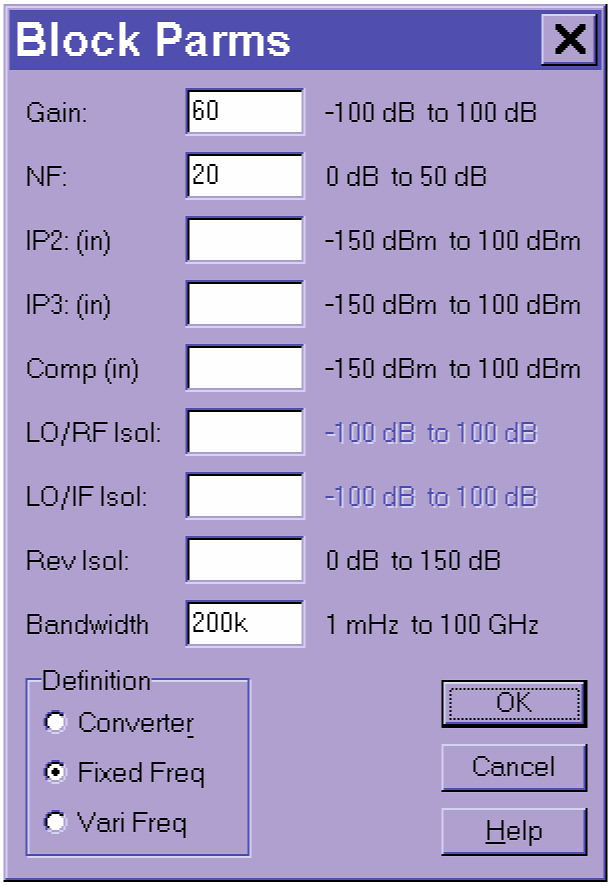
3.2.4 IF Module Definition

One again press the Append button in the Receiver Modules dialog, to creat the final receiver module. We'll name this one "IF Module", and enter "IF Amplifier / Limiter" as the module description. Select the Module Parameters radio button, and again bring up the Module Parameter dialog.

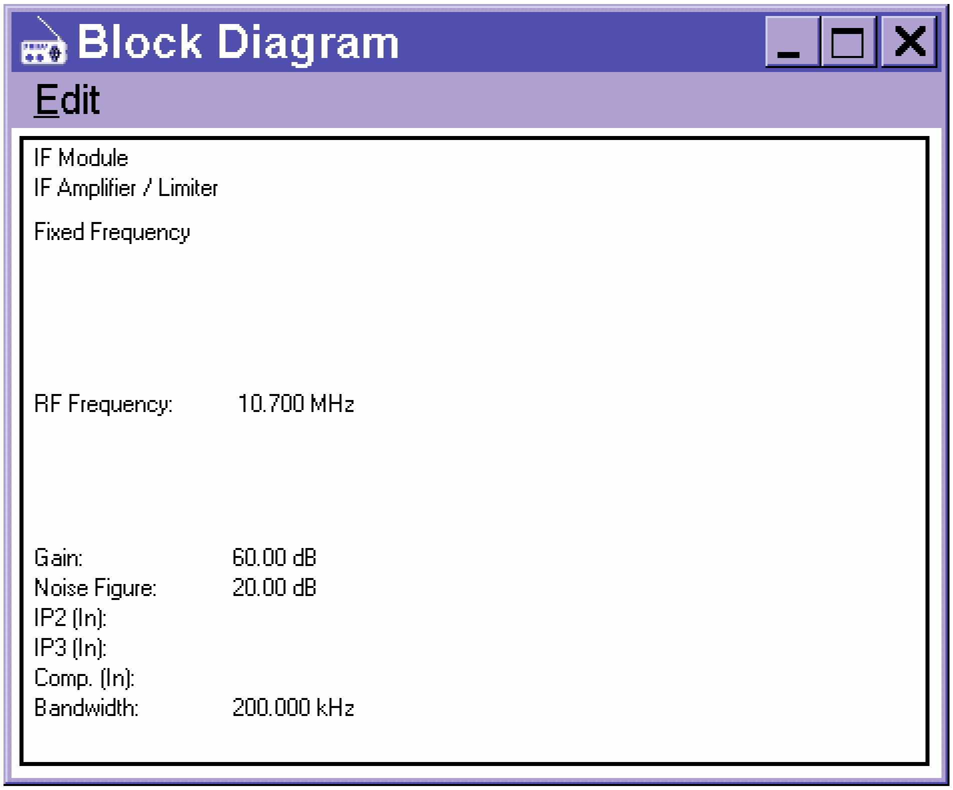


So far, we've defined the RF Preselector module with a gain of 20 dB, and the convertor stage with a gain of 20 dB as well. Since we want to detect a minimum signal level of -110 dBm, and have defined the demodulator to require an input level of -10 dBm, the total receiver gain of must be 100 dB. WIth 40 dB of gain accounted for in the first two modules, the IF Module must display a gain of 60 dB.

Set the module gain to 60 dB, and select a module noise figure of 20 dB. Set the bandwidth to 200k (the noise bandwidth is required for calculating noise power), and select the Fixed Freq radio button, as this is a fixed intermediate frequency module.



Close the Module Parameters dialog by pressing the "OK" button, and again display the module diagram.

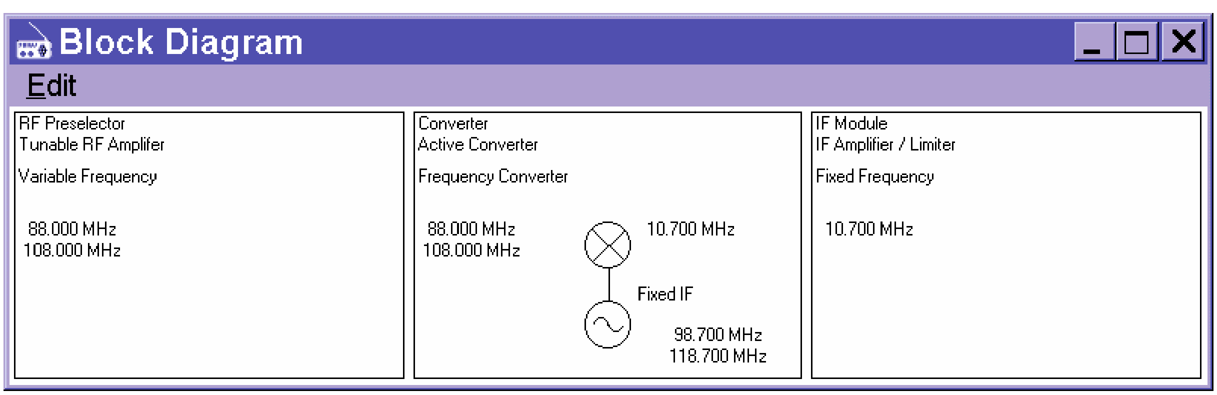


Again the gain and noise figure are displayed, along with the module center frequency and bandwidth. Close this window, and the Module Definition dialog. Close the Receiver Modules dialog by pressing the "OK" button, returning to the main simulator window.

3.3 Receiver Analysis

A number of system performance analyses can now be performed on the receiver. We can examine the cascaded performance of the three modules. We can plot the system signal to noise ratio. We can also display the spurious signal suseptibility for the convertor stage.

First, display a cascade of the three modules Select the View|Receiver Modules menu item. Each module is represented by the same block as we saw using the View|Module menu item under each module description:

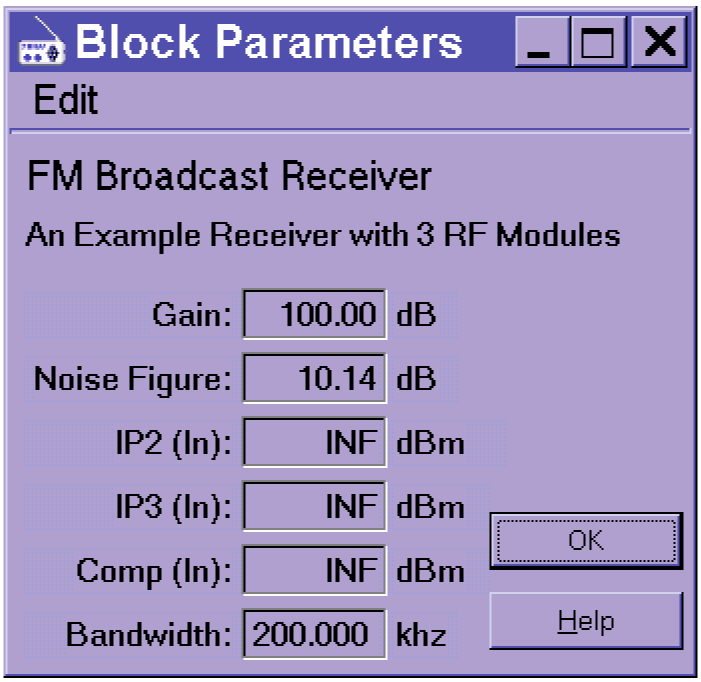


Because of the small size of each module displayed, only the minimum information is displayed here for each module. Notice that the frequency characteristics of the RF Preselector module are now defined.

Note that the input frequency range is now displayed in the preselector module, as a result of defining the frequency plan of the converter module.

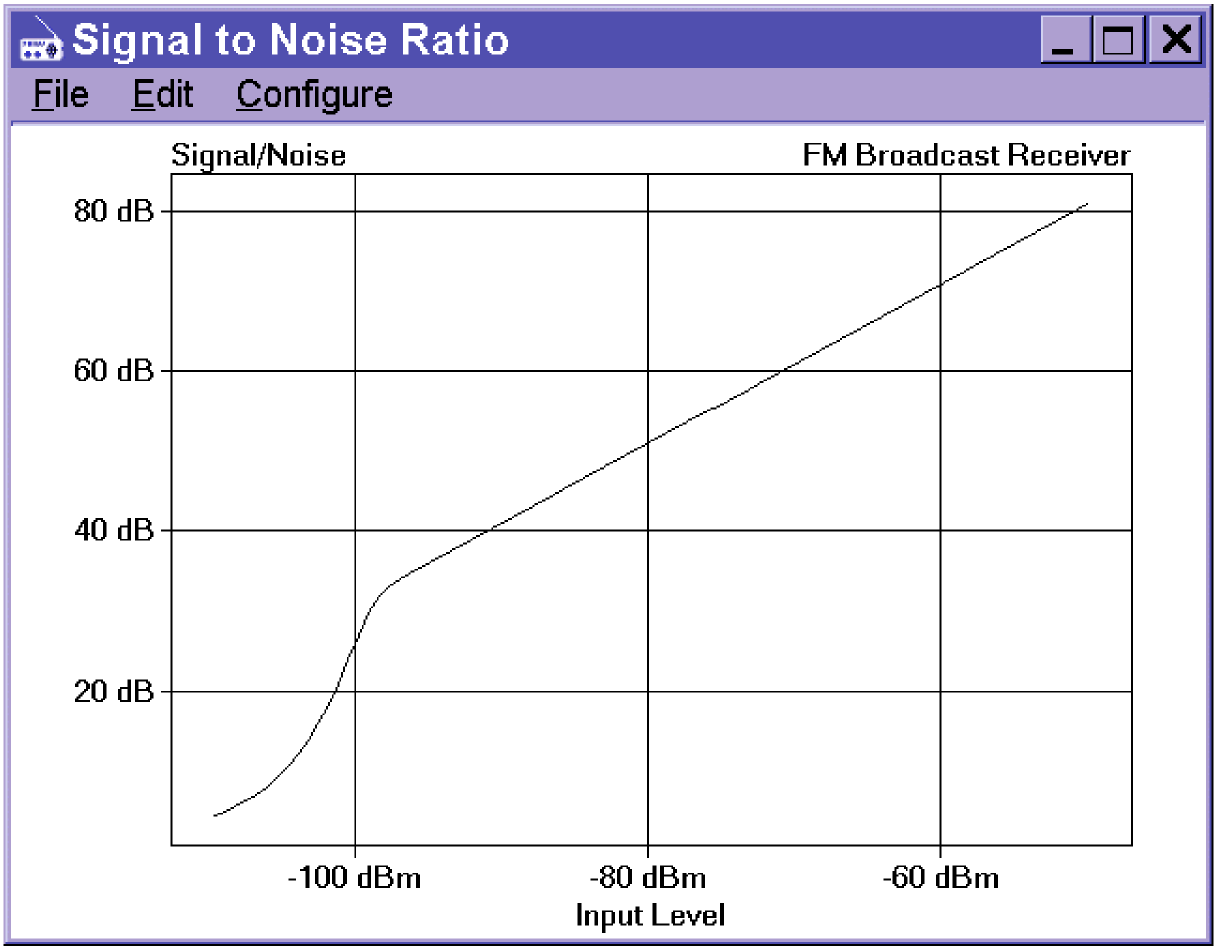
3.3.1 Cascade Performance

At this time it would be desirable to display the system performance, to determine the affect of cascading these three modules. Start by selecting the Analysis|Block|Summary menu item.



As shown here, the total receiver gain is now 100 dB, and the system noise figure has been degraded to just 10.14 dB by the cascading of the three stages. Since we have not defined any intercept or compression points, these characteristics have defaulted to infinity. Close the Block Parameter Summary window.

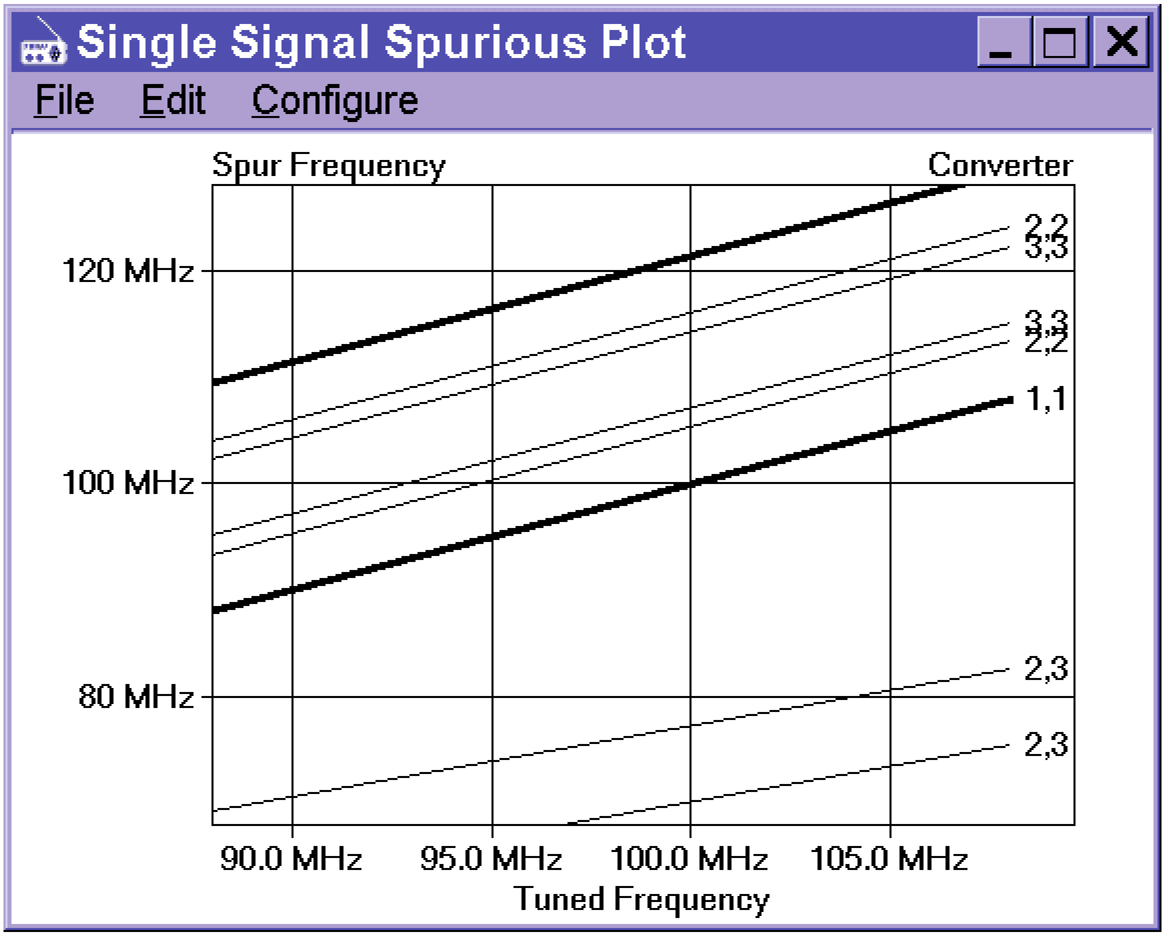
The signal to noise performance of the receiver can be displayed by selecting the Analysis|SNR menu item. This will be essentially the same signal to noise ratio plot as was obtained by using the Tools|Calculate SNR menu item.



The only difference from the earlier plot is that our cascaded noise figure is 10.14 dB, rather than the 10.00 dB assumed in the initial calculation. This slight difference is not visible in this plot.

3.3.2 Spurious Performance

At this time it would be instructive to determine the single signal spurious performance of the receiver. Single signal spurious responses are generated in converter stages. Select the converter stage by selecting the Edit|Receiver menu item, then double clicking on the converter module. Select the Analysis|Spurious Suscetpibility menu item, bringing up a spurious plot. Note that the display is in terms of absolute frequency.



The lower bold line is the desired tuned frequency. When the receiver is tuned to 100 MHz, as shown on the horizontal axis, the "spurious frequency", in this case the tuned frequency, is shown as 100 MHz on the vertical axis. The upper bold line is the image frequency, 21.4 MHz (twice the IF frequency) above the desired frequency. Note that with a tuned frequency of 100 MHz, the image is at 121.4 MHz.

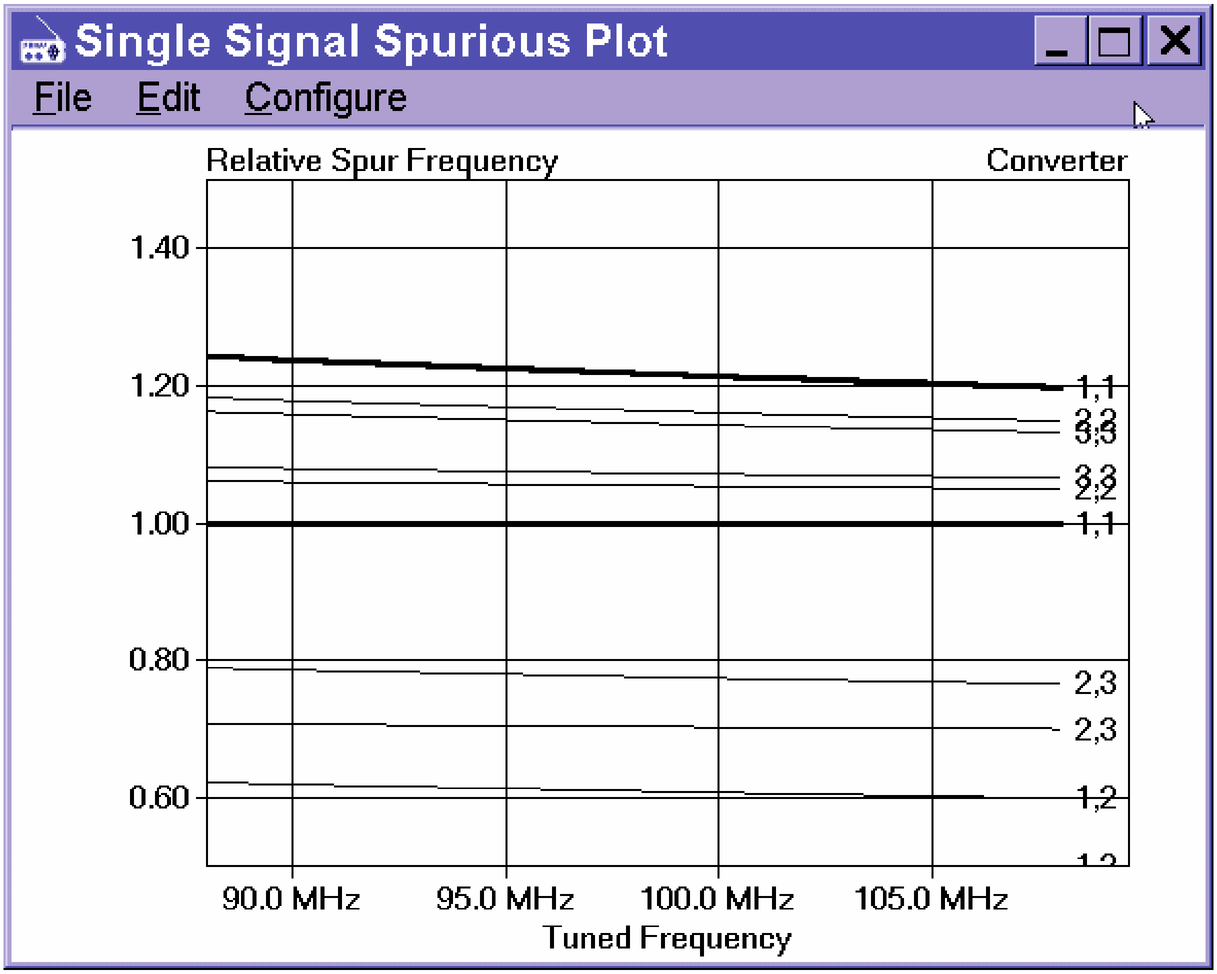
A series of "IF spurs" exist between the tuned frequency and the image frequency, generated from equal harmonics of the RF and LO signals. This series of spurious responses lie at a frequency separation of (n-1)/n from the tuned and image frequencies. For example, the 2x2 IF spur lies at 1/2 the IF frequency above the tuned frequency, and below the image frequency.

At the bottom of the chart are two spurious signals, each due to the second harmonic of the LO signal, and the third harmonic of the RF signal. In particular, with the receiver tuned to 105 MHz, and an LO frequency of 115.7 MHz, the second harmonic of the LO will mix with the third harmonic of an input signal at either 80.7 MHz, or 73.567 MHz, to produce an IF signal at 10.7 MHz.

Notice that the highest tuned frequency is just slightly lower than the lowest image frequency. This is why a fixed tuned bandpass RF filter cannot be used in this application - if it passes the highest signal frequency, it will also pass the lowest image frequency. Instead, we have provided a tuned preselector where the preselector tuned frequency tracks the frequency of the tuned signal, and hence the frequency of the local oscillator.

The rejection characteristics of the preselector are difficult to determine from the above plot, since the preselector is tuned as the receiver is tuned. SInce the preselector has been defined as a fixed percentage bandwidth, we would prefer to display the spurious signal frequencies relative to the tuned frequency.

If we select the Configure|Display menu item, and select the Relative radio button in the Spur Format Dialog, we can get a more meaningful display. Close the Spur Format dialog.



In this display the spurious frequencies are displayed on the vertical axis relative to the tuned frequency. We can see that the image frequency approaches the tuned frequency (as a percentage of the tuned frequency) as the tuned frequency increases. At the closest approach, the image frequency is about twenty percent above the tuned frequency. Thus the preselector module must provide the required image rejection at twenty percent above the tuned frequency.

Close the spurious plot, and dialog windows until you return to the main simulator window.

3.4 Refining the Receiver Description

By defining the receiver in terms of module performance, we've been able to verify the signal to noise ratio performance of the receiver, and plot the spurious susceptibility of the converter stage. By defining module gains, we've established signal levels at several points in the receiver. We could have also evaluated the large signal performance of the receiver by defining the intercept points of the modules.

To continue refining the receiver definition, we'll introduce elements to replace the module parameters presently used to define the module performance.

3.4.1 Refining the Preselector Module

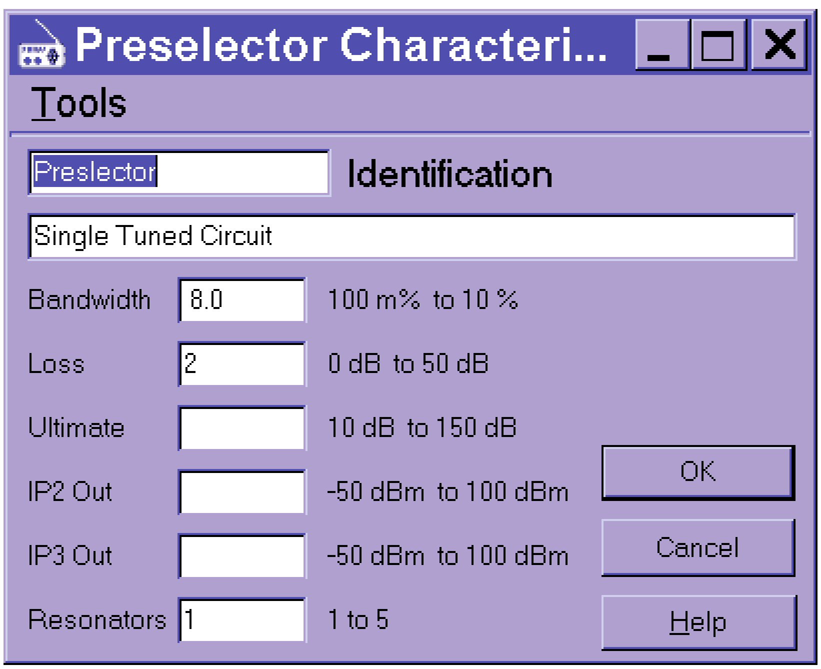
The preselector module was defined with a noise figure of 10 dB, and a gain of 20 dB. In replacing the module parameters, we'll need to come up with a cascade of elements that will meet these requirements. As a minimum, the module will need to contain one or more preselector elements, and one or more amplifiers.

From the main simulator window, select the Edit|Receiver menu item. Double click on the RF Preselector Module, bringing up the RF Presector Module Definition dialog. Select the Edit|Elements menu item on the Module Definition dialog, bringing up the Edit Element dialog. From this dialog, we'll define the two elements that will be included in the RF Preselector module.

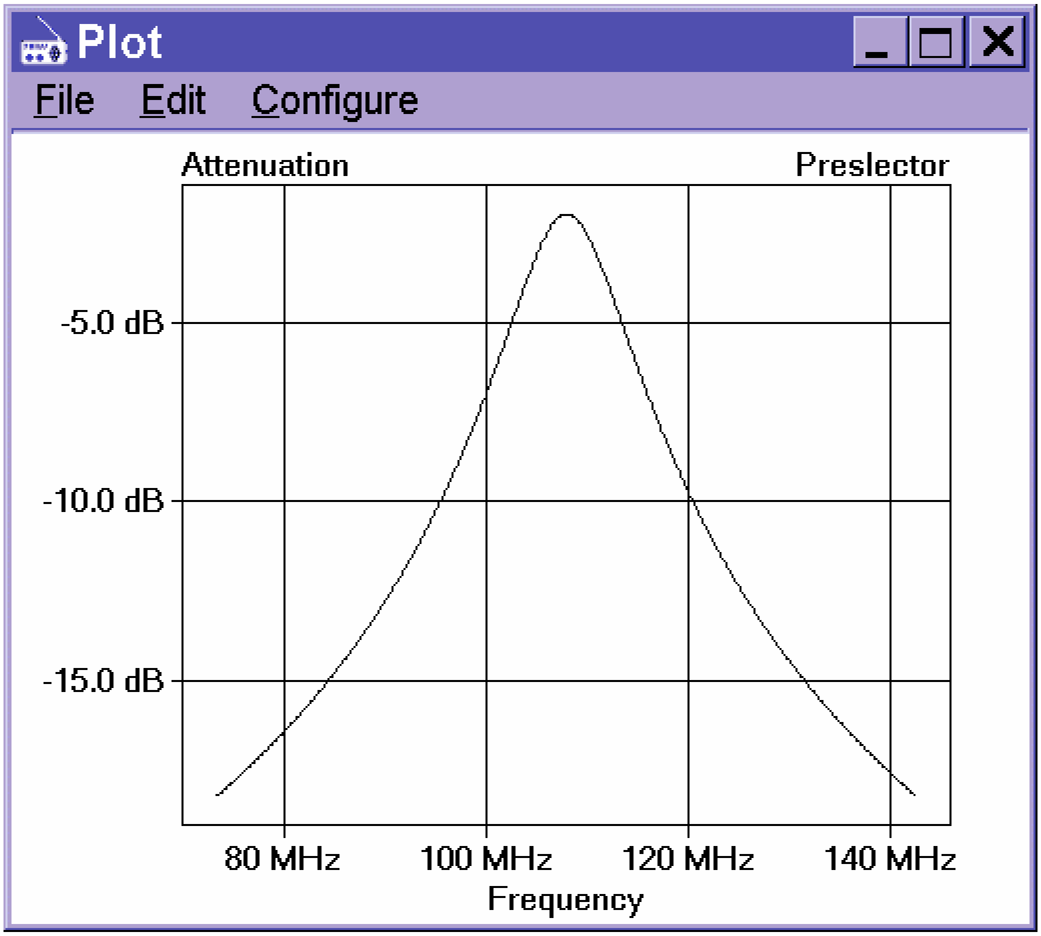
3.4.1.1 Defining the Preselector Element

The Edit Element dialog contains a list box, that is presently empty, because we have not defined any elements. Select the New|Filter|Preselector menu item, bringing up a Preselector Characteristics dialog. Assign a name and description to the preselector element.

Next, define the preselector performance characteristics. We'll select an 8 percent bandwidth, and a loss of 2 dB. Most FM tuners designed in this fashion used two tunable resonators, one in front of the RF amplifier, and one after the RF amplifier. In order to simulate this configuration, we'll define the preselector as a single resonator, and use it twice in the preselector module. The preselector definition should appear similar to this:



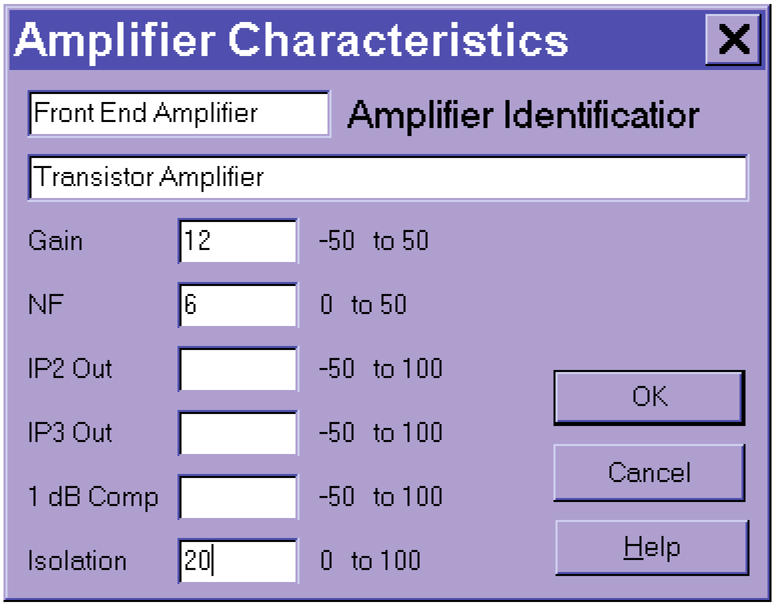
The approximate preselector response can now be viewed by selecting the Tools|Attenuation menu item. When the dialog opens requesting the preselector center frequency, chose 108M, the highest frequency to which the preselector will tune. By looking at the preselector response at 129.4 MHz iamge frequency, we can see that we should expect an image rejection of approximately 14 dB from this single section. With two sections cascaded, we should expect about 28 dB of image rejection. Improved image rejection is available by either increasing the number of tuned circuits, which may be impractical because of tracking requirements, or narrowing the bandwidth of the tuned circuit.



Close the Preselector response window, and add the preselector element to the element library by pressing the OK button on the preselector dialog. Note that the preselector envelope delay could have been displayed as well, from the Tools menu of the preselector dialog.

3.4.1.2 Defining the RF Amplifier Element

Next, select the New|Active|Amplifier menu item, to bring up a new Amplifier Characteristics dialog. Again assign a name and description to the element. Set the gain to 12 dB, and the noise figure to 6 dB. Set the reverse Isolation to 20 dB. The amplifier dialog should look something like this:



Close the Amplifier dialog by pressing the OK button. The Edit Element dialog should now show two elements in the list. Close the Edit Element dialog by pressing the OK button, returning to the RF Preselector Module dialog.

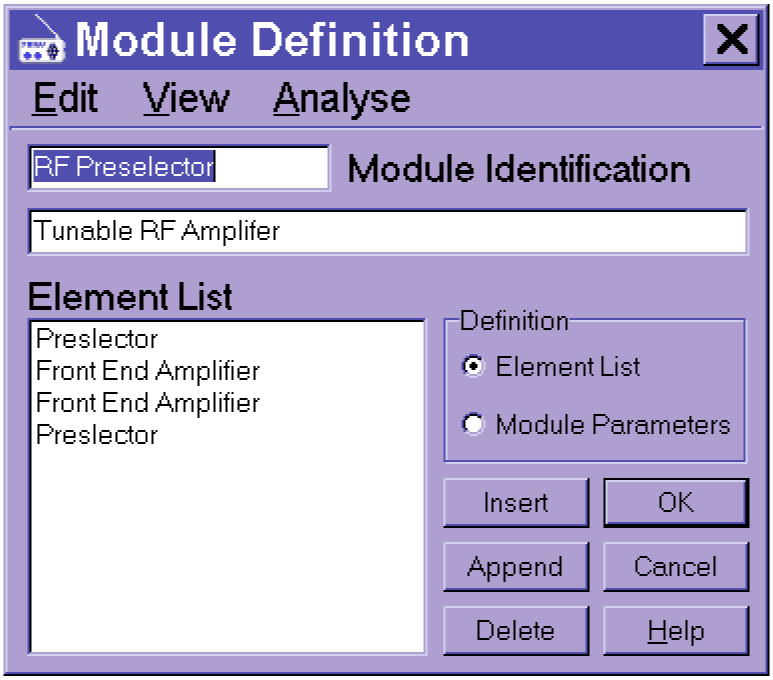
3.4.1.3 Adding Elements to the Preselector Module

At this time, we should be focused on the RF Preselector Module dialog. We'll define the RF Preselector module as a cascade of one preselector section, followed by two RF amplifiers, and another preselector section.

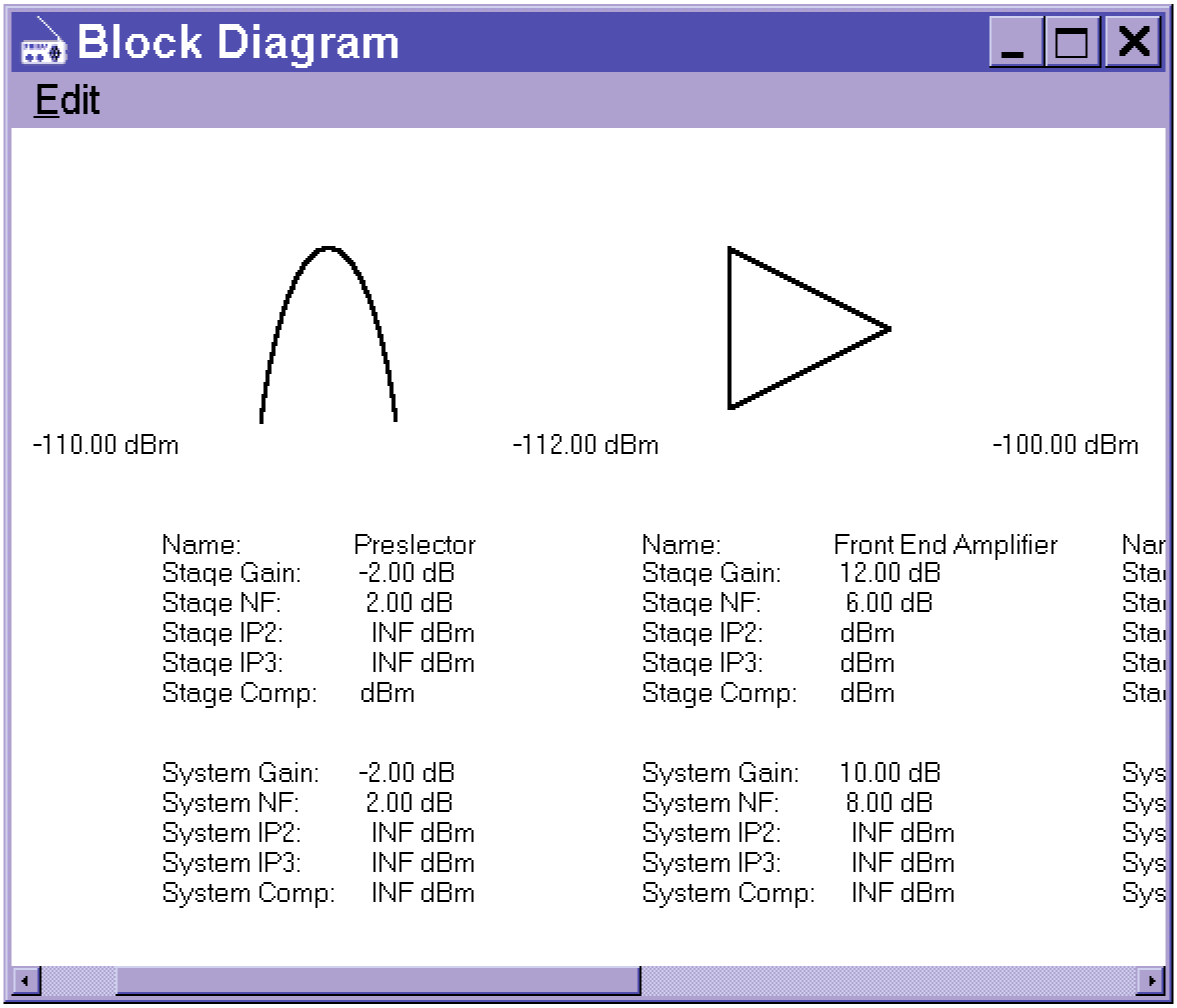
Press the Append button (the Insert button would work just as well here), bringing up the Edit Element dialog. Select the Preselector Element from the Element list box, and press the OK button. The module definition will now show a single Preselector element in the RF Preselector module.

Again press the Append button. This time select the RF amplifer, and press the OK button. The RF Preselector module definition should now show a cascade of the Preselector Element, followed by an RF Amplifier.

Continue by appending another RF amplifier, and finally another Preselector element. The RF Preselector module definition should now show a Preselector element, followed by two RF Amplifiers, and finally another RF Preselector element. Select the Element List radio button in the Defintion box, causing the RF Preselector Module characteristics to be determined from the contained elements, rather than from the module definitions entered earlier.



Selecting the View|Block Diagram menu item should now show the four element cascade that defines the module. Along with the block diagram, also shown are the signal levels along the chain, the block parameters for each element, and the cascaded block parameters, including partial block performance as each new element is appended to the receiver chain. The cascaded system performance shows a module gain of 20 dB, and noise figure of 8.2 dB. The gain meets the design requirements, and the noise figure is less than the requirement.



Note that only the first two stages can be seen in this figure.

The module performance can also be evaluated from the Analysis menu. In particular, several different displays of the block performance are available from the Analysis|Block sub-menu. The different analyses are described elsewhere in this document.

Close the Preselector Module Window by clicking the OK button.

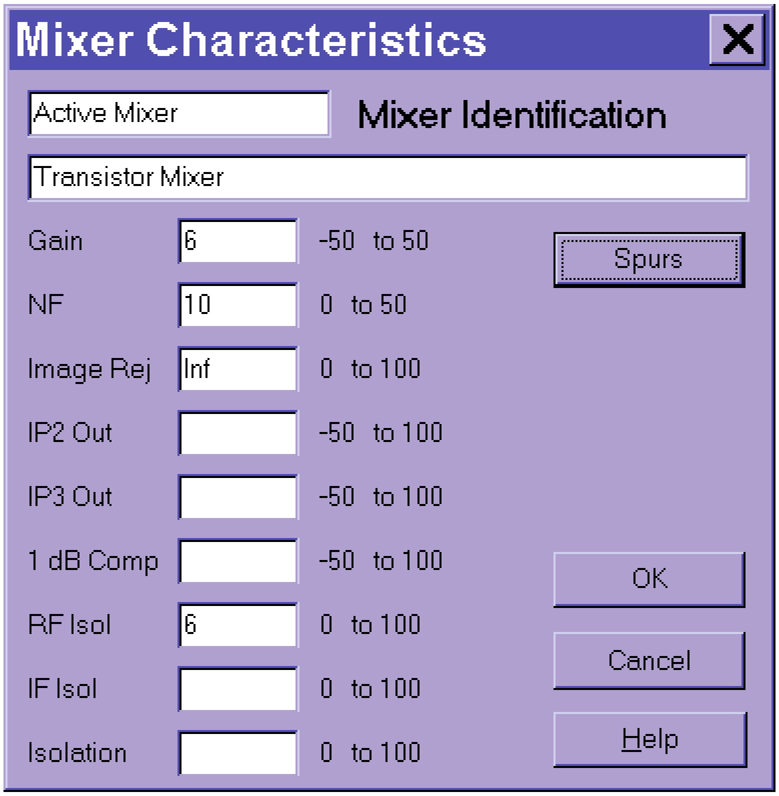
3.4.2 Refining the Converter Module

Inexpensive broadcast receivers generally used some type of active mixer, often just a transistor with the RF signal and LO signal both applied to the same junction. While this technique does not offer excellent signal handling performance, or LO isolation, it is inexpensive, ideal for consumer products.

Open the Converter Module by double clicking on the Converter module in the Modules list. This time we'll define the elements as we are appending them to the Converter Module definition.

3.4.2.1 Defining the Mixer Element

Press the Insert Button, bringing up the Edit Element dialog. Create a Mixier Characteristics dialog by selecting the New|Active|mixer menu item.



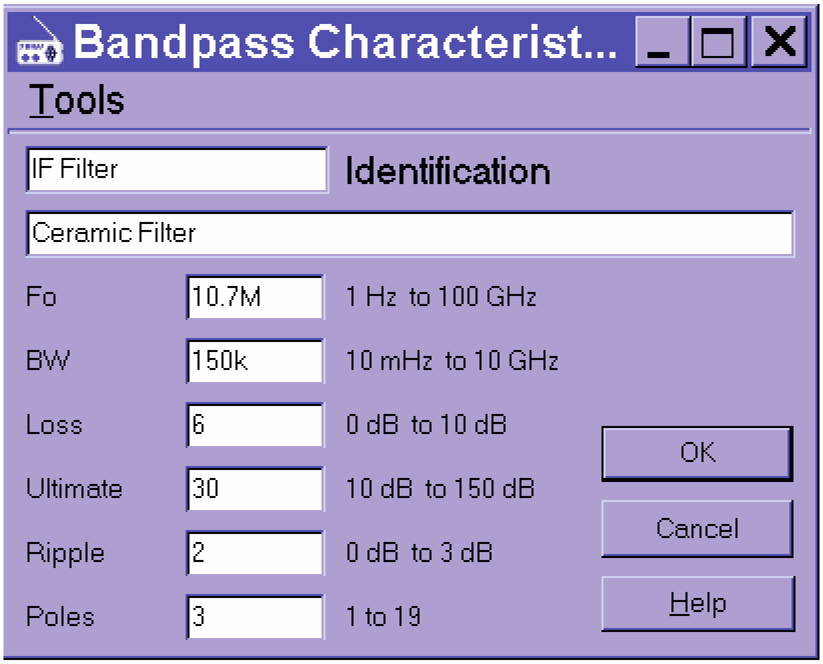
As shown above, define a mixer element with a gain of 6 dB, and a noise figure of 10 dB. Notice that the next item is Image Rejection, which is specified as infinite. Most programs that calculate cascaded noise figure ignor the introduction of image noise. If the Image Rejection parameter is left as infinity, this program should calculate the same noise figure as these other programs. For a more realistic calculation, the image rejection should be set to zero. If an image reject mixer is used, the actual image rejection can be entered here.

The RF isolation, that is the LO to RF isolation, is poor for a single transistor mixer. The 6 dB isolation may actually be more than the mixer delivers.

Click on the OK button, to close the mixer dialog, enterring the mixer element into the element list. The new mixer element will be highlighted in the Element List. Click OK to exit the Edit Element dialog, inserting the new mixer element into the module definition.

3.4.2.2 Defining the IF Filter Element

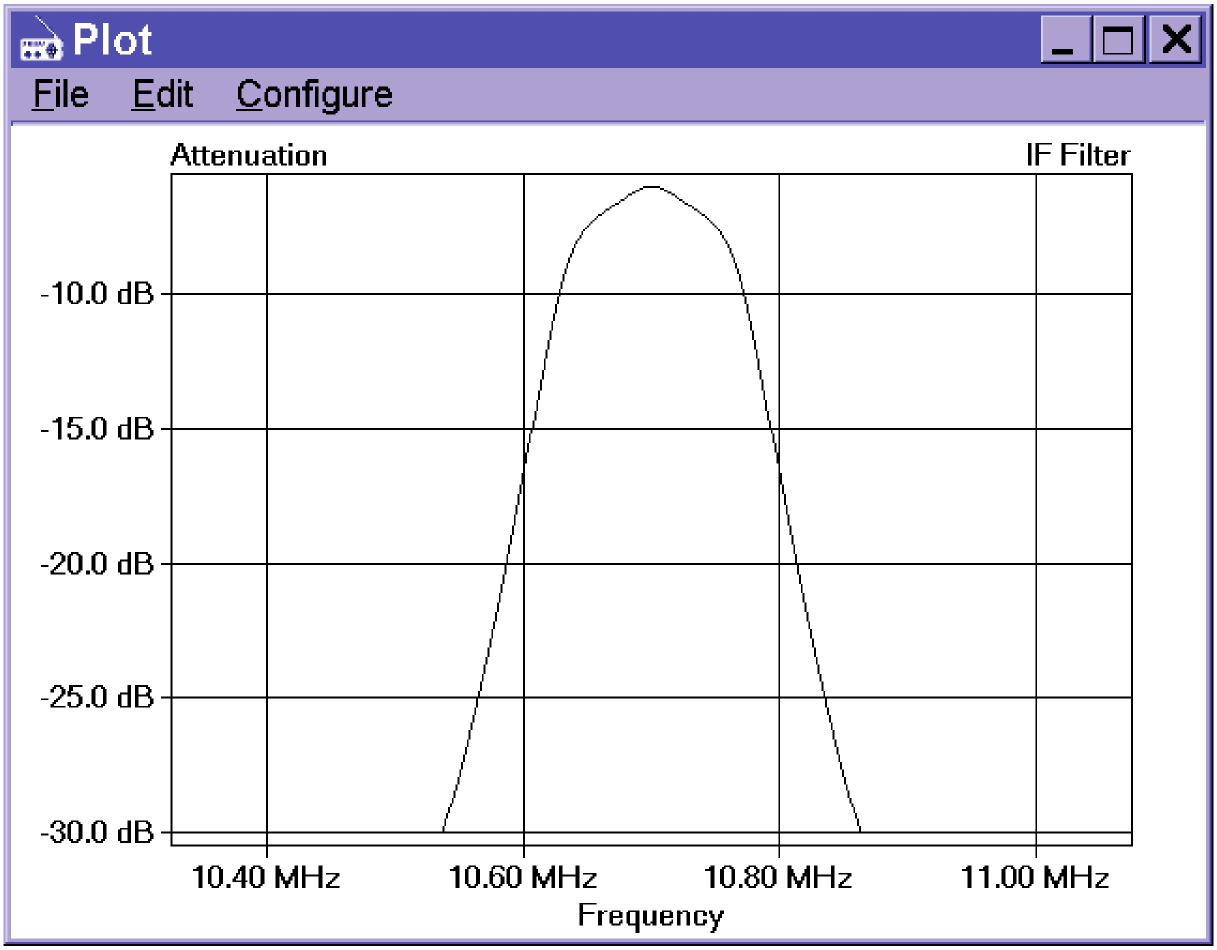
Next press the "Append" button to again bring up the Edit Element dialog. Open a Bandpass Filter definition dialog window by selecting the New|Filter|Bandpass menu item.



A simple IF filter would consist of a ceramic filter at 10.7 MHz. In this example we've defined the bandpass filter element with a 150 kHz bandwidth, and three resonators (Poles). The loss is specified as 6 dB, and the as 2 dB.

The ultimate rejection has been specified as 30 dB. Typically the filter will provide more rejection than this, but this minimum value will be used to determine the filter rejection when calculating leakage around the filter.

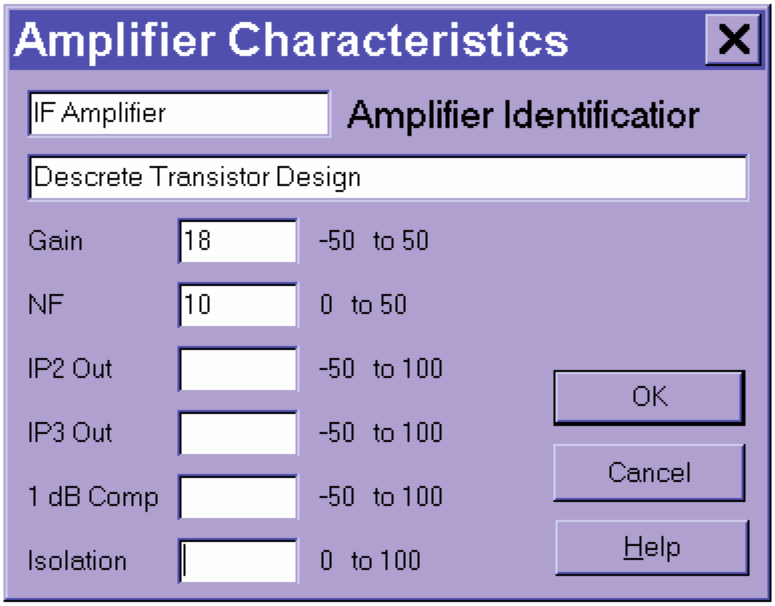
The Tools menu can be used to plot either the amplitude or group delay response of the filter at this time. The amplitude response is quite rounded in the passband because of the large loss.



Close the plot. Close the IF Filter dialog by pressing the OK button. Append the IF filter to the converter by clicking the OK button on the Edit Element Dialog.

3.4.2.3 Defining the IF Amplifier

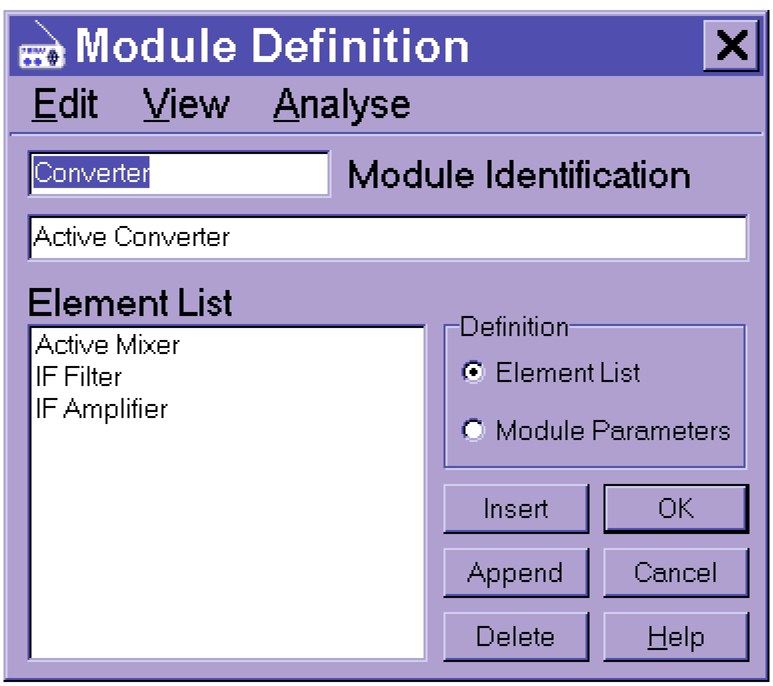
Once again press the "Append" button to again bring up the Edit Element dialog. Open an amplifier definition dialog window by selecting the New|Active|Amplifier menu item.



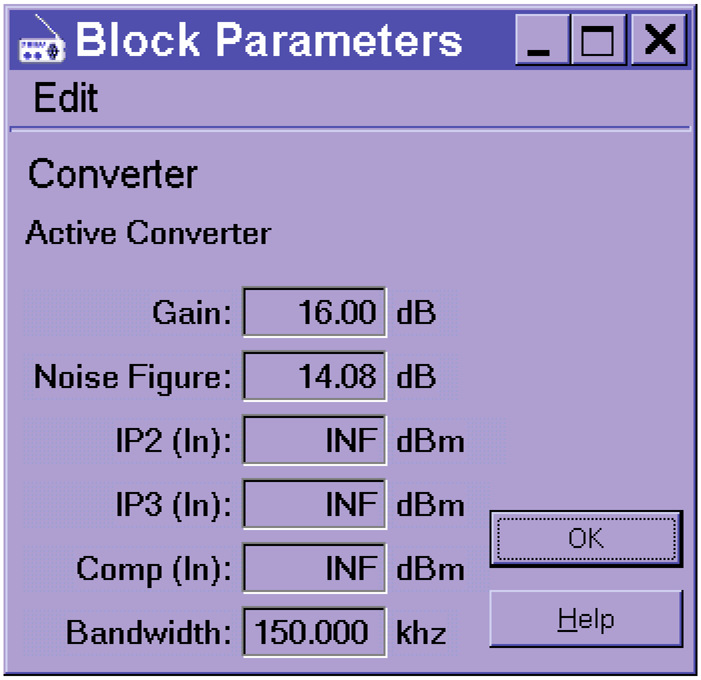
Define an amplifier element with a gain of 18 dB, and a noise figure of 10 dB. We won't define any of the other parameters at this time.

Close the Amplifier Characteristics dialog by clicking the OK button. Append the amplifier to the module definition by clicking the OK button on the Edit Element dialog.

3.4.2.4 Converter Module Performance



Make sure that the Element List radio button is selected in the Module Definition dialog. Then select the Analysis|Block|Summary menu item to display a summary of the module characteristics, based on the three contained elements.



The gain is quite a bit below the 20 dB we had specified in the module definition, and the noise figure is slightly less than the 15 dB we had specified. Rather than attempt to increase the gain by 4 dB, we'll try to compensate by adding an additional 4 dB of gain in the IF Module.

Close the Block Parameter summary window, and the Converter Module dialog by clicking the OK button in each window.

3.4.3 Refining the IF Module

The IF module will contain a cascade of limiters. In general, these limiters would be designed somewhat differently than a typical amplifier used for unsaturated gain. However, for this simulation we'll use the same IF amplifier as we have already designed.

It is normal in an FM receiver to include a "roofing filter" just prior to the receiver detector. This is a low order filter, often just two resonators, whose function is to limit the noise bandwidth of the signal just before it is processed by the detector.

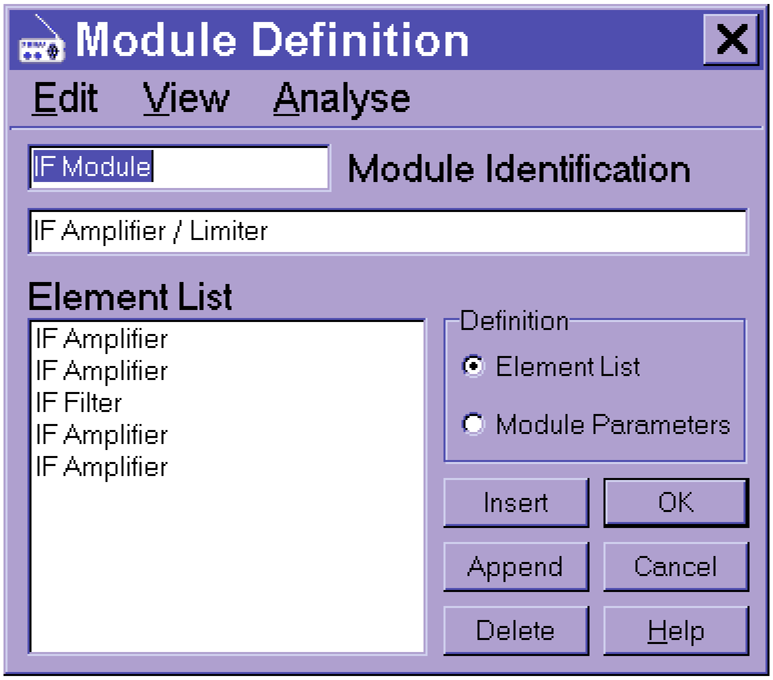
Because the first filter contains only three resonators, we would like to place same IF filter as the roofing filter. Because it is providing a significant part of the IF filtering function, we'd like to move it a bit forward in the IF chain. This is to prevent large signals on other channels from capturing the receiver. This will cause some compromise in the wideband noise rejection, but improve the signal handling capability of the receiver.

3.4.3.1 Adding Elements to the IF Module

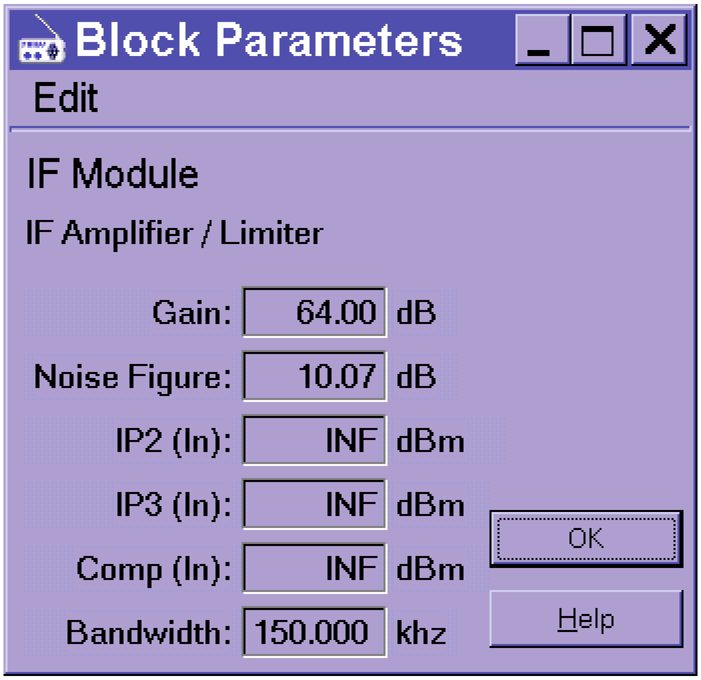
Open the IF Module Definition dialog by double clicking on the IF Module in the Module list. Press the Insert button to bring up the Edit Element dialog. Select the IF Amplifier Element, and press the OK button. The IF Amplifier Element should now appear in the Element List.

Press the Append button, to again bring up the Edit Element dialog. Since the IF Amplifier element is already highlighted, press the OK button to append a second IF amplifier to the IF Module.

Again press the Append button. This time highlight the IF Filter element, and press the OK button, appending the IF filter to the IF module.



Similarly, append two more IF amplifiers to the IF module. Make sure that the Element List radio button is selected. Select the Analyse|Block|Summary button to display the module block parameters. Notice that the IF module achieves a gain of 64 dB, just making up for the 4 dB shortfall in the Converter module, with a noise figure well below the noise figure of 20 dB that we specified int the original module definition.



Close the Block Summary window, the IF Module window, and the Receiver Modules window by clicking on the OK button of each window. Save the receiver file.

3.5 Additional Analyses

Once the receiver has been defined by it's contained elements, rather than by parameters defining the three modules, additional analyses can be performed.

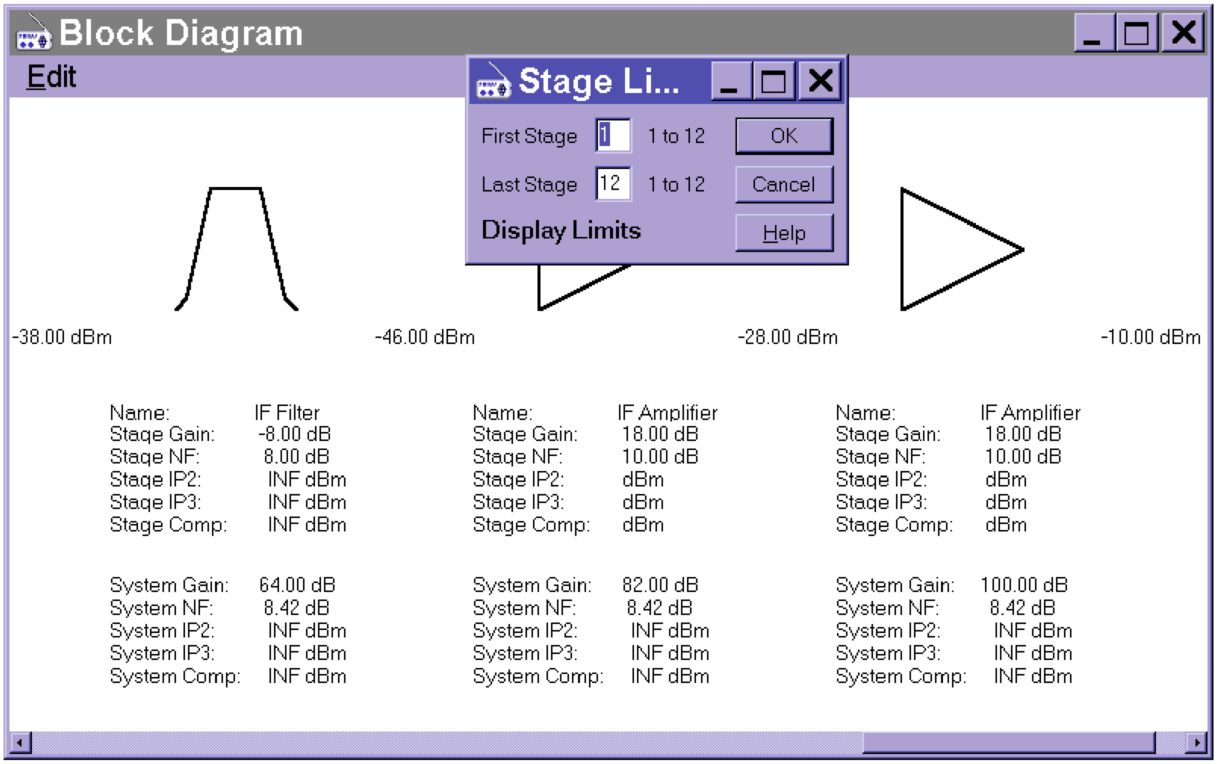
Cascaded and normalized block parameters can be displayed to evaluated the performance of each element in the receiver. The block diagram can be displayed, also showing the cascaded block parameters. And the LO rejection can be calculated.

In addition, it might be instructive to return to the SNR plot, to verify that the cascaded performance is acceptable, as the performance has changed slightly as we've gone from the module definition to the element definition.

3.5.1 Block Diagram

At this time the receiver Block Diagram can be displayed.

From the Simulator main window select the View|Block Diagram menu item. The receiver block diagram, along with individual and cascaded block parameters will be displayed in a window that can be scrolled left and right.



This example shows the lst three stages of the receiver block diagram. The top set of block parameters represent the parameters for each individual stage. The bottom set of parameters show the cumulative characteristics. As shown, the receiver noise figure has degraded to 8.2 dB after the signal has passed through the first three blocks.

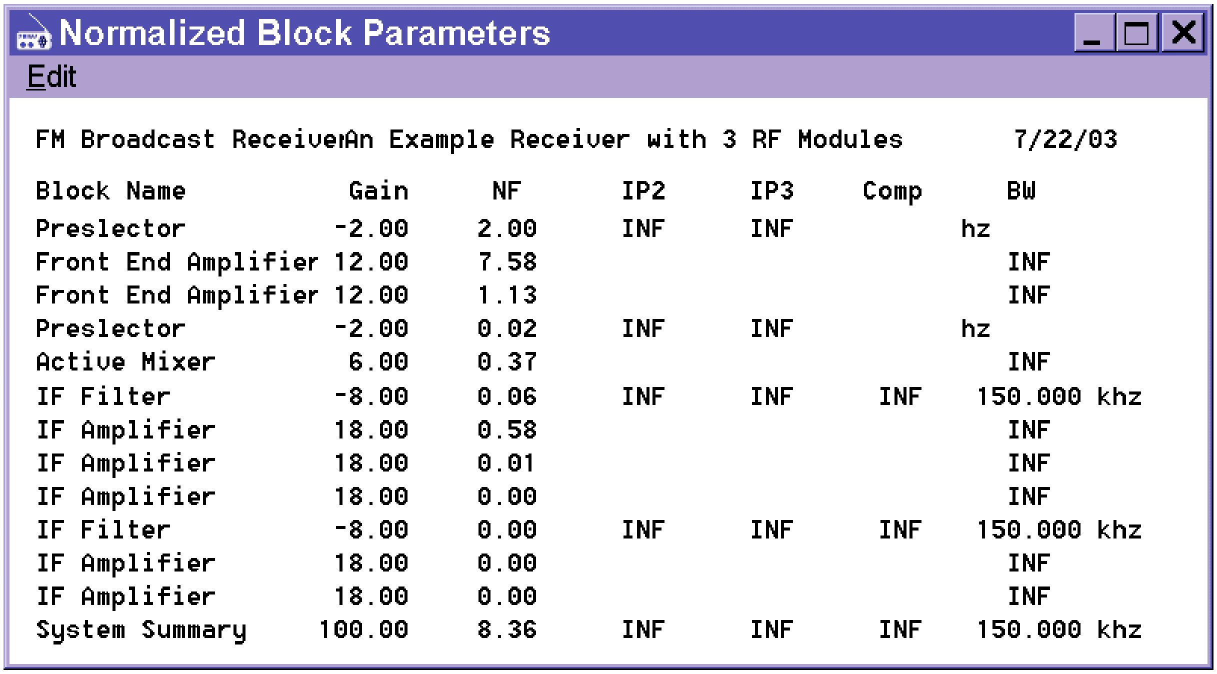
The Edit menu can be used to copy part, or all of the block diagram into the clipboard, for pasting into another document. In general, the block diagram should be copied as several groups of blocks, perhaps corresponding to the three modules. If the entire receiver is copied to the clipboard at once, it will probably be too long to paste into a document while maintaining a legible display. The above figure shows the limits dialog, which can be used to select which elements will be displayed. It is accessing by selecting the Edit|Set Limits menu item.

Block diagrams can also be displayed and copied from each of the three modules, but the cascaded block diagram will be relative to the input of the module, rather than the input of the receiver.

Close the block diagram.

3.5.2 Normalized Parameters

The normalized block parameters can be displayed by selecting the Analysis|Block|Normalize menu item:



FM Broadcast ReceiverAn Example Receiver with 3 RF Modules 7/22/03

Block Name	Gain	NF	IP2	IP3	Comp	BW
Preselector	-2.00	2.00	INF	INF		hz
Front End Amplifier	12.00	7.58				INF
Front End Amplifier	12.00	1.13				INF
Preselector	-2.00	0.02	INF	INF		hz
Active Mixer	6.00	0.37				INF
IF Filter	-8.00	0.06	INF	INF	INF	150.000 khz
IF Amplifier	18.00	0.58				INF
IF Amplifier	18.00	0.01				INF
IF Amplifier	18.00	0.00				INF
IF Filter	-8.00	0.00	INF	INF	INF	150.000 khz
IF Amplifier	18.00	0.00				INF
IF Amplifier	18.00	0.00				INF
System Summary	100.00	8.36	INF	INF	INF	150.000 khz

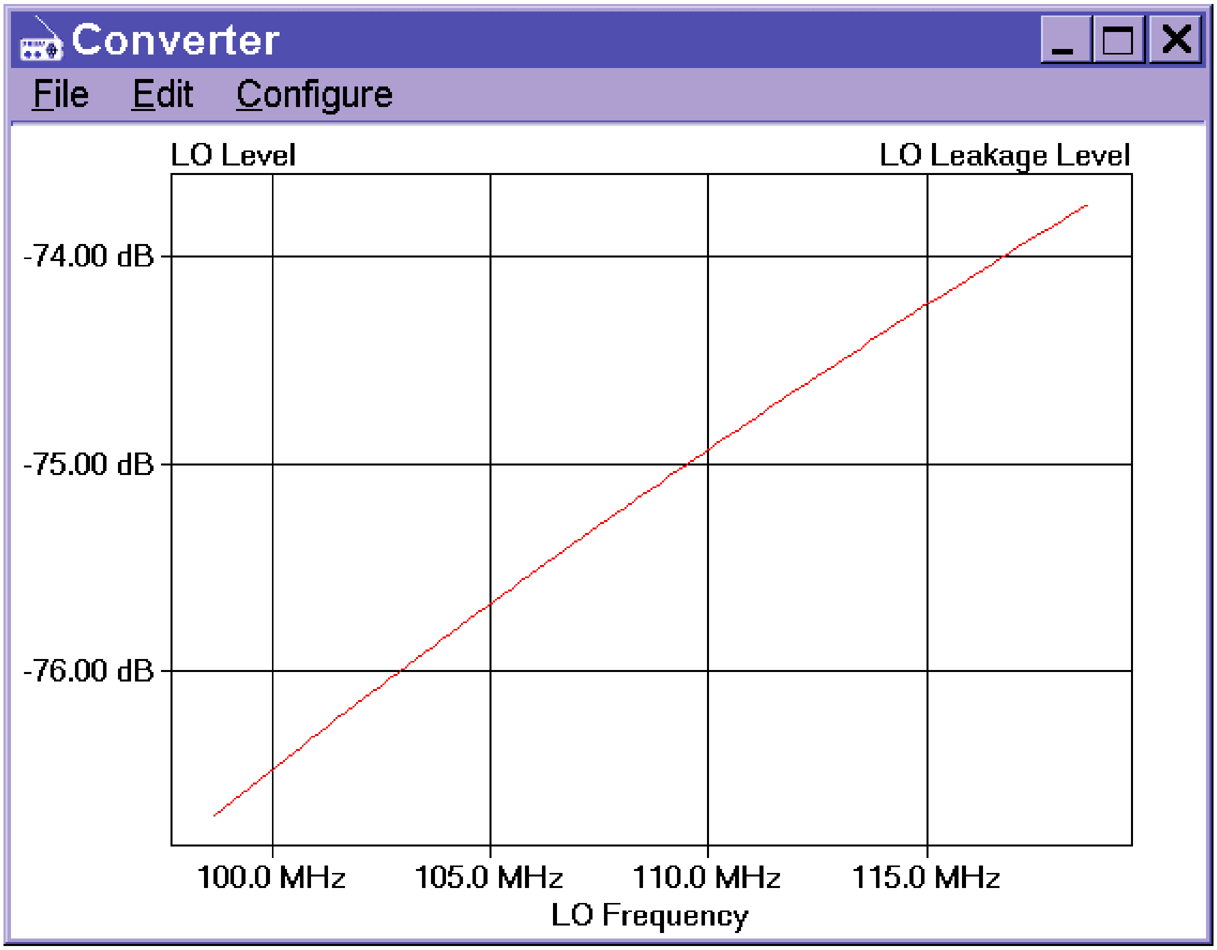
This display shows the block parameters for each element normalized to the input. The System Summary, at the bottom, is the cascaded performance for the entire receiver.

Looking at the noise figure (NF) column, the cascaded noise performance of the receiver is 8.36 dB. As shown in the NF column, a noise figure of 7.58 dB would result if only the noise contribution of the first Front End Amplifier were considered (all other elements are assume to contribute no noise to the receiver.) Using this anaysis, it's easy to see that the noise figure is set primarily by this amplifier. Noise contribution from the second IF amplifier and beyond is insignificant.

Although we have not defined any second or third order intercept points in this receiver, the contribution of each element to these intercept points would be apparent in this display as well.

3.5.3 LO Leakage

As a final analysis, we can display the LO leakage plot of this receiver by selecting the Analysis|LO Leakage menu item on the simulator main window:



Note that, as the receiver tuned frequency tunes from 88 to 108 MHz, the LO frequency tunes from 98.7 to 118.7 MHz, as shown above. The LO leakage degrades as the tuned frequency increases. This is because the preselectors are a fixed percentage bandwidth. As the tuned frequency increases, the filter bandwidth increases, exhibiting a lower rejection at the LO frequency.

3.6 Example Summary

This FM Receiver Example has shown us how to start with a basic receiver concept, defined by cascading Receiver Modules, selecting parameters to represent each module. The potential presence of spurious signals could be identified by defining the frequency plan for each converter module. Signal to noise performance could be evaluated by selecting the SNR plot.

Once the individual module performance was acceptable, each module was fleshed out with elements, corresponding to the individual stages contained in each module. When this process was completed, the cascaded performance was be evaluated, based on the element definitions. During the process module performance was modified slightly, to account for the actual performance of the contained Elements. For example, the gain distribution was changed slightly, pulling some gain out of the converter module, and moving it into the the IF module.

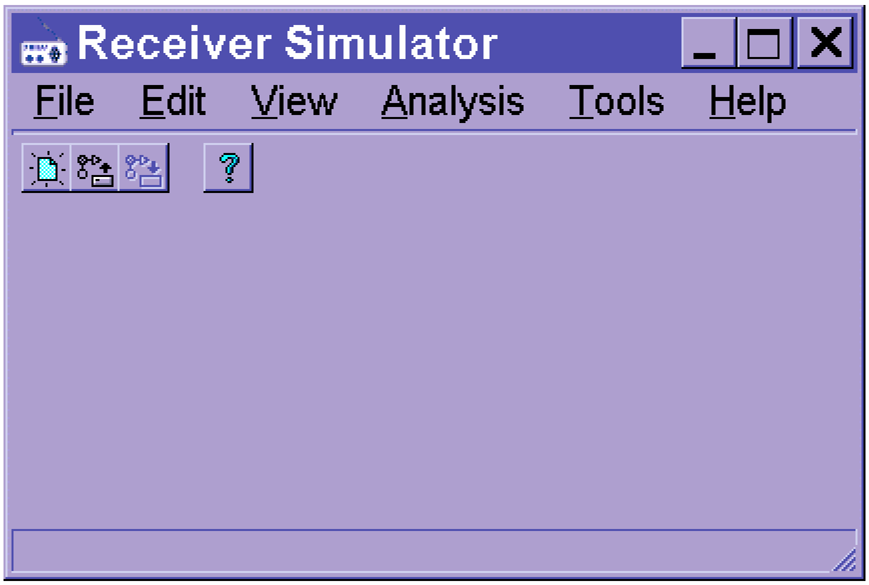
When the receiver definition is complete, various performance characteristics, and graphics, can be copied over into the clipboard, for insertion into other documents.

Having gone quickly through an example receiver, we'll now look at the process of building a receiver in greater detail.

4 Building a Receiver

The process of building a receiver involves defining modules, and elements to be contained in those modules. Before looking at how this is done, we'll examine the main simulator window, and the menu items available.

4.1 Receiver Simulator Window



When the Receiver Simulator application is opened, the Receiver Simulator window shown above will appear on the screen. Access to the simulator and analysis routines is through the main menu contained on this window. Appearing below the menu are speed buttons for creating a new receiver definition, opening an existing receiver definition file, or saving an existing receiver definition, along with a speed button used to open this help file.

At the bottom of the window is a status bar, used primarily for displaying "hint" messages as the user moves the cursor around.

The client area of the window is not used for any purpose at this time.

The main menu contains six menu items. These menu items are described in the following topics.

4.2 Simulator File Menu

The File menu provides commands to create a new Receiver, retrieve an existing Receiver definition, save the present Receiver definition, and exit the application.

New:

This command opens a new, untitled Receiver Definition. The application will prompt you to name the untitled definition when it is saved.

Open:

This command displays the Open File dialog so you can select a Receiver Definition File to load into the simulator.

Save:

This command saves the current Receiver Definition to disk. If the Receiver is unnamed, the Save File As dialog box is displayed so you can name the File, and choose where it is to be saved.

Save As:

This command allows you to save a Receiver Definition under an new name, or in a new location on disk. The command displays the Save File As dialog box. You can enter the new file name, and select the drive and directory.

Exit:

This command exits the Receiver Simulator. If you've modified the current Receiver Definition without saving, you'll be prompted to save before exiting.

4.3 Simulator Edit Menu

The edit menu is the pathway to editing any of the receiver parameters. The following submenu items appear under the Edit Menu.

Receiver

Selecting this menu item will open the Receiver Module dialog, allowing the user to create, modify, or delete the RF modules that form the receiver signal chain.

Panel

Selecting this menu item will open the Receiver Front Panel dialog, allowing the user to modify the AGC control voltage range, input signal range, and receiver tuned frequency.

Input Signal

Selecting this menu item will open the Input Signal dialog, allowing the user to define the input signal frequency, amplitude, and other characteristics.

Demodulator

Selecting this menu item will open the Receiver Signal Demodulator dialog, allowing the user to set up the desired demodulator characteristics for the receiver.

AGC Detector

Selecting this menu item will open the Receiver AGC Detector dialog, allowing the user set the characteristics of the receiver's AGC detector.

Element

Selecting this menu item will open the Edit Element dialog, allowing the user to create, modify, or delete the elements that will be included in the RF Modules to form the receiver signal chain.

4.4 Simulator View Menu

The view menu allows the user to display the receiver block diagram, and print or copy to the clipboard.

Receiver Modules

Selecting this menu item will display the receiver configuration as a cascade of RF modules. The modules are defined as either fixed frequency, such as an IF stage, variable frequency, such as a tuned preselector, or converter. Additionally, the diagram will display frequency information, and may display the module block parameters as well. This display would normally be selected to show the system details of the receiver.

Block Diagram

Selecting this menu item will display the receiver configuration as a cascade of elements. Because the number of elements can be quite large, thie block diagram display will usually scroll from left to right. The block diagram will also display the block parameters of each stage, and the cascaded block parameters for the receiver (this is the same as the Cumulative block parameters available from the Analysis Menu) , along with signal levels between stages.

4.5 Simulator Analysis Menu

The analysis menu is the pathway to performing various analyses on the entire receiver. Many of these menu choices duplicate the menu choices avalable in the Receiver Modules dialog.

Block|Summary

Selecting this menu item will display a summary of the cascaded block parameters of the receiver.

Block|Expanded

Selecting this menu item will display a table showing the block parameters of each block contained in the receiver.

Block|Cumulative

Selecting this menu item will display the cumulative block parameters of the receiver in a table.

Block|Normalize

Selecting this menu item will display a a table of the normalized block parameters for each block contained in the receiver.

Block|Plot

This menu item displays several sub-menus that allow the user to plot the block parameters of the receiver as a function of the AGC voltage.

LO Leakage

Selecting this menu item will display a plot of the local oscillator leakage at the input of the receiver. The LO leakage is plotted for every module in the receiver containing a mixer and local oscillator.

SNR

Selecting this menu item will display a plot of the receiver's signal to noise characteristics as a function of the input signal.

Bit Error Rate

Selecting this menu item will display a plot of the receiver's bit error rate as a function of the input signal.

4.6 Simulator Tools Menu

The tool menu is the pathway to using some of the analysis and calculation tools available in the receiver toolbox. These tools are used independent of a receiver simulator, to perform calculations useful in designing a receiver.

System|Calculate BER

Selecting this menu item will allow the entry of parameters required to calculate the Bit Error Rate of a receiver.

System|Calculate SNR

Selecting this menu item will allow the entry of parameters required to calculate the Bit Error Rate of a receiver.

Components|PI Attenuator

Components|T Attenuator

Selecting these menu items will allow the calculation of the resistor values to create a PI or T attenuator of the desired attenuation and impedance.

4.7 Simulator Help Menu

The help menu allows several selections for the user to obtain help on the simulator program.

Contents

Displays this help file's Table of Contents.

Search for Help On

Brings up the Index for this help file.

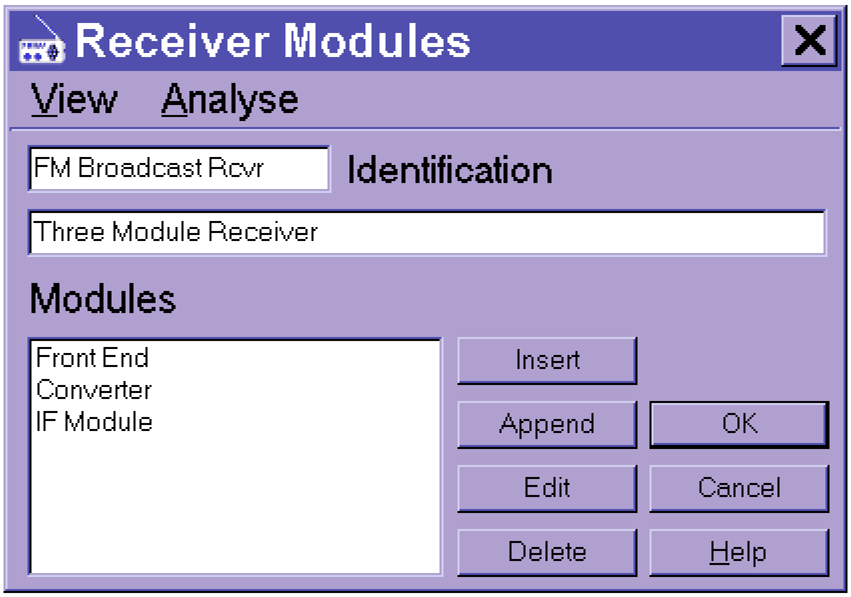
How to Use Help

Displays this a Help Files describing the use of the Help Engine.

About

Displays the programs About dialog.

4.8 Receiver Modules Window



The Receiver Modules dialog is opened by selecting "Edit|Receiver" on the Receiver Simulator main window.

At the top of the "Receiver Modules" dialog box are edit boxes for the receiver name, and a short description of the receiver. Below that is a list showing all the RF Modules presently defined for the receiver. They will be cascaded in the order listed. A row of buttons to the right of the Modules list allows the user to Insert or Append a new RF Module, Edit an existing Module, or Delete an existing RF Module.

The View menu allows a selection to display either a Receiver Module Diagram, or a Block Diagram of the receiver.

The Analysis menu allows a variety of block analysis options.

The following discussions assume that the Receiver Modules dialog is open.

4.9 Creating a new RF Module

The first RF Module is created by pressing the "Append" or "Insert" button on the Receiver Modules dialog, bringing up the Module Definition]dialog. The first items to be entered should be a module name, and a short description of the module. The module will be identified by it's name as defined here.

At this point, we'll assume that we want to define the RF Module block parameters. To open the Module Parameters dialog, select the "Edit|Module Parameters" menu item from the Module Definition dialog. A dialog will open, allowing the user to define the block parameters of this new RF Module. Note in the lower left corner that the default RF module is a Fixed Frequency module. Alternative choices are Converter, and Variable Frequency. Most IF stages will be "Fixed Frequency". An RF stage (and some IF stages) containing tuned preselectors or filters, should be defined as "Variable Frequency".

Upon closing the Module Parameters dialog and Module Definition dialog, the Receiver Modules dialog box will become active again. Additional RF Modules may be appended to the receiver chain by pressing the Append button, and defining the new RF Module. RF Modules may be inserted anywhere in the chain by highlighting a module, and pressing the Insert button, to create a new module, to be inserted in front of the highlighted module.

At this time there is no way to change the module order, other than deleting a module, and redefining it at the correct location.

During simulations, the RF Modules will be cascaded in the order in which they appear in the RF Module List.

4.10 Editing an RF Module

An Existing RF Module can be edited by selecting opening the Receiver Modules dialog by selecting "Edit|Receiver" from the main menu. A list of existing RF Modules will be displayed in the Receiver Modules list box. Select an RF Module to edit by double clicking on it's name, or highlighting the name and pressing the "Edit" button.

An existing RF Module can be deleted from the receiver by highlighting the name in th Receiver Modules list box, and pressing the "Delete" button.

4.11 Receiver Analysis Menu

The analysis menu is the pathway to performing various analyses on the cascade of the receiver modules. They duplicate the block analysis options available on the main receiver simulator window.

Block|Summary

Selecting this menu item will display a summary of the cascaded block parameters of the receiver.

Block|Expanded

Selecting this menu item will display a table showing the block parameters of each block contained in the receiver.

Block|Cumulative

Selecting this menu item will display the cumulative block parameters of the receiver in a table.

Block|Normalize

Selecting this menu item will display a a table of the normalized block parameters for each block contained in the receiver.

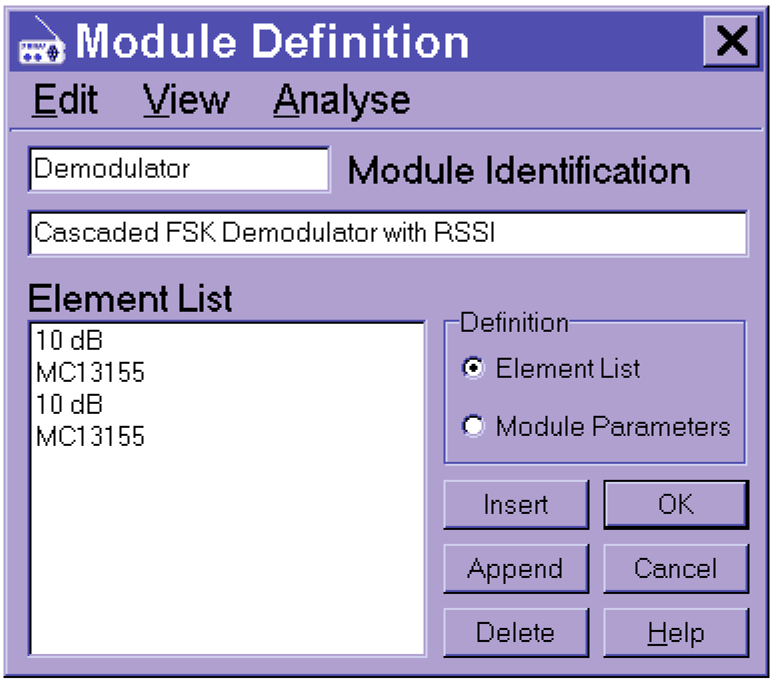
Block|Plot

This menu item displays several sub-menus that allow the user to plot the block parameters of the receiver as a function of the AGC voltage.

4.12 Receiver View Menu

The Receiver View menu duplicates the View Menu on the main Receiver Simulator Window.

4.13 Module Definition Dialog



The Module Definition dialog is opened by double clicking on an RF Module name in the Receiver Modules dialog, or by highlighting an RF Module name and pressing the Edit button.

At the top of the "Module Definition" dialog box are edit boxes for the RF Module name, and a short description of the RF Module. Below that is a list showing all the Elements contained in this RF Module. They are cascaded in the order listed. A row of buttons to the right of the Modules list allows the user to Insert, Append, or Delete existing elements from the RF Module. Note that defined Elements cannot be modified directly from this dialog.

The menu on this window allows the user to perform several types of analysis of this RF Module, display two formats of block diagram for this RF Module, or edit several aspects of this Module.

The following discussions assume that the Module Definition dialog is open.

4.14 Module Edit Menu

The edit menu is the pathway to editing any of the Module parameters, including frequency plan and local oscillator description.

LO

Selecting this menu item will open the Local Oscillator dialog, allowing the user to edit the parameters of the local oscillator used in this module. The module must be defined as a converter before the user will be allowed to edit the LO description.

Freq Plan

Selecting this menu item will open the Frequency Plan dialog, allowing the user to modify this module's frequency plan. The module must be defined as a converter before the user will be allowed to edit the Frequency Plan.

Elements

Selecting this menu item will open the Edit Element dialog, allowing the user to define or modify element descriptions. The new or modified elements can then be added to the module description using the buttons on this window.

Module Parameters

Selecting this menu item will open the Module Parameters dialog, allowing the user to change the defined parameters of this module. For these parameters to be used, the module must be represented by these parameters, rather than any contained elements. (The Module Parameters radio button in the Module Definition dialog must be selected.)

4.15 Module View Menu

The view menu allows the user to display the module block diagram, and print or copy to the clipboard.

Module

This menu item will display a block diagram of this RF Module, in the same format as used for the receiver block diagram.

Block Diagram

This menu item will display a block diagram of this RF Module, displaying each element contained in the module as a block.

4.16 Module Analysis Menu

The analysis menu is the pathway to performing various analyses on this RF module.

Block|Summary

Selecting this menu item will display a summary of the cascaded block parameters of this RF module.

Block|Expanded

Selecting this menu item will display a table showing the block parameters of each block contained in this RF module.

Block|Cumulative

Selecting this menu item will display the cumulative block parameters of this RF Module in a table.

Block|Normalize

Selecting this menu item will display a a table of the normalized block parameters for each block contained in this RF module.

Block|Plot

This menu item displays several sub-menus that allow the user to plot the block parameters of this RF module as a function of the AGC voltage.

LO Leakage

Selecting this menu item will display a plot local oscillator leakage at the input of the module. The module must be defined as a converter.

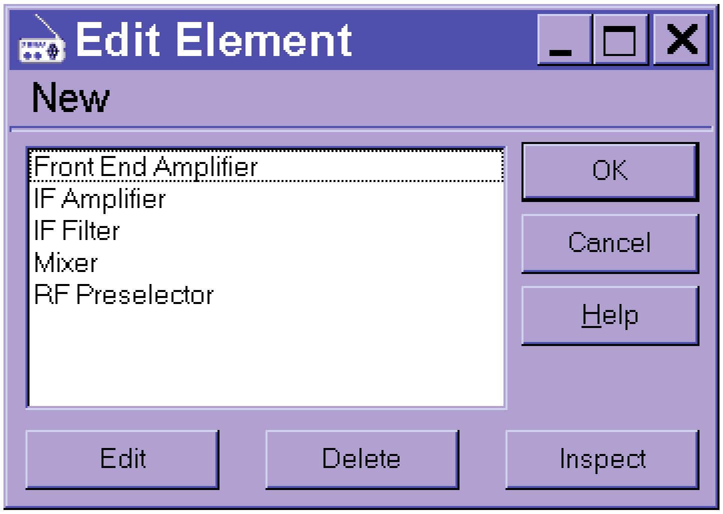
Spurious Susceptibility

Selecting this menu item will display a plot of the single signal spurious frequencies for this module. The module must be defined as a converter for this menu item to be meaningful.

Birdies

Selecting this menu item will display a plot of the birdies, or self quieting spurious signals, for this module. The module must be defined as a converter.

4.17 Edit Element Dialog



The Edit Element dialog is opened by selecting "Edit|Element" from the Receiver Simulator main window.

The Edit Element dialog box contains a list showing all the Elements presently defined in this simulation. This list is also referred to as the Element Library. Buttons at the bottom of the list allow the user to edit or delete Elements in the list, or inspect the block parameters for an element in the list.

The "New" menu item allow the creation of a new Element for use in the simulation. These elements are grouped into several catagories under the "New" menu item.

The following discussions assume that the Edit Element dialog is open.

4.18 Creating a New Element

To create a new element from the Edit Element dialog, select an element by selecting the "New" menu item, and then one of the catagories, and finally an element type. For example, to create a new amplifer element, select New|Active|Amplifier from the menu.

The appropriate Element dialog box will open, allowing you to define the new Element. You should first enter a name and short description for the Element. The Element name will be used to identify the Element in the RF Module list. You can then modify the various parameters defining the Element. Clicking "OK" will close the Element dialog and add the new Element to the Element Library.

The new Element will be listed in the Edit Element dialog list box along with the other defined elements. They will be listed in alphabetical order by the names defined in the Element Dialogs.

4.19 Editing an Element

An Existing Element can be edited by selecting an Element in the list box of the Edit Element dialog, and double clicking on it's name, or by highlighting the Element and clicking the Edit button.

An Existing Element can be deleted by highlighting an Element in the list box. Press the 'Delete' button to remove the Element from the List.

You can check the block parameters of the highlighted element by pressing the Inspect button. The block parameters, referred to the input of the element, will be displayed.

5 Element Descriptions

Elements are the most basic definitions contained in the Receiver Simulator. Elements correspond to the stages, or blocks contained in the receiver. Mixers, amplifiers, and filters are examples of elements in this simulator program.

5.1 Basic Element Types

The simulation is built from these basic element types:

Attenuator:

A linear attenuator.

Amplifier:

An amplifier characterized by it's gain, noise figure, second and third order intercept points, compression, and isolation.

AGC Amplifier:

Similar to the amplifier element, except that the characteristics are a function of the system AGC voltage, and isolation is not defined.

Mixer:

A mixer characterized by it's gain, noise figure, second and third order intercept points, compression, image rejection, and isolation.

Lowpass Filter:

A Butterworth or Chebyshev lowpass filter characterized by it's cutoff frequency, loss, ripple, and number of poles.

Highpass Filter:

A Butterworth or Chebyshev highpass filter characterized by it's cutoff frequency, loss, ripple, and number of poles.

Bandpass Filter:

A Butterworth or Chebyshev bandpass filter characterized by it's center frequency, bandwidth, loss, ripple, and number of poles.

Preselector:

A constant percentage bandwidth, tunable Butterworth filter characterized by it's percent bandwidth, loss, second and third order intercept points, 1 dB compression point, number of poles, and number of zeros at zero frequency.

Switch:

An RF switch characterized by it's loss, second and third order intercept points, compression, and off isolation.

5.2 Attenuator Element

The Attenuator element represents an ideal attenuator, characterized entirely by it's attenuation. The attenuator response is constant at all frequencies. The attenuator does not produce any distortion, or excess noise.

Block Parameters:

Gain: Set to the negative of the attenuator loss.

Noise Figure: Set to the attenuator loss.

IP2: Set to infinity.

IP3: Set to infinity.

Compression: Set to infinity.

Isolation: Set to the attenuator loss.

Frequency: Set to Undefined.

Bandwidth: Set to Infinity.

The Attenuator element is created with the Attenuator Dialog

5.3 Amplifier Element

The Amplifier Element represents an amplifier, characterized by it's gain, noise figure, second and third order intercept points, compression point, and reverse isolation. The amplifier bandwidth is assumed to be infinite (the actual bandwidth would normally be limited by Filter Elements in the Receiver.)

As is common practice, the second and third order intercept points and compression point are defined at the output of the amplifier. (It looks better that way.)

Block Parameters:

Gain: Set to the specified amplifier gain.

Noise Figure: Set to the specified amplifier noise figure.

IP2: Set to the specified amplifier IP2, reflected to the input.

IP3: Set to the specified amplifier IP3, reflected to the input.

Compression: Set to specified amplifier compression point, reflected to the input.

Isolation: Set to the specified amplifier reverse isolation.

Frequency: Set to Undefined.

Bandwidth: Set to Infinity.

The Amplifier element is created with the Amplifier dialog.

5.4 AGC Amplifier Element

The AGC Amplifier Element represents an amplifier whose characteristics are a function of an applied control voltage. This would typically be used for controlling the gain, with the other parameters varying with control voltage as a secondary effect. Note that there is a single control voltage available in the receiver. If delayed AGC is required, it will have to be built into the gain control characteristics of another AGC amplifier element.

The AGC Point dialog can be opened to specify the AGC amplifier's characteristics as a list, keyed to the AGC voltage. The characteristics are interpolated between data points. AGC voltages beyond the defined limits will result in characteristics at the appropriate end of the control voltage list.

The reverse isolation is defined as a constant value for an AGC Amplifier.

Block Parameters:

Gain: Set to the specified amplifier gain, interpolated for the control voltage.

Noise Figure: Set to the specified amplifier noise figure, interpolated for the control voltage.

IP2: Set to the specified amplifier IP2, reflected to the input, interpolated for the control voltage.

IP3: Set to the specified amplifier IP3, reflected to the input, interpolated for the control voltage.

Compression: Set to specified amplifier compression point, reflected to the input, interpolated for the control voltage.

Isolation: Set to the specified constant amplifier reverse isolation.

Frequency: Set to Undefined.

Bandwidth: Set to Infinity.

The AGC Amplifier element is created with the AGC Amplifier dialog.

5.5 Mixer Element

The Mixer Element represents a mixer, characterized by it's gain, noise figure, image rejection, second and third order intercept points, compression point, and LO to RF port LO to IF port isolation and reverse (IF to LO port) isolation. The mixer bandwidth is assumed to be infinite (the actual bandwidth would normally be limited by Filter Elements in the Receiver.)

During any noise analysis, this program will attempt to fold image noise into a conversion. The contribution of image noise comes from all elements prior to the mixer, but after a frequency limiting element, such as a bandpass or preselector filter, or possibly a lowpass or highpass filter. Image noise, like image signals, will be reduced in level if the mixer displays image rejection. The default image rejection is infinity, which will provide results identical to an analysis program that doesn't account for image noise. This parameter should normally be set to zero, representing a mixer with no image rejection.

The intercept points and compression point are defined at the output of the mixer. This is normal for specifying an active mixer. However, passive mixers usually specify these points at the input.

For a passive mixer, the noise figure is usually set equal to the mixer loss, although it may be slightly higher.

Block Parameters:

Gain: Set to the specified mixer gain (gain is negative for a passive mixer.)

Noise Figure: Set to the specified mixer noise figure.

IP2: Set to the specified mixer IP2, reflected to the input.

IP3: Set to the specified mixer IP3, reflected to the input.

Compression: Set to specified mixer compression point, reflected to the input.

Isolation: Set to the specified mixer reverse isolation.

Frequency: Set to Undefined.

Bandwidth: Set to Infinity.

The Mixer element is created with the Mixer dialog.

From within the Mixer Dialog, a Spurious Table Dialog can be opened, allowing the entry of mixer spurious levels. These are levels of mixer outputs due to various combinations of LO and RF harmonics. The RF level is specified in the Spurious Table Dialog.

The LO level is assumed to be fixed, while the RF level can vary. It is assumed that the level of the spur drops as the power corresponding to the order of the RF harmonic. Thus, if the spurious involves the fundamental of the RF signal, it will drop 10 dB as the RF level drops 10 dB. Since the desired signal also drops by 10 dB, the ratio remains fixed. For a second harmonic signal, the spurious response will drop 20 dB as the RF signal drops 10 dB. Since the desired response dropped 10 dB, the spurious response will drop 10 dB more than does the desired response as the RF level drops 10 dB. This continues with harmonic level. A spurious response involving the 10th harnonic of the RF signal will drop 100 dB as the RF signal drops 10 dB, or 90 dB more than the desired response.

It should be noted that these levels depend upon delivering clean RF and LO signals to the mixer. For example, if the RF amplifier generates second harmonic, any spurious response due to the second harmonic of the RF signal would be expected to exceed the level due to the mixer spurious response alone. And if the LO signal contains harmonics, especially even order harmonics, spurious responses due to those harmonics would be expected to rise.

5.6 Lowpass Filter Element

The Lowpass Filter Element represents a Butterworth or Chebyshev lowpass filter, characterized by it's cutoff frequency, loss, ultimate rejection, ripple, and the number of poles. When a loss is specified, it will be considered to be a constant offset in the filter response, and will not contribute the calculation of the filter shape. The Lowpass Filter is assumed to produce no distortion products.

The cutoff frequency is represents the 3 dB bandwidth of the filter, for either a Butterworth or Chebyshev response. A zero ripple value will indicate a Butterworth response, while a non-zero value will indicate a Chebyshev filter response. The block parameters will presently return the 3 dB bandwidth, not the noise bandwidth of the filter.

The response of the filter will include the affect of the lossy elements. As a result, a Chebyshev filter will lose it's passband ripple as the filter loss increases, and a lossy filter will display shrinkage of the 3 dB bandwidth.

Note that the isolation parameter represents the isolation at the tuned frequency. As such, isolation cannot be used to determine reverse isolation to out of band signals, such as the local oscillator. LO rejection can be plotted by using the LO Leakage analysis.

Block Parameters:

Gain:	Set to the negative of the specified filter loss plus ripple (-(loss + ripple)).
Noise Figure:	Set to the filter loss plus ripple
IP2:	Set to Infinity.
IP3:	Set to Infinity.
Compression:	Set to Infinity.
Isolation:	Set to the filter loss.
Frequency:	Set to Undefined.
Bandwidth:	Set to the Cutoff Frequency.

The Lowpass Filter element is created with the Lowpass dialog.

5.7 Highpass Filter Element

The Highpass Filter Element represents a Butterworth or Chebyshev highpass filter, characterized by it's cutoff frequency, loss, ultimate rejection, ripple, and the number of poles. When a loss is specified, it will be considered to be a constant offset in the filter response, and will not contribute to the calculation of the filter shape. The Highpass Filter is assumed to produce no distortion products.

The cutoff frequency is defined as the 3 dB bandwidth for both the Chebyshev and Butterworth filter responses. A zero ripple value will indicate a Butterworth response, while a non-zero value will indicate a Chebyshev filter response.

The response of the filter will include the affect of the lossy elements. As a result, a Chebyshev filter will lose it's passband ripple as the filter loss increases, and a lossy filter will display a 3 dB cutoff frequency higher than specified.

Block Parameters:

Gain: Set to the negative of the specified filter loss plus ripple (-(loss + ripple)).

Noise Figure: Set to the filter loss plus ripple

IP2: Set to Infinity.

IP3: Set to Infinity.

Compression: Set to Infinity.

Isolation: Set to the filter loss.

Frequency: Set to Undefined.

Bandwidth: Set to Infinity.

The Highpass Filter element is created with the Highpass dialog.

5.8 Bandpass Filter Element

The Bandpass Filter Element represents a Butterworth or Chebyshev bandpass filter, characterized by it's center frequency, Bandwidth, loss, ripple, ultimate rejection, and the number of poles. A zero value of ripple will specify a Butterworth response. A non-zero value for the ripple will specify a Chebyshev response.

The specified bandwidth is the 3 dB bandwidth of the lossless filter design, whether it's Butterworth or Chebyshev. At present, this 3 dB bandwidth will also be used in calculating the noise response of the filter.

The response of the filter is calculated from the equivalent lowpass filter response. As a result, the filter response will be exactly symmetrical. If a loss is specified, it will be the loss at the center of the filter passband. The response of the filter will include the affect of the lossy elements. As a result, a Chebyshev filter will lose it's passband ripple as the filter loss increases, and a lossy filter will display shrinkage of the 3 dB bandwidth.

For more information on the equivalent lowpass filter, see the the discussion of lowpass equivalent responses.

Block Parameters:

Gain: Set to the negative of the specified filter loss plus ripple.

Noise Figure: Set to the filter loss plus ripple.

IP2: Set to Infinity.

IP3: Set to Infinity.

Compression: Set to Infinity.

Isolation: Set to the filter loss.

Frequency: Set to specified center frequency.

Bandwidth: Set to the specified 3 dB bandwidth.

The Bandpass Filter element is created with the Bandpass dialog.

5.9 Preselector Element

The Preselector Element represents a tunable preselector stage, usually implemented with a one or two stage varactor tuned preselector. The preselector is characterized by it's percentage bandwidth, loss, ultimate rejection, second and third order incercept points, 1 dB compression point, and number of resonators.

Preselectors are typically somewhat sloppy, and display a variable response as the filter is tuned across it's frequency range. Because of this, it is somewhat difficult to predict the response of the preselector filter. As a compromise, we will assume a Butterworth filter response whose percentage bandwidth is constant over the tuning range.

The response of the filter is calculated from the equivalent lowpass filter response. As a result, the filter response will be exactly symmetrical. If a loss is specified, it will be the loss at the center of the filter passband. The response of the filter will include the affect of the lossy elements. As a result, a lossy filter will display shrinkage of the 3 dB bandwidth.

Because these filters are typically varactor tuned, they generate distortion products. These products will be characterized by specifying the second and third order intercept points and compression point (referred to the output of the preselector.)

The Preselector Element will always be assumed to be tuned to the frequency required to tune the frequency as specified in the Front Panel dialog.

Block Parameters:

Gain: Set to the negative of the specified filter loss.

Noise Figure: Set to the filter loss.

IP2: Set to the specified intercept point reflected to the preselector input.

IP3: Set to the specified intercept point reflected to the preselector input.

Compression: Set to the specified compression point reflected to the preselector input.

Isolation: Set to the filter loss.

Frequency: Set to center the preselector to the frequency to which the receiver is tuned (by the front panel dialog.)

Bandwidth: Set to the specified bandwidth, unnormalized to the center frequency.

The Preselector element is created with the Preselector dialog.

5.10 Switch Element

The Switch Element represents an electronic swith, usually implemented with PIN diodes, or a GaAs MMIC. The switch is characterized by a loss, the second and third order intercept points, compression point (all at the output), and off isolation. Note that at present the isolation of the block is set equal to the isolation of the switch. This assumes that the switch is turned off when the isolation is being calculated. This may be undesirable.

All parameters are considered to be independent of frequency.

Block Parameters:

Gain: Set to the negative of the specified attenuator loss.

Noise Figure: Set to the attenuator loss.

IP2: Set to the specified intercept point reflected to the attenuator input.

IP3: Set to the specified intercept point reflected to the attenuator input.

Compression: Set to the specified compression point reflected to the attenuator input.

Isolation: Set to the specified off isolation.

Frequency: Set to Undefined.

Bandwidth: Set to the Infinity.

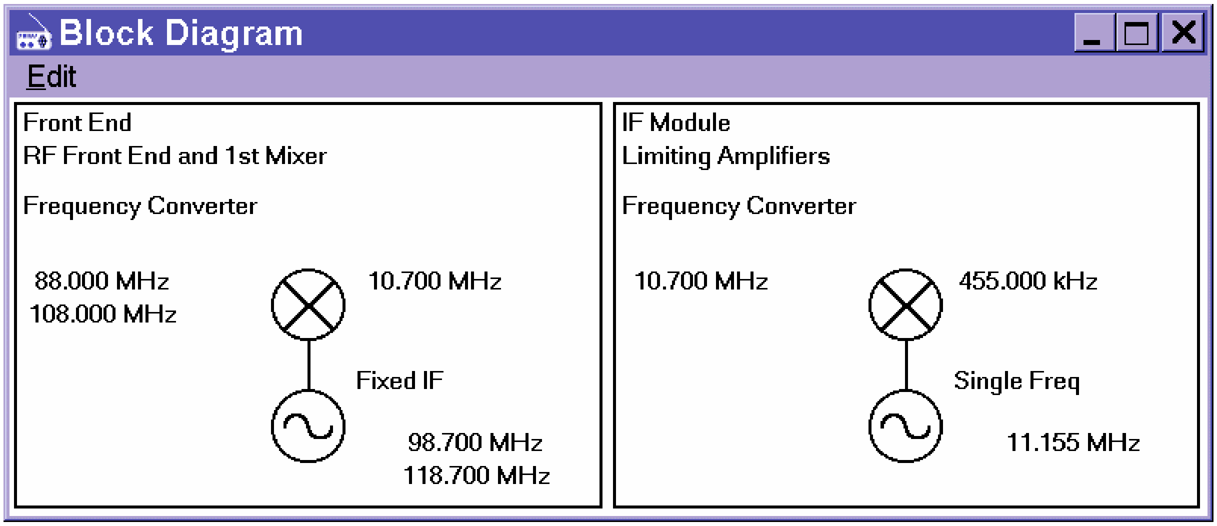
The Switch element is created with the Switch dialog.

6 Receiver Diagrams

Two diagrams are available withing this program. The receiver may be displayed as either a cascade of modules, useful for an overview of the receiver, and for displaying the frequency plan of the receiver, or as a block diagram, or cascade of the contained elements, useful when considering the performance contribution of each individual block.

The module diagram or block diagram can be displayed for either the entire receiver, or for a single module.

6.1 Receiver Module Diagram

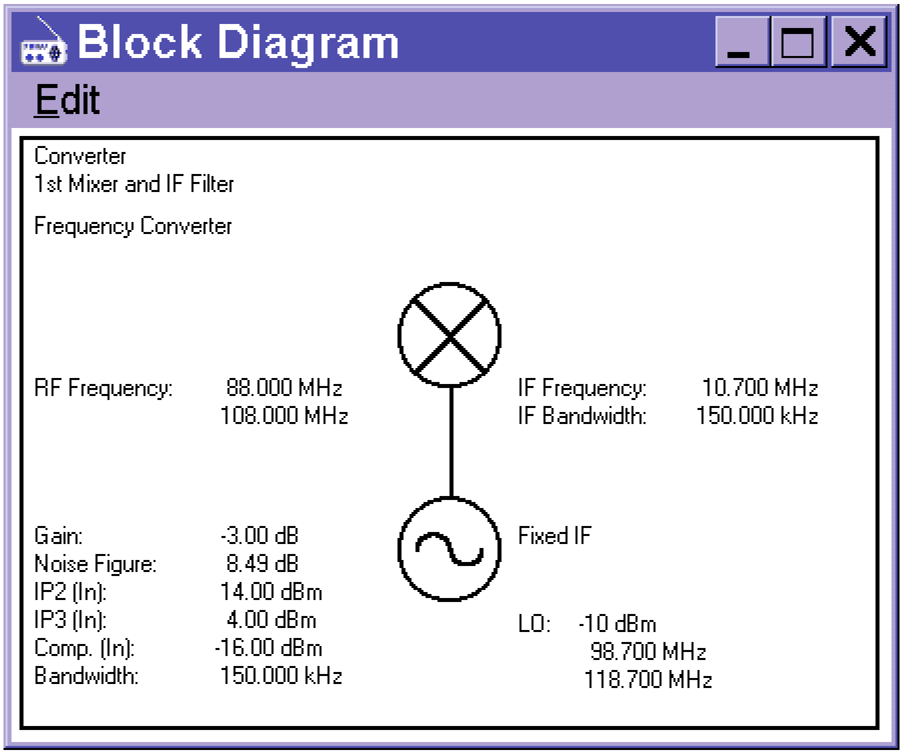


The Receiver Module Window can be accessed from either the Simulator dialog, Receiver Modules dialog by selecting the View|Receiver Modules menu item.

The Receiver Module Window will display a block diagram of the receiver, emphasizing the frequency plan and architecture of the receiver. The amount of information displayed in the diagram will depend on the size of the individual module diagrams. The module will always display the module name and description, along with a basic frequency plan for the module. If the module converts, a mixer and local oscillator will be shown as blocks in the module.

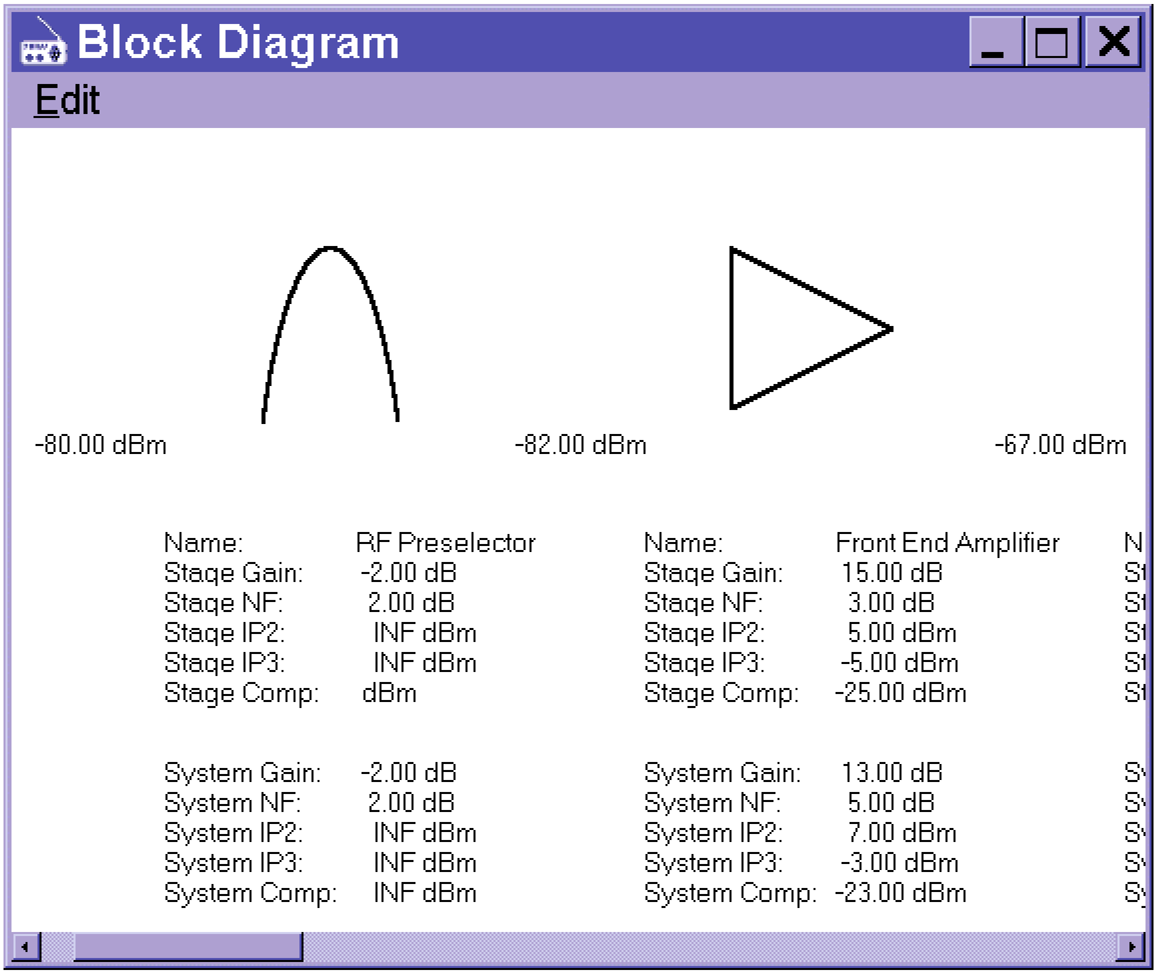
A larger window will include a description of each module as Fixed Frequency, such as an IF, Variable Frequency, such as a tuned preselector, or Converter. If the window is expanded still more, the Block Parameters and LO parameters will be included.

The Edit menu contains two items, Close and Copy. Copy will place a metafile copy the Module Diagram into the clipboard, for pasting into other documents.



A single receiver module, as shown above, can be displayed in a window by selecting the View|Module menu item from the Module Definition dialog. This window has been expanded sufficiently to incorporate all available information into the window. From this window, the module gain, noise figure, intercept points, compression point, and bandwidth can be determined. The frequency conversion plan for this module is also displayed in this window.

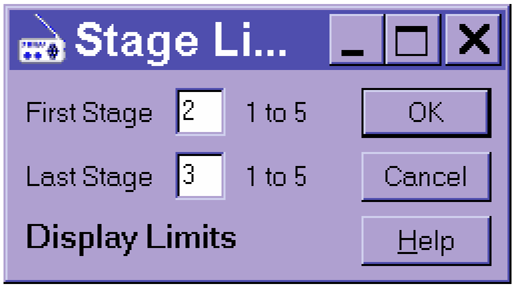
6.2 Block Diagram



A receiver or module block diagram window can be displayed by selecting the View|Block Diagram menu item on either the Simulator dialog, Receiver Modules dialog or the Module Definition dialog.

The Block Diagram window will display a block diagram of the receiver or module emphasizing the individual Elements contained in the receiver. Because the number of elements may be quite large, the window has a scroll bar to allow scrolling the display to the left and right. Signal levels are displayed between elements, and at the beginning and end of the chain, based on the input signal level entered in the Input Signal dialog. Individual element block parameters, and cascaded or cumulative block parameters (identical to those displayed by the Cumulative Block Parameter analysis are displayed below each element.

If the Edit|Set Limits menu item is selected, a plot limits dialog will open.



By entering a First and Last stage number in this dialog, we can limit the range of stages, or elements displayed in the Block Diagram.

7 Analysis

A variety of analyses are available in the receiver simulator. System performance can be evaluated, such as signal to noise ratio. Block performance can be displayed, either for the system or for each contained element. Spurious frequencies, either spurious susceptablility or birdies, and be analysed. Other analyses include LO Leakage, and bit error rate.

7.1 Block Analysis Description

The Block Analysis is used to calculate the Gain, Noise Figure, Second and Third Order Intercept Points, and 1 dB Compression, for a cascade of elements in the Receiver.

The Block Analysis uses standard assumptions in calculating the effects of cascading stages In particular, all interfaces are assumed to be perfectly matched. With mixers, this includes the matching at the image frequency. Mismatches between stages will introduce deviations from the calculated values. This will be especially noticeable in comparisons between calculated and measured noise figure. A mismatch at the image frequency, usually caused by narrowband filters, can cause an appreciable error in the Noise Figure calculation.

Intercept calculations will assume that all stages contribute in a worst case scenario. For third order intercept calculations, this will most likely be the correct scenario, as the third order distortion in all stages will almost certainly be caused by amplifier compression. This is not the case, however, for second order distortion, which is caused by an amplifier characteristic that compresses differently at the plus and minus extremes. In this case two second order distortion products could just as likely cancel as add.

If there are AGC amplifiers in the receiver, the block parameters will be calculated with the gain control voltage set to the value specified in the manual gain control edit box in the Front Panel Dialog. To calculate the block parameters for the input signal level specified in the input signal dialog, select the AGC mode, and press the "Set" button in the Front Panel Dialog.

Each Block Analysis lists the following options:

Summary

Selecting this menu item will display a summary of the cascaded block parameters of the receiver.

Expanded

Selecting this menu item will display a table showing the block parameters of each block contained in the receiver.

Cumulative

Selecting this menu item will display the cumulative block parameters of the receiver in a table.

Normalize

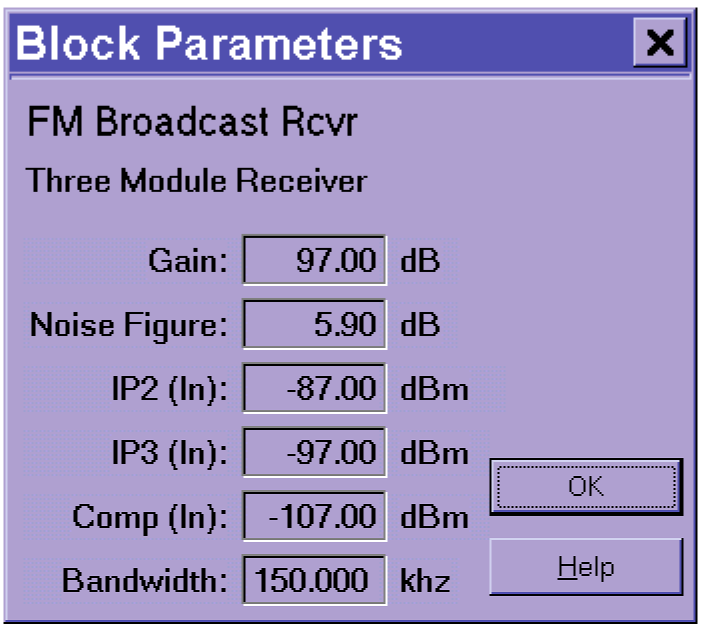
Selecting this menu item will display a a table of the normalized block parameters for each block contained in the receiver.

Plot

This menu item displays several sub-menus that allow the user to plot the block parameters of the receiver as a function of the AGC voltage.

7.2 Block Parameter Summary

The Block|Summary menu item will display a summary of the block parameters of an element, or the cascaded block parameters for a module, or the entire receiver.



For a module or receiver, the bandwidth is taken from the narrowest bandwidth element contained in the module or receiver.

7.3 Expanded Block Parameters

The Block|Expanded menu item will display a table of the block parameters for each Element in the receiver or module analysed. The entry for each Element will display the block parameters for that Element, with intercept and compression reflected to the input.

If any module is defined by module parameters, rather than contained Elements, the defined parameters for that module will appear in the table, rather than the block parameters for any Elements in the module.

The last entry in the table will be a summary of the cascaded block parameters for the receiver or module.

System Summary

Edit

FM Receiver FM Broadcast Band 7/18/00

Block Name	Gain	NF	IP2	IP3	Comp	BW
RF Preselector	-2.00	2.00	INF	INF		hz
Front End Amplifier	15.00	3.00	5.00	-5.00	-25.00	INF
RF Preselector	-2.00	2.00	INF	INF		hz
Mixer	6.00	5.00	14.00	4.00	-16.00	INF
IF Filter	-9.00	9.00	INF	INF	INF	150.000 khz
IF Amplifier	25.00	3.00	-5.00	-15.00	-35.00	INF
IF Amplifier	25.00	3.00	-5.00	-15.00	-35.00	INF
IF Amplifier	25.00	3.00	-5.00	-15.00	-35.00	INF
IF Amplifier	25.00	3.00	-5.00	-15.00	-35.00	INF
IF Filter	-9.00	9.00	INF	INF	INF	150.000 khz
System Summary	99.00	5.83	-88.50	-98.01	-118.01	150.000 khz

7.4 Cumulative Block Parameters

The Block|Cumulative menu item will display a table of the block parameters for the receiver or module as each new Element is appended to the receiver. The first entry will display the block parameters for the first Element, reflected to the input. As each additional Element is appended to the receiver, the cascaded block parameters for receiver up to, and including that new Element, will be calculated and displayed in the table. In this way you can track how each new Element degrades the receiver performance.

If any module is defined by module parameters, rather than contained Elements, the defined parameters for that module will be cascaded, rather than the block parameters for any Elements in the module.

The last entry in the table will be a summary of the cascaded block parameters for the receiver or module.

Cumulative Block Parameters

Edit

FM Receiver FM Broadcast Band 7/18/00

Block Name	Gain	NF	IP2	IP3	Comp	BW
RF Preselector	-2.00	2.00	INF	INF	INF	INF
Front End Amplifier	13.00	5.00	7.00	-3.00	-23.00	INF
RF Preselector	11.00	5.04	7.00	-3.00	-23.00	INF
Mixer	17.00	5.48	-1.25	-8.46	-28.46	INF
IF Filter	8.00	5.65	-1.25	-8.46	-28.46	150.000 khz
IF Amplifier	33.00	5.83	-15.00	-23.15	-43.15	150.000 khz
IF Amplifier	58.00	5.83	-38.59	-48.01	-68.01	150.000 khz
IF Amplifier	83.00	5.83	-63.51	-73.01	-93.01	150.000 khz
IF Amplifier	108.00	5.83	-88.50	-98.01	-118.01	150.000 khz
IF Filter	99.00	5.83	-88.50	-98.01	-118.01	150.000 khz
System Summary	99.00	5.83	-88.50	-98.01	-118.01	150.000 khz

7.5 Normalized Block Parameters

The Block|Normalize menu item will display a table of the block parameters for each Element in the receiver or module, normalized to the receiver input, assuming all other Elements to be perfect. In this way the user can compare the contribution of each Element in the receiver or module to all the others.

If any module is defined by module parameters, rather than contained Elements, the defined parameters for that module will be normalized, rather than the block parameters for any Elements in the module.

The last entry in the table will be a summary of the cascaded block parameters for the receiver or module.

Normalized Block Parameters

Edit

FM Receiver FM Broadcast Band 7/18/00

Block Name	Gain	NF	IP2	IP3	Comp	BW
RF Preselector	-2.00	2.00	INF	INF		hz
Front End Amplifier	15.00	4.11	7.00	-3.00	-23.00	INF
RF Preselector	-2.00	0.13	INF	INF		hz
Mixer	6.00	1.53	3.00	-7.00	-27.00	INF
IF Filter	-9.00	0.56	INF	INF	INF	150.000 khz
IF Amplifier	25.00	0.64	-13.00	-23.00	-43.00	INF
IF Amplifier	25.00	0.00	-38.00	-48.00	-68.00	INF
IF Amplifier	25.00	0.00	-63.00	-73.00	-93.00	INF
IF Amplifier	25.00	0.00	-88.00	-98.00	-118.00	INF
IF Filter	-9.00	0.00	INF	INF	INF	150.000 khz
System Summary	99.00	5.83	-88.50	-98.01	-118.01	150.000 khz

For example, the "Front End Amplifer" contributes the most to the noise figure degradation in this receiver.

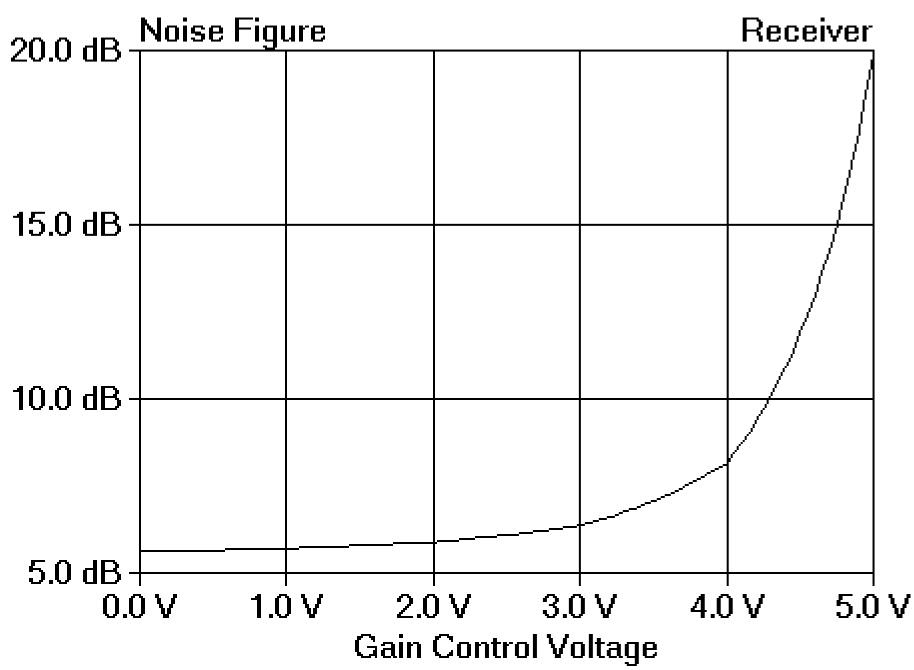
7.6 Block Analysis Plots

One option for the Block Analysis is a plot of one of the block parameters, as a function of the AGC control voltage. From the plot menu item, a submenu opens allowing the user to choose to plot the gain, noise figure, second order intercept point, , third order intercept point, or 1 dB compression point, as a function of the AGC control voltage.

If the receiver or RF module do not contain any AGC amplifiers, selecting from the submenu will display an error message.

The AGC range over which the plot will be constructed is define in the Front Panel dialog for the receiver simulation.

The following is a plot of the noise figure for an AM receiver as a function of the AGC control voltage.



7.7 Gain Calculations

System gain is calculated by adding all the gains of the individual elements, with gains expressed in decibels.

The gain of two elements in cascade will equal the sum of the gains of the two elements only if the impedances are perfectly matched. In reality, the total gain will vary from this sum somewhat, depending on the degree of mismatch between the two elements, and the mismatch of each element to the system used to measure the individual gain.

In the Block Analysis we assume that the signal levels are low enough to avoid saturating any of the amplifiers. Thus we will not consider compression characteristics during the gain calculations.

The cumulative gain factors into the calculations for Noise Figure and Intercept point. Thus any error in the gain parameters due to gain variations, or errors caused by mismatches between Elements, will degrade the accuracy of the these calculations.

7.8 Noise Figure Calculations

The Noise Figure calculated in a Block Analysis represents the noise figure of the system formed by cascading all the Elements in the selected RF Module, or in the entire Receiver. The Noise Figure is calculated cumulatively from the previous system noise figure by cascading the following Element in the chain, as follows:

$$N' = N + \frac{Nelem}{G}$$

where:

N′ represents the Noise Factor of the System after cascading the following Element.

N represents the Noise Factor of the System prior to cascading the following Element.

Nelem represents the Noise Factor of the following Element.

G represents the Gain of the System prior to cascading the following Element.

The Noise Factor, which appears in the above equations, represents the total noise (thermal plus excess noise) normalized to thermal noise. The Noise Factor is expressed as a ratio. The Noise Figure, which is specified and displayed in this program, is the Noise Factor expressed in decibels.

A special condition exists when mixers are present in the signal path. If the mixer is not an image rejection mixer, and is matched at both the desired signal frequency and the image frequency, it will convert noise equally from both frequencies to the IF output frequency. In most Block Analysis programs this effect is ignored.

This program will attempt to fold in this image noise, so the calculated Noise Figure more closely represents the actual Noise Figure that you would measure in the system. As an example, if you create a Receiver consisting of a single mixer, using the default noise figure of 8 dB, then analyse the system (or the single RF Module containing the mixer), the analysis will not display a Noise Figure of 8 dB, but a noise figure of 11.01 dB, reflecting the degradation caused by folding in the image noise (both thermal and excess.)

A receiver will usually include filters to limit the amount of image noise that gets folded into the IF. In order to accurately calculate the system Noise Figure, we must also take into account the influence of this filters on the noise folded into the IF. This is accomplished in this program by calculating the noise backwards, starting at the last Element in the RF Module, or the receiver. Each time a mixer is encountered, the total noise at the input to that mixer (both thermal and excess) is doubled, reflecting the extra noise folded in from the image frequency. As we work our way towards the front of the receiver, every time additional excess noise is added to further degrade the System Noise Figure, the amount of excess noise is also doubled, to represent the excess noise folded in from the image. This continues forward until a filter is reached (lowpass, highpass or bandpass.) The noise weighting is then set back to one, to allow for the elimination of image noise arriving prior to this filter element.

Because the program does not check the bandwidths of the filters, or even if they are the correct type to eliminate the image noise, and does not calculate the rejection at the image frequency, these calculations may not be correct. Usually, however, they will calculate a Noise Figure that reflects the correct image calculations.

Cascaded Noise Figure calculations depend on accurate characterization of the Noise Figure and Gain of the cascaded Elements. Both Noise Figure and Gain will vary depending on the mismatch between cascaded Elements, and between each Element and the measurement system used to characterize that Element. We should therefore expect the calculated System Noise Figure to vary somewhat from the actual measured System Noise Figure.

7.9 Intercept Point Calculations

The Intercept point (Second or Third order) calculated in a Block Analysis represents the Intercept point of the system, defined at the input of the receiver or RF module, formed by cascading all the Elements in the selected RF Module, or in the entire Receiver.

The system intercept point is calculated cumulatively by taking the intercept point calculation for the partial system, and cascading the following Element in the chain. The intercept points must both be normalized to the Receiver input. The Intercept Point for the partial system has already been calculated, referenced to the input of the Receiver. We now reference the intercept point of the next element to the receiver input, using the system gain prior to this element. The system intercept point and the normalized next Element intercept point are then used to calculate the composite intercept point, representing the partial system with the next element now in place. Similarly, additional Elements are brought into the calculation, one at a time.

If the Third Order Intercept Point is being calculated, the new Intercept Point is equal to the reciprocal of the sum of the reciprocals. This is similar to resistors added in parallel:

$$\frac{1}{IP_t} = \frac{1}{IP_1} + \frac{1}{IP_2}$$

where IP_t is the new system Third Order Intercept point resulting from the combination of the system prior to appending the new Element (IP_1) referenced to the input, and the newly appended Element (IP_2) referenced to the input. Because third order intermodulation products usually arise from amplifier compression, they are likely to add in phase, creating the worst case condition predicted by the above expression.

Because compression is due to the same third order mechanism as the third order intercept point, we use the same expression to calculate 1 dB compression point as for the third order intercept point.

The Second Order Intercept Point calculation is similar, but in this case the square root of the composite intercept point is equal to the sum of the square roots of the individual intercept points.

$$\frac{1}{\sqrt{IP_t}} = \frac{1}{\sqrt{IP_1}} + \frac{1}{\sqrt{IP_2}}$$

Second order distortion products arise from unsymetrical amplifier characteristics. As a result, second order products from two amplifiers can actually cancel.

7.10 Compression

The 1 dB compression point calculated in a Block Analysis represents the signal level, defined at the input of the receiver or RF module, at which the output signal level will have compressed 1 dB below what the small signal gain would predict.

The system compression is caused primarily by third order distortion as the signal becomes clipped on the positive and negative peaks. As such, the cascaded compression characteristics are calculated in the same manner as the third order products. In particular, the 1 dB compression point degrades in the same manner as the third order intercept point.

7.11 Bandwidth

Bandwidth can take on many meanings in a receiver.

For signal to noise and bit error rate calculations, the bandwidth will be the equivalent noise bandwidth. At this time all specified bandwidths will be assumed to be noise bandwidths. In general, this will be different from the noise bandwidth of the filter. This may change in the future as the bandwidth calculations for filters become more sophisticated.

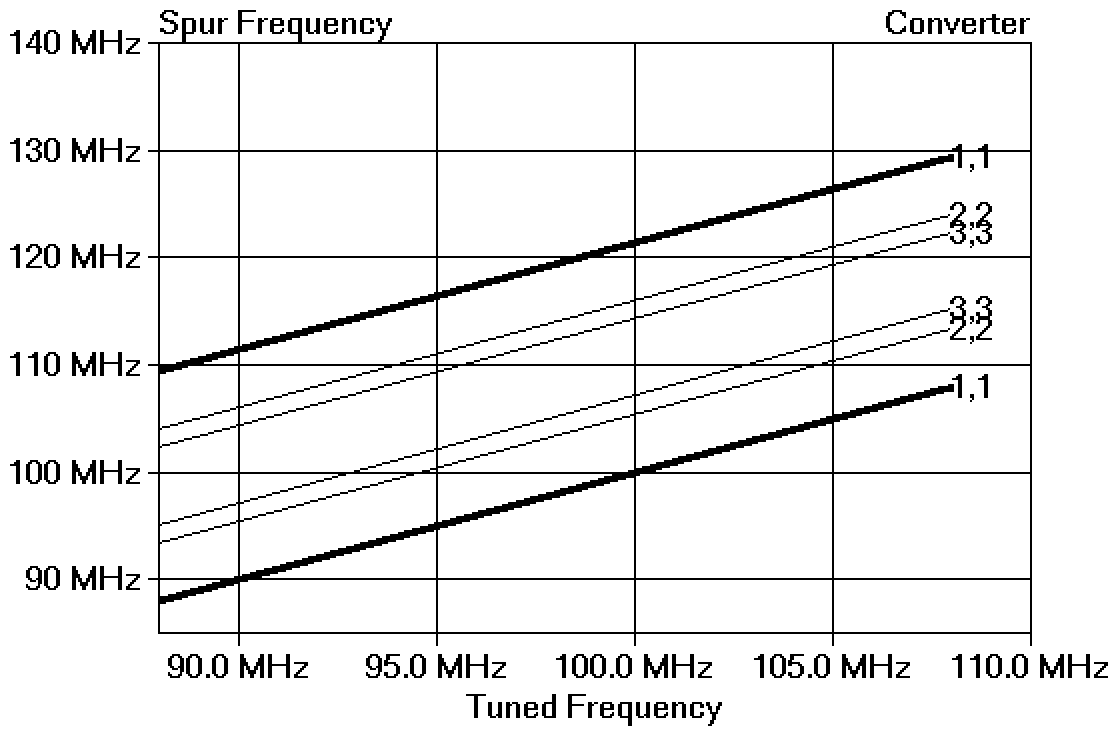
For block analysis tables, the specified element bandwidth will simply be displayed.

7.12 Single Signal Spurious Calculation

The Single Signal Spurious analysis will plot the many single signal spurious susceptibilities existing in a selected converter.

Every mixer will respond to a number of input frequencies. The most obvious is the desired input frequency. A group of other responses, called single signal spurious responses, are frequencies where the mixer will convert an undesired signal frequency to the IF frequency. The worst single signal spurious response is the image frequency.

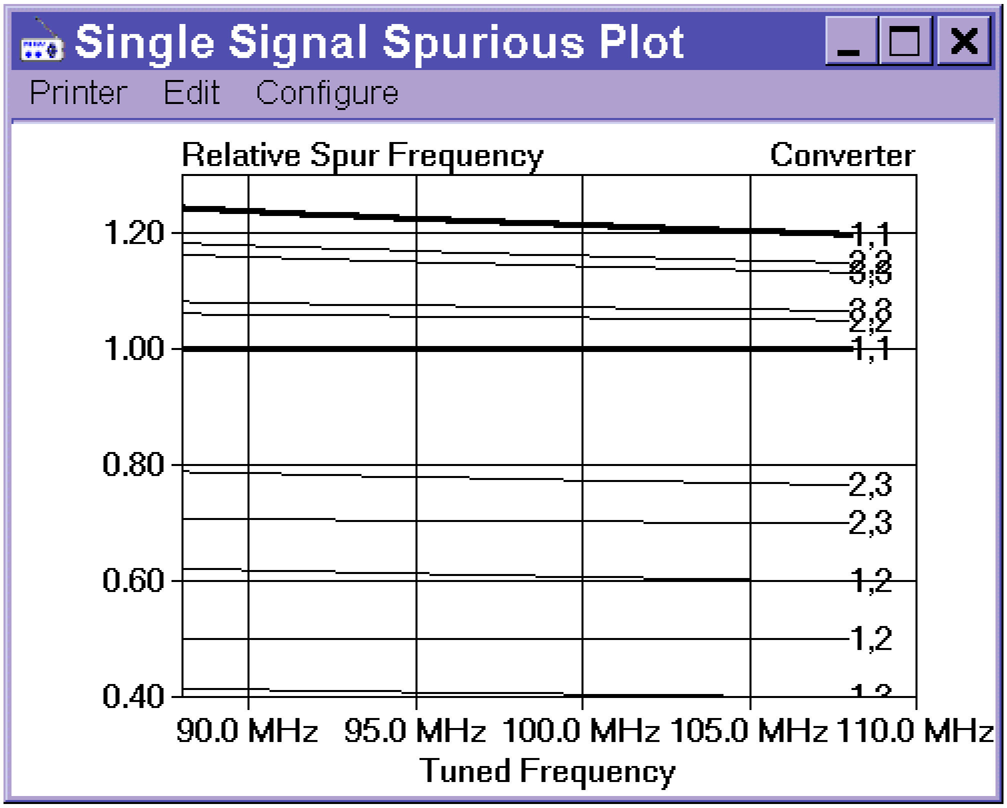
This Receiver Simulator allows a single mixer in each RF Module. Any RF Module that contains a Mixer Element can be the subject of a single signal spurious analysis. The horizontal axis will display the receiver tuned frequency. The vertical axis represents the frequency of the desired input signal, and frequencies where undesired spurious signals will be converted to the IF frequency. The resulting plot displays the variation in the spurious signal frequency (as well as the desired signal frequency) as the local oscillator is tuned to vary the frequency of the desired input signal.



The preceding spurious plot displays the single signal spurious response to an FM broadcast receiver, converting the desired FM band of 88 - 108 MHz to a 10.7 MHz IF frequency. The lower bold line is the desired signal, ranging from 88 MHz to 108 MHz as the receiver is tuned from 88 to 108 MHz. The upper bold line is the image frequency. Other lines represent the other spurious responses.

These undesired responses are due to the presence of harmonics of the RF and LO signals, either present in the signals, or generated by the mixer. The two numbers at the end of each line are the RF and LO harmonics that are producing the response. For example, the desired signal is due to the fundamental of the RF and LO signals (1,1).

The single signal spurious responses can also be displayed in a relative format, where the spurious frequency is shown normalized to the tuned frequency:



This format should prove more useful in cases where the RF filtering is accomplished with a tunable preselector. This would be required for this FM receiver, as the absolute plot shows that the lowest image frequency is almost as low as the highest desired frequency. As such, it would be difficult to provide a fixed tuned filter that would pass the desired RF frequency of 108 MHz, while at the same time providing rejection to the lowest undesired image frequency of 109.4 MHz.

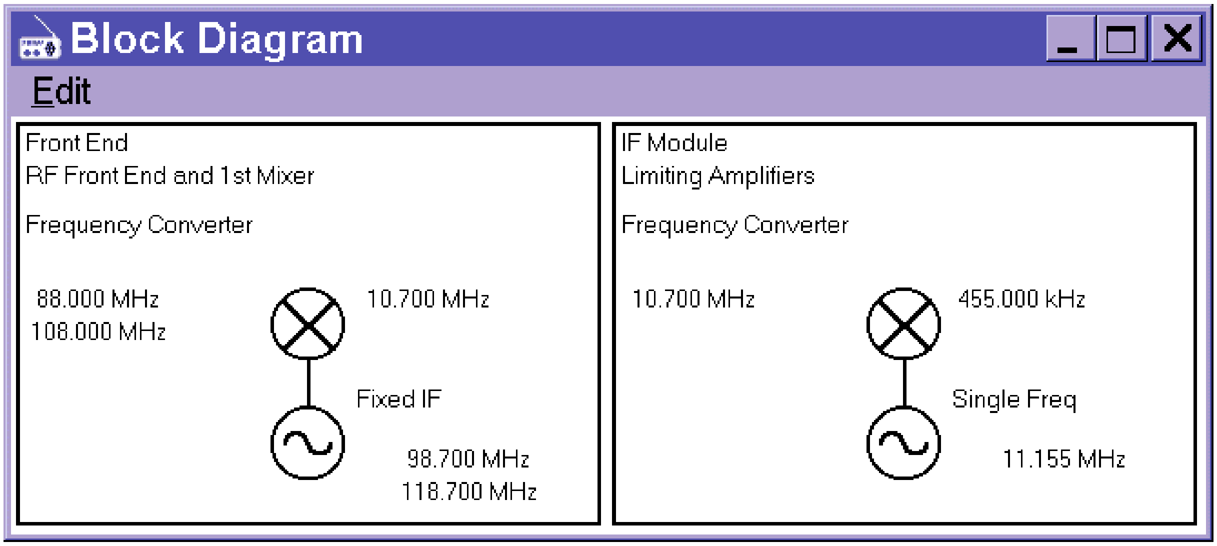
In general, as the harmonic numbers increase, the severity of the spurious response will lessen. Harmonics of the local oscillator tend to be more troublesome than harmonics of the RF signal, as they local oscillator signal is usually present at a much higher level. In addition, odd order harmonics of the local oscillator are especially troublesome, as the mixer is usually limiting on the local oscillator signal, generating large levels of odd order harmonics.

7.13 Birdies

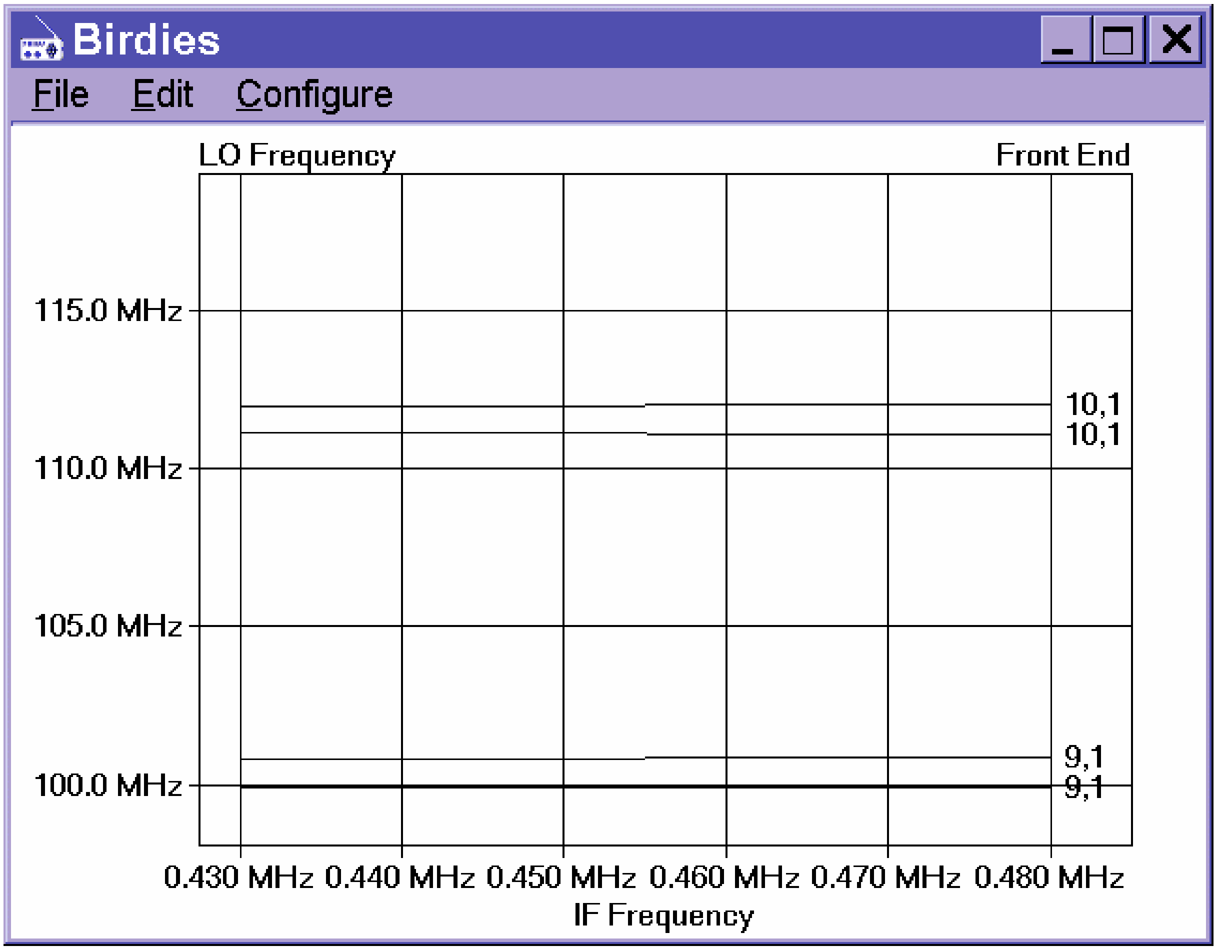
Birdies (also known as self-quieting spurs) are frequencies where some mixing product of two or more local oscillators falls into the final IF band. This definition will allow us to locate any potential birdie frequency, but it does not in any way account for the mechanism that generates the birdies.

This simulation program will consider only birdies generated by two adjacent local oscillators. Thus a Birdie produced as a mixing product of the first and third LO in a triple conversion receiver will not be located. The rational behind this decision is that most birdies will be caused by harmonics of one LO leaking into the next mixer and mixing with it's local oscillator. In this case the first LO is falling on a Single Signal Spurious Susceptibility frequency in the following mixer. Thus the birdie search is in fact identical to the Single Signal Spurious search, except that we are identifying susceptibilities that are coincident with the frequency of the preceding local oscillator.

Other mixing products can cause Birdies. For example, some harmonic of the third LO may fall onto the receive frequency, which is a mixing product that involves all three of the LO's in the hypothetical triple conversion receiver. At this time, a Birdie of this sort will not be identified.



The above Receiver Module Diagram shows a dual conversion receiver, using standard IF frequencies of 10.7 MHz, and 455 kHz. If a birdie analysis is performed on the first mixer stage, the following plot results:



In this plot, the first of the two numbers on the right represents the harmonic number of the following local oscillator, and the second number represents the harmonic number of this mixer stage. Thus, when this stage is tuned to approximately 100 MHz, the listener might hear a beat note cause by the 9th harmonic of the 11.155 local oscillator mixing with this local oscillator at approximately 110.7 MHz. In fact, the nineth harmonic of 110.395 MHz minus 99.94 MHz is 0.455 MHz. With a local oscillator frequency in the first module of 99.94 MHz, the tuned frequency is 89.24 MHz. Thus a whistle might be heard in the receiver when it is tuned past 89.24 MHz.

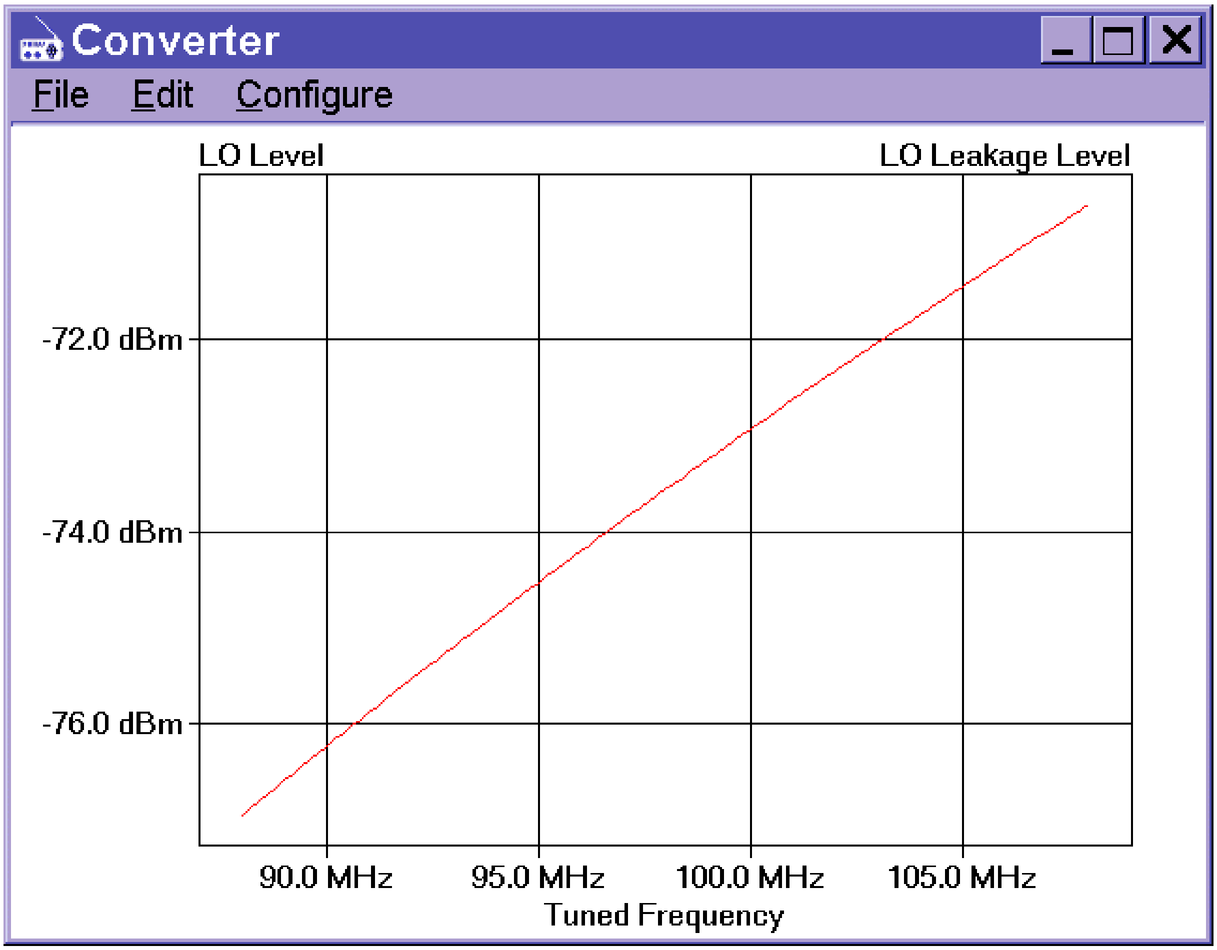
In a single conversion receiver, or the final mixer of a receiver, the birdie plot will be prepared assuming a final conversion down to baseband, with the local oscillator at the same frequency as the intermediate frequency. If the receiver contains a synchronous, or product detector, this will in fact be the case. Even if this is not the case, there will generally be significant harmonic levels of the IF stage that could generate birdies.

In general, as the harmonic numbers increase, the apparent level of the birdie will drop. Odd order harmonics are more troublesome than even order, as the local oscillator normally drives the mixer into limiting on the LO port, producing large odd order harmonic levels.

In order to prevent LO harmonics from getting into mixers further down the receiver chain, it is important that IF filters provide good rejection over a wide frequency range - they should not exhibit degraded rejection at frequencies far removed from the passband.

7.14 LO Leakage

The Local Oscillator analysis will calculate and plot the local oscillator leakage at the input to the receiver, or at the input to a particular RF module, as a function of the tuned frequency. In some cases the leakage is a fixed number, and will be displayed in a dialog window.



This plot shows the calculated LO leakage for a typical FM broadcast receiver as the receiver is tuned over the 88 - 108 MHz broadcast band. The leakage varies as a function of frequency because the front end of the receiver employs two tuned preselector stages with a bandwidth that increases as the tuned frequency increases. The larger bandwidth at higher frequencies results in less rejection of the local oscillator.

In many cases the calculated LO rejection will be a very small number, perhaps -200 dBm. This simply means that the direct path back through the receiver chain has execellent rejection, and LO leakage will probably be limited by sneak paths. When low leakage is required, these sneak paths must be controlled.

7.15 Signal to Noise Ratio

The signal to noise ratio is calculated as a function of the input signal level (as specified in the Front Panel dialog), and plotted against the input signal level. If AGC stages are present, the performance will be plotted over the defined AGC range (also specified in the Front Panel), although it will still be plotted as a function of the input signal level.

The carrier to noise ratio at the detector is calculated by comparing the input signal level with the equivalent input noise, taken in the bandwidth of the narrowest filter through which the noise passes. The equivalent input noise is due to the input thermal noise, and the excess noise created due to the non-zero Receiver Noise Figure. In many cases the baseband filters will be the narrowest filters in the signal path (the double sided bandwidth is used to determine an equivalent RF bandwidth of twice the baseband filter bandwidth), and the approximation will be close. If the narrow filters are in the front of the receiver, with wideband excess noise added after the narrow filters, this approximation will be in error.

If the signal is SSB, we'll assume that the opposite sideband noise has been eliminated, and we'll use the single sided baseband filter bandwidth (assume an RF bandwidth equal to the baseband bandwidth.) If the detector is a discriminator, the IF filter width will also affect the output signal to noise ratio.

The output signal to noise ratio is calculated as follows:

SSB: An SSB signal must be detected using the product detector. The output signal to noise ratio of the product detector will be identical to the carrier to noise ratio at the input of the demodulator. The noise power will be determined by either the RF / IF filtering, or the single sided baseband filter bandwidth, whichever is the narrowest.

AM: An AM signal may be demodulated by either a product detector (synchronous detection), or an envelope detector. In either case, the input power level is taken to be the carrier level. The output signal to noise ratio is equal to the input carrier to noise ratio, reduced by a factor equal to m^2 / 2, where m is the modulation depth. With 100% modulation, the output signal to noise ratio is then half of the input carrier to noise ratio. This is because the sideband power in a 100% modulated AM signal is equal to half of the carrier power.

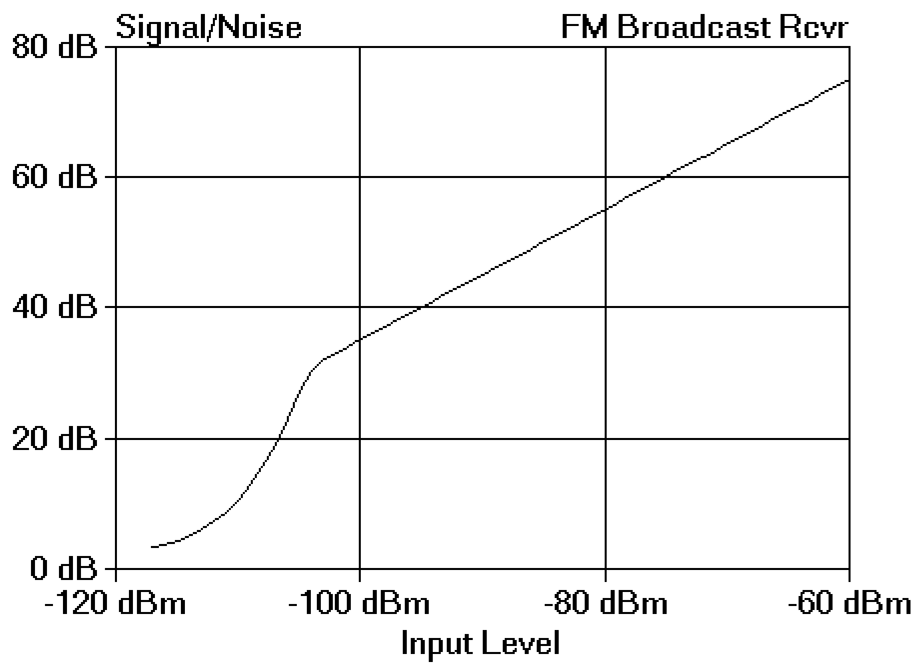
If the AM signal is demodulated by an envelope detector, the output signal to noise ratio will eventually start to degrade as the square of the input power. This occurs somewhere around 0 dB input carrier to noise ratio. As a result, we don't plot output signal to noise ratio for input carrier to noise ratios below 0 dB.

The noise power is determined by either the RF / IF filters, or the double sided baseband filter bandwidth, whichever is narrower.

DSB: A DSB signal may be demodulated only with a product detector. The output signal to noise ratio is identical to the input carrier to noise ratio. The noise power is determined by either the RF / IF filters, or the double sided baseband filter bandwidth, whichever is narrower.

FM: An FM signal may be demodulated only with a discriminator. The output signal to noise ratio at large signals is equal to the input carrier to noise ratio times the FM improvement, given by 1.5 * β^2, where β is the ratio of the FM deviation to the baseband bandwidth. The noise power is calculated in the double sided baseband filter bandwidth.

The FM threshold is simulated by calculating a degradation in the output signal to noise ratio caused by burst noise as the input carrier level drops. This effect is a function of the RF / IF bandwidth.



This is a plot of the signal to noise ratio for an FM detector.

7.16 Bit Error Rate

The Bit Error Rate (BER) is calculated as a function of the input signal level (as specified in the Front Panel dialog), and plotted against the input signal level. If AGC stages are present, the performance will be plotted over the defined AGC range (also specified in the Front Panel dialog), although it will still be plotted as a function of the input signal level.

The carrier to noise ratio at the detector is calculated by comparing the input signal level with the equivalent input noise, taken in the bandwidth of the narrowest filter through which the noise passes. The equivalent input noise is due to the input thermal noise, and the excess noise created due to the non-zero Receiver Noise Figure. In most cases the baseband filters will be the narrowest filters in the signal path (the double sided bandwidth is used - assume an RF bandwidth of twice the baseband bandwidth), and the approximation will be close. If the narrow filters are in the front of the receiver, with wideband excess noise added after the narrow filters, this approximation will be in error.

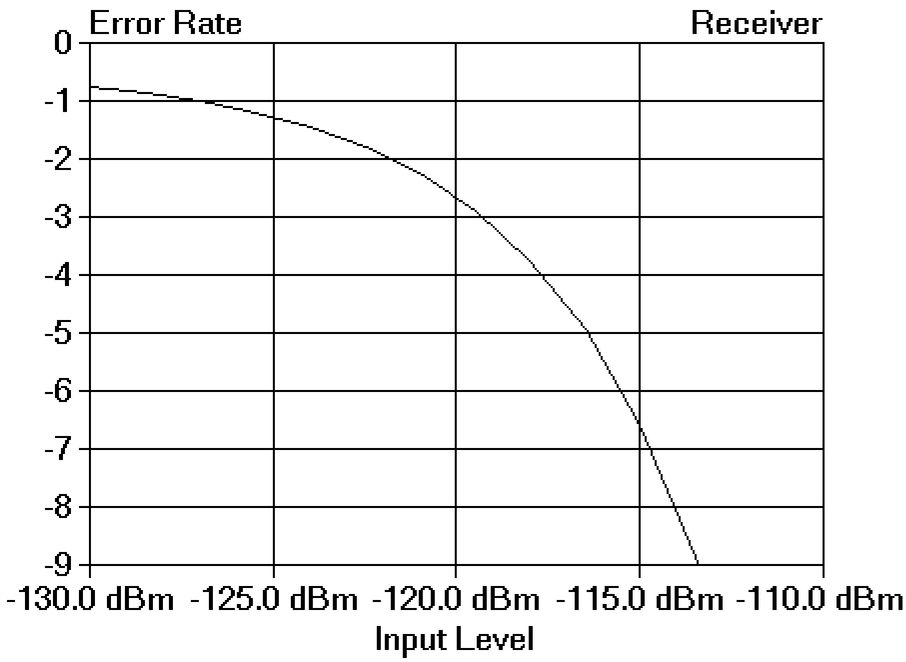
The Bit Error Rate is calculated from the detector input carrier to noise ratio, the characteristics of the particular detector, and the baseband bandwidth. The expressions used in the FSK calculations come from Digital Communications, by Korn.

FSK: An FSK signal must be demodulated with a discriminator. The bit error rate takes into account the normal demodulator noise, as well as the burst noise that occurs at threshold. The approximations are only correct for a fairly large carrier to noise ratio. As a result, we don't plot BER for a carrier to noise ratio below 5 dB. The calculations take into account both the RF / IF filter bandwidths, and the baseband bandwidth.

The calculations assume unfiltered transmit data, and therefore an integrate and dump filter at the demodulator for the baseband filtering.

BPSK: BPSK must be demodulated with a product detector. The noise bandwidth is determined by the minimum of the double sided baseband bandwidth, and the RF / IF filter bandwidths

QPSK: The QPSK calculation is identical to the BPSK calculation, except that the bit error rates are calculated for a 3 dB lower power level. This occurs because the power is split between the two data streams, and the input power is the sum of the two quadrature components. Since each data stream has half power, the bit error rate of each data stream, and the total as well, must be calculated at the half power level.



This is an example of a Bit Error Rate plot.

The Y axis represents number of errors on a log scale, where the axis is labled in powers of ten. Thus -1 is 1 error in 10 bits. -6 is 1 error in 1,000,000 bits.

The X axis represents the receiver input power.

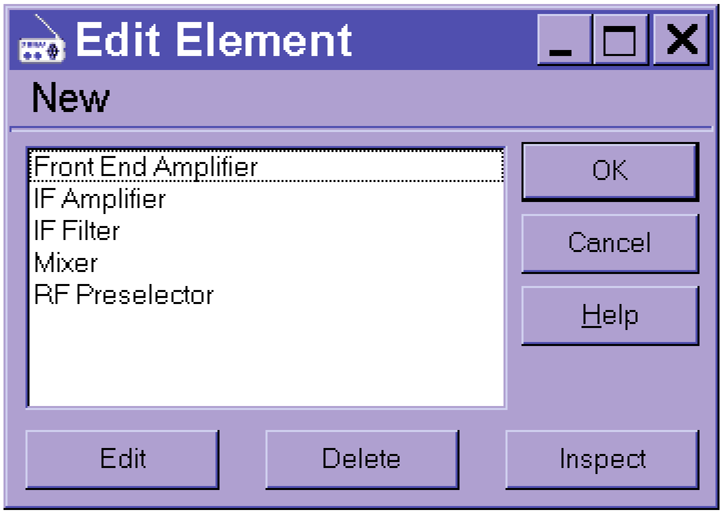
8 Receiver Dialogs

A variety of dialogs are available for defining the receiver configuration, and for performing analyses on the receiver. Additional dialogs are available for accessing tools, such as a Pi and T attenuator calculator.

8.1 Element Dialogs

The following dialogs will be used in the process of defining and editing Element descriptions. These Element definitions will then be used to define the modules.

8.1.1 Edit Element Dialog



New (menu):

Selecting this menu item will open a multilevel menu leading to several different element types. Selecting an element sub-menu item will create a new default version of the corresponding element. The element's dialog will be opened, allowing the user to edit the element parameters, and then save it to the element library.

Element List:

This contains a list of all the Elements presently defined. They are listed in alphabetical order by name. Double clicking on an element in this list will open up the element's dialog box, to allow editing the selected element.

Edit:

Pressing this button while and element is highlighted will open up the element's dialog box, to allow editing the selected element.

Delete

Pressing this button will delete the presently highlighted Element. The user will not be allowed to delete the element if it is presently included in the definition of any RF Module.

Inspect:

Pressing this button will calculate and display the block parameters for the highlighted element, referenced to the input.

OK:

Pressing this button will close the Edit Element dialog.

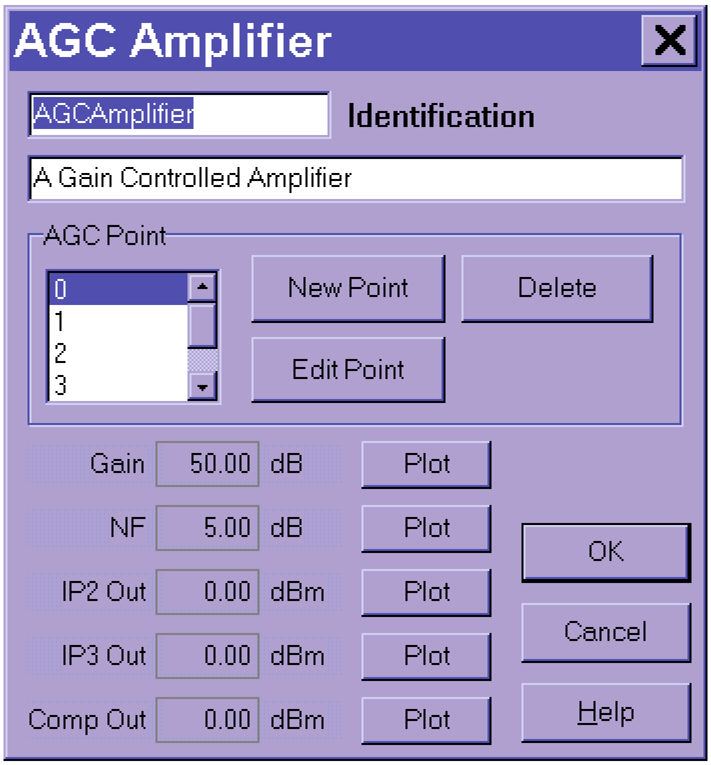
Cancel:

Pressing this button is identical to pressing the OK button. Any changes already made to the elements or list will be retained.

Help:

Displays this help page.

8.1.2 AGC Amplifier Dialog



For information on the agc amplifier element, see the AGC Amplifier Element Description.

Amplifier Identification:

The identification consists of two strings. First is the name that will be assigned to this amplifier element. In the "Module Definition" dialog, and any block lists, this AGC Amplifier will be identified by the string "AGCAmplifier". The second string allows the user to enter a short description of the AGC Amplifier, in this case "A Gain Controlled Amplifier".

AGC Point:

A list of AGC control voltages at which the amplifier characteristics (Gain, NF, IP2 Out, IP3 Out, and Comp Out) are defined. Clicking on any voltage in the list will display these characteristics for that AGC control point in the five boxes below. Note that these characteristics apply at all frequencies. Double clicking on a voltage will open the parameter dialog for that voltage, allowing the user to edit the data. These data are defined as follows:

Gain: The amplifier gain, expressed in decibels.

NF: The amplifier noise figure, expressed in decibels.

IP2 Out: The second order intercept point of the amplifier, at the output, expressed in dBm.

IP3 Out: The third order intercept point of the amplifier, at the output, expressed in dBm.

1 dB Comp: The amplifier's 1 dB compression point, at the output, expressed in dBm.

New Point:

Pressing this button will create a new AGC point, and open a dialog allowing you to edit the parameters.

Edit Point:

Pressing this button will open a dialog box allowing you to edit the parameters of the highlighted AGC point.

Delete:

Pressing this button will delete the highlighted AGC point.

Plot:

Pressing any of the "Plot" buttons will plot the characteristic directly to the left of the button, as a function of the AGC voltage.

OK:

Pressing this button will accept the new AGC amplifier definition, and add the AGC Amplifier, or replace it with the new definition, in the list of elements available in the element library.

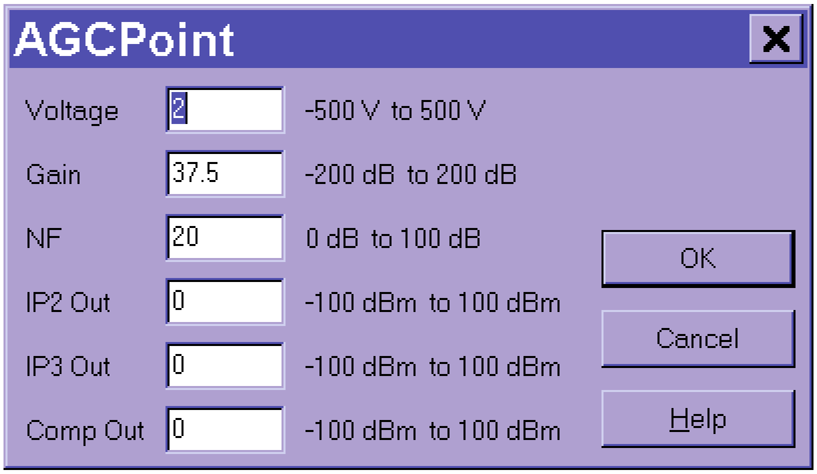
Cancel:

Pressing this button will abort this dialog box. If you were editing an existing AGC amplifier, it's entry in the element library will be unchanged. If this was a new element definition, it will be discarded.

Help:

Displays this help page.

8.1.3 AGC Point Dialog



The AGC Point dialog allows the user to edit the AGC Amplifier block parameters defined at a particular AGC voltage. Note that these parameters apply at all frequencies.

Voltage: The AGC voltage at which the following data are defined. This voltage may be changed.

Gain: The amplifier gain, expressed in decibels.

NF: The amplifier noise figure, expressed in decibels.

IP2 Out: The second order intercept point of the amplifier, at the output, expressed in dBm.

IP3 Out: The third order intercept point of the amplifier, at the output, expressed in dBm.

1 dB Comp: The amplifier's 1 dB compression point, at the output, expressed in dBm.

OK:

Pressing this button will accept the new AGC Point definition, and add the AGC Point, or replace it, in the list of AGC Points listed in the AGC Amplifier dialog.

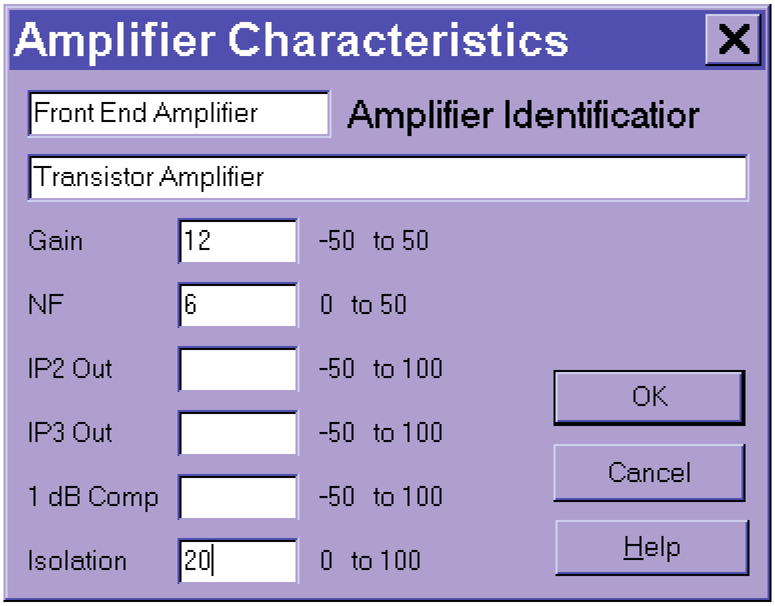
Cancel:

Pressing this button will abort this dialog box. If you were editing an existing AGC Point, it's entry in the AGC Amplifier point list will be unchanged. If this was a new AGC Point definition, it will be discarded.

Help:

Displays this help page.

8.1.4 Ampilfier Dialog



For information on the amplifier element, see the Amplifier Element Description.

Amplifier Identification:

The identification consists of two strings. First is the name that will be assigned to this amplifier element. In the "Module Definition" dialog, and any block lists, this Amplifier will be identified by the string "XYZ-123A". The second string allows the user to enter a short description of the Amplifier, in this case "Low Noise Amplifier".

Note that the following amplifier characteristics are all frequency independent.

Gain:

The amplifier gain, expressed in decibels.

NF:

The amplifier noise figure, expressed in decibels.

IP2 Out:

The second order intercept point of the amplifier, at the output, expressed in dBm.

IP3 Out:

The third order intercept point of the amplifier, at the output, expressed in dBm.

1 dB Comp:

The amplifier's 1 dB compression point, at the output, expressed in dBm.

Isolation:

The amplifier's reverse isolation, expressed in decibels.

OK:

Pressing this button will accept the new amplifier definition, and add the Amplifier, or replace it with the new definition, in the list of elements available in the element library.

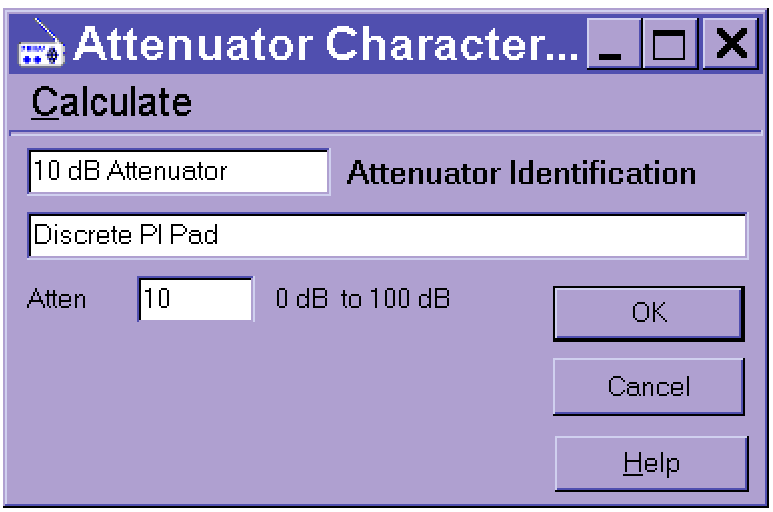
Cancel:

Pressing this button will abort this dialog box. If you were editing an existing element, it's entry in the element library will be unchanged. If this was a new element definition, it will discarded.

Help:

Displays this help page.

8.1.5 Attenuator Dialog



For information on the attenuator element, see the Attenuator Element Description.

Calculate:

This menu item allows the user to calculate resistor values for a PI or T attenuator. The calculation will occur in the Attenuator Calculation dialog.

Attenuator Identification:

The identification consists of two strings. First is the name that will be assigned to this Attenuator element. In the "Module Definition" dialog, and any block lists, this attenuator will be identified by the string "10 dB Attenuator". The second string allows the user to enter a short description of the attenuator, in this case "Discrete PI Pad".

Atten:

The attenuator element is defined completely by it's attenuation, expressed in decibels.

OK:

Pressing this button will accept the new attenuator definition, and add the attenuator, or replace it with the new definition, in the list of elements available in the element library.

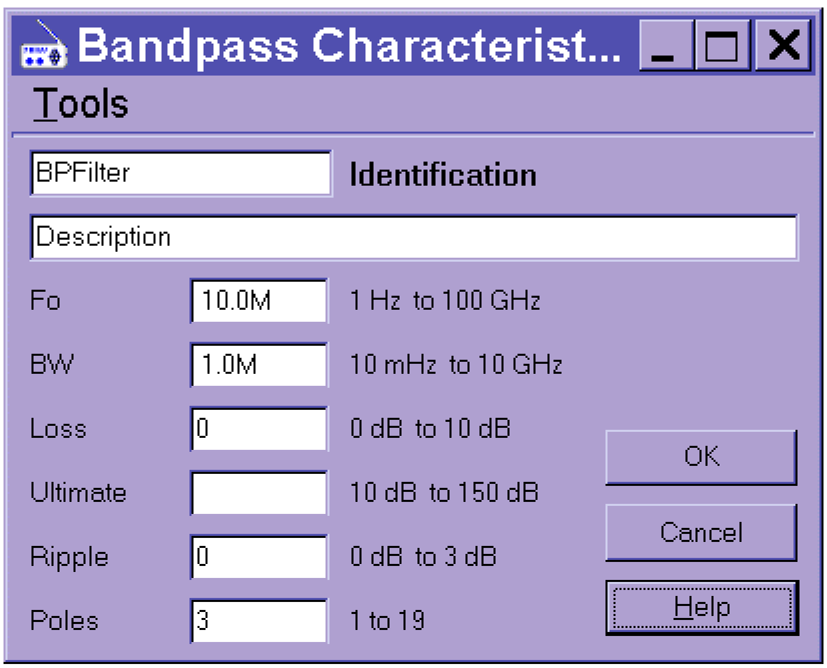
Cancel:

Pressing this button will abort this dialog box. If you were editing an existing attenuator, it's entry in the element library will be unchanged. If this was a new attenuator definition, it will discarded.

Help:

Displays this help page.

8.1.6 Bandpass Filter



For information on the bandpass filter element, see the Bandpass Filter element description.

Tools:

This menu item allows the user to plot either the amplitude, or the delay response of the filter. These responses are based on the lowpass equivalent filter (see Lowpass Equivalent Filter discussion.)

Bandpass Identification:

The identification consists of two strings. First is the name that will be assigned to this bandpass element. In the "Module Definition" dialog, and any block lists, this bandpass filter will be identified by the string "IF Filter". The second string allows the user to enter a short description of the filter, in this case "3 Resonator LC Filter".

Fo:

Bandpass center frequency, expressed in engineering notation.

BW:

Bandpass passband bandwidth, expressed in engineering notation. This will be the 3 dB bandwidth of the lossless filter design. A lossy filter will display shrinkage of the 3 dB bandwidth.

Loss:

The loss of the bandpass filter. During a block analysis, the bandpass element will be modeled with a loss equal to this specified loss plus the specified passband ripple.

Ultimate:

The ultimate attenuation of the filter. After reaching the rejection reaches this level, it will be assumed to remain equal to this level. This is used to model leakage around the filter.

Ripple:

The amount of ripple in the bandpass passband. If this value is zero, a Butterworth filter will be assumed. If a non-zero ripple is specified, the response will be Chebyshev. During a block analysis, the bandpass element will be modeled with a loss equal to the specified loss plus the specified passband ripple.

Poles:

The number of poles or resonators in the bandpass filter. This information is used to calculate the response of the filter.

OK:

Pressing this button will accept the new bandpass filter definition, and add the bandpass filter, or replace it, in the list of elements available in the element library.

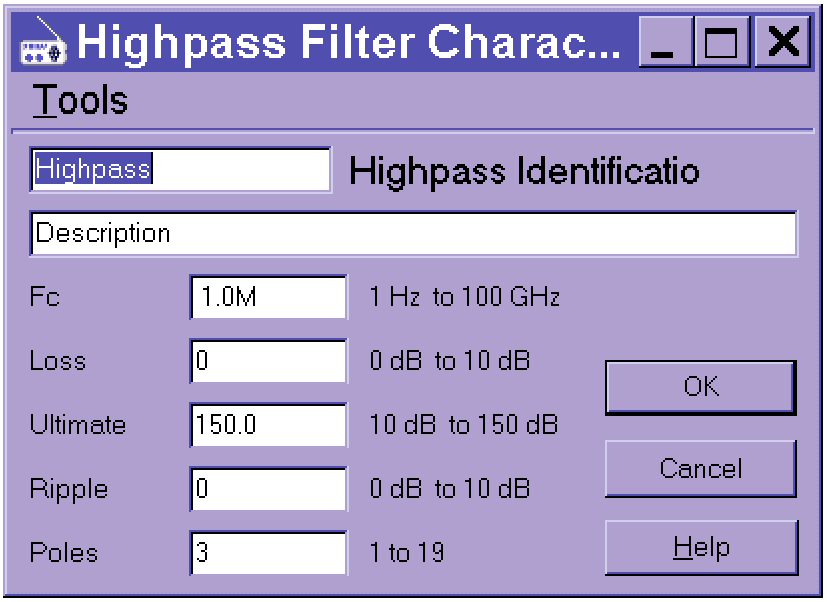
Cancel:

Pressing this button will abort this dialog box. If you were editing an existing bandpass filter, it's entry in the element library will be unchanged. If this was a new filter definition, it will discarded.

Help:

Displays this help page.

8.1.7 Highpass Dialog



For information on the bandpass filter element, see the Highpass Filter element Description.

Tools:

This menu item allows the user to plot either the amplitude, or the delay response of the filter.

Highpass Identification:

The identification consists of two strings. First is the name that will be assigned to this highpass element. In the "Module Definition" dialog, and any block lists, this highpass filter will be identified by the string "1 MHz Highpass". The second string allows the user to enter a short description of the filter, in this case "1 MHz, 3 section, Butterworth Filter".

Fc:

highpass cutoff frequency, expressed in engineering notation. At present, this cutoff frequency is loosely defined.

Loss:

The loss of the highpass filter. During a block analysis, the highpass element will be modeled with a loss equal to this specified loss plus the specified passband ripple.

Ultimate:

The ultimate attenuation of the filter. After reaching the rejection reaches this level, it will be assumed to remain equal to this level. This is used to model leakage around the filter.

Ripple:

The amount of ripple in the highpass passband. This would normally specify the ripple of a Chebyshev passband. During a block analysis, the highpass element will be modeled with a loss equal to the specified loss plus the specified passband ripple.

Poles:

The number of poles in the highpass filter. At present this value is not used by the program, but may be used at a later time to calculate highpass rejection in the stopband.

OK:

Pressing this button will accept the new highpass filter definition, and add the highpass filter, or replace it with the modified definition, in the list of elements available in the element library.

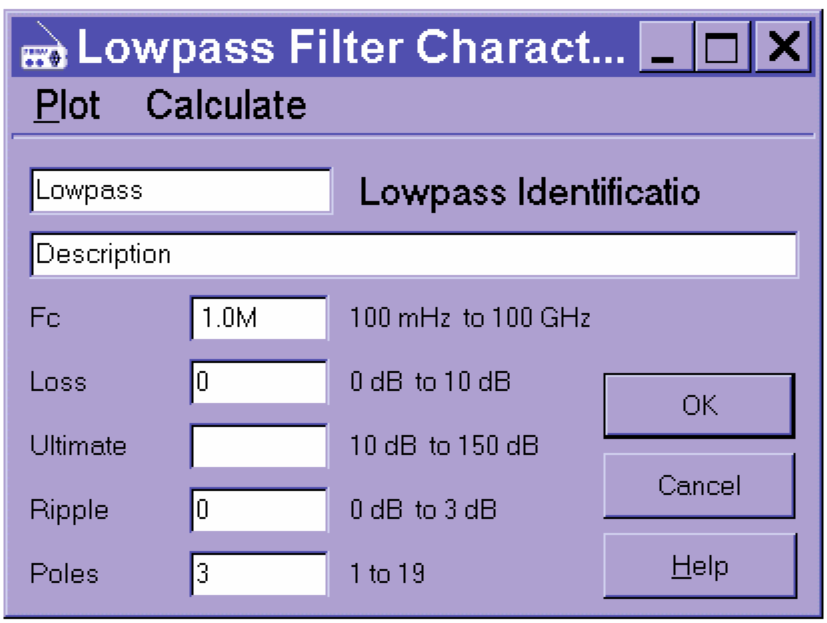
Cancel:

Pressing this button will abort this dialog box. If you were editing an existing highpass filter, it's entry in the element library will be unchanged. If this was a new filter definition, it will discarded.

Help:

Displays this help page.

8.1.8 Lowpass Dialog



For information on the bandpass filter element, see the Lowpass Filter element Description.

Tools:

This menu item allows the user to plot either the amplitude, or the delay response of the filter.

Lowpass Identification:

The identification consists of two strings. First is the name that will be assigned to this lowpass element. In the "Module Definition" dialog, and any block lists, this lowpass filter will be identified by the string "100 MHz Lowpass". The second string allows the user to enter a short description of the filter, in this case "7 Element 0.5 dB Chebyshev".

Fc:

Lowpass cutoff frequency, expressed in engineering notation. At present, this cutoff frequency is loosely defined. In some analyses, it will be assumed to be the noise bandwidth.

Loss:

The loss of the lowpass filter. Usually, a lowpass filter will have no loss at DC, and some finite loss near cutoff. During a block analysis, the lowpass element will be modeled with a loss equal to this specified loss plus the specified passband ripple.

Ripple:

The amount of ripple in the lowpass passband. This would normally specify the ripple of a Chebyshev passband. During a block analysis, the lowpass element will be modeled with a loss equal to this specified loss plus the specified passband ripple.

Poles:

The number of poles in the lowpass filter. At present this value is not used by the program, but may be used at a later time to calculate lowpass rejection in the stopband.

OK:

Pressing this button will accept the new lowpass filter definition, and add the lowpass filter, or replace it with the new definition, in the list of elements available in the element library.

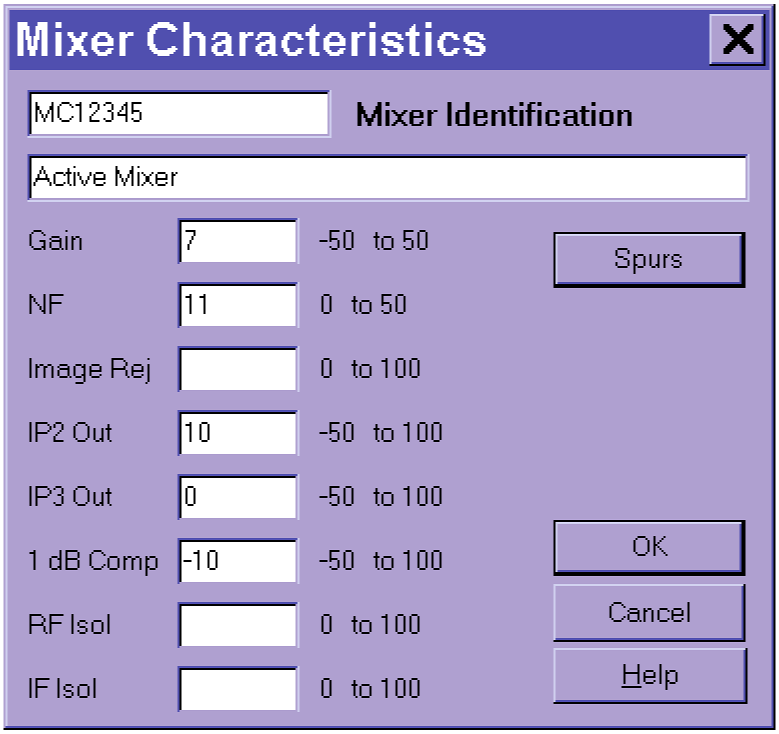
Cancel:

Pressing this button will abort this dialog box. If you were editing an existing lowpass filter, it's entry in the element library will be unchanged. If this was a new filter definition, it will discarded.

Help:

Displays this help page.

8.1.9 Mixer Dialog



For information on the mixer element, see the Mixer Element Description.

Mixer Identification:

The identification consists of two strings. First is the name that will be assigned to this mixer element. In the "Module Definition" dialog, and any block lists, this mixer will be identified by the string "M12345". The second string allows the user to enter a short description of the mixer, in this case "Active Mixer".

Note that the following mixer characteristics are all frequency independent.

Gain:

The mixer gain, expressed in decibels. Loss in a passive mixer is expressed as a negative number.

NF:

The mixer noise figure, expressed in decibels.

Image Rej:

The mixer image rejection. If no rejection is specified, the mixer will fold in image noise.

IP2 Out:

The second order intercept point of the mixer, at the output, expressed in dBm.

IP3 Out:

The third order intercept point of the mixer, at the output, expressed in dBm.

1 dB Comp:

The mixer's 1 dB compression point, at the output, expressed in dBm.

RF Isol:

The mixer's isolation from the LO to the RF port.

IF Isol:

The mixer's isolation from the LO to the IF port.

Spurs:

Pressing this button will open another window, the Spurious Table Dialog, allowing the entry of mixer spurious levels. These are levels of mixer outputs due to various combinations of LO and RF harmonics. The LO harmonic level is assumed to be the specified LO driver for the mixer. The RF level is specified in the Spurious Table Dialog. At the present time, these spurious level characteristics are not used for any purpose.

OK:

Pressing this button will accept the new mixer definition, and add the mixer, or replace it with the new definition, in the list of elements available in the element library.

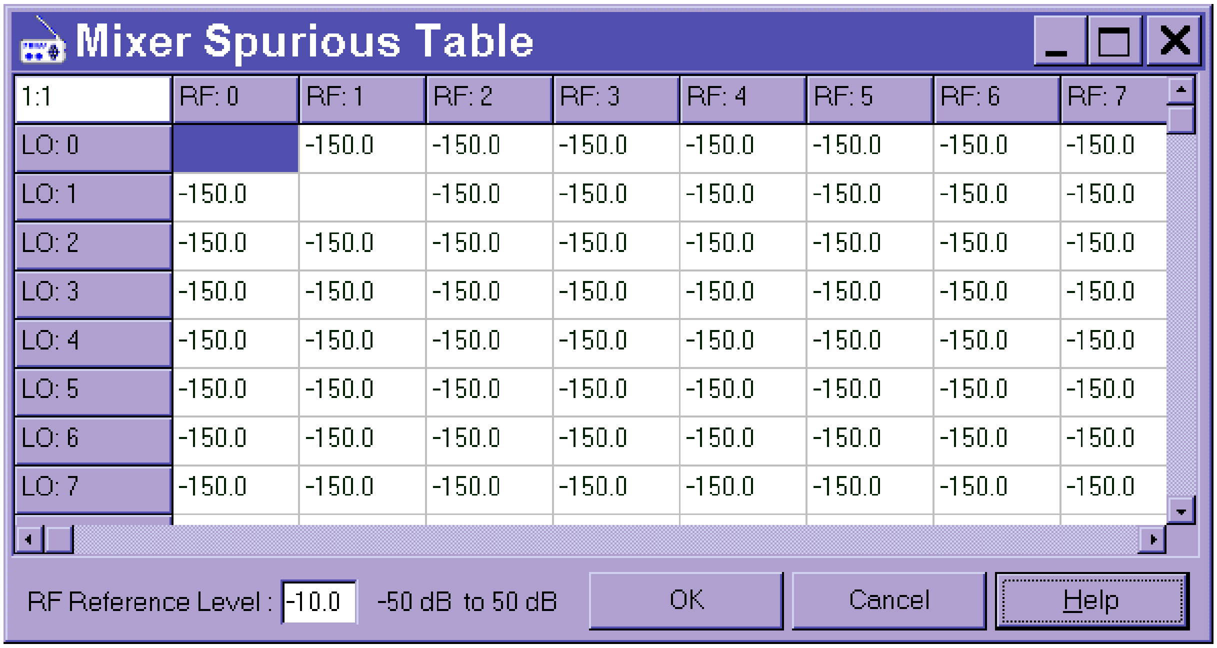
Cancel:

Pressing this button will abort this dialog box. If you were editing an existing mixer, it's entry in the element library will be unchanged. If this was a new mxier definition, it will discarded.

Help:

Displays this help page.

8.1.10 Mixer Spurious Dialog



1:1	RF: 0	RF: 1	RF: 2	RF: 3	RF: 4	RF: 5	RF: 6	RF: 7
LO: 0		-150.0	-150.0	-150.0	-150.0	-150.0	-150.0	-150.0
LO: 1	-150.0		-150.0	-150.0	-150.0	-150.0	-150.0	-150.0
LO: 2	-150.0	-150.0	-150.0	-150.0	-150.0	-150.0	-150.0	-150.0
LO: 3	-150.0	-150.0	-150.0	-150.0	-150.0	-150.0	-150.0	-150.0
LO: 4	-150.0	-150.0	-150.0	-150.0	-150.0	-150.0	-150.0	-150.0
LO: 5	-150.0	-150.0	-150.0	-150.0	-150.0	-150.0	-150.0	-150.0
LO: 6	-150.0	-150.0	-150.0	-150.0	-150.0	-150.0	-150.0	-150.0
LO: 7	-150.0	-150.0	-150.0	-150.0	-150.0	-150.0	-150.0	-150.0

The Mixer Spurious Dialog allows the entry of mixer spurious levels. These are levels of mixer outputs due to various combinations of LO and RF harmonics. The LO harmonic level is assumed to be the specified LO driver for the mixer. The RF level is specified in the Dialog.

This table can be called up from the Mixer Element dialog.

Spurious Levels:

The main portion of the window contains a table of spurious mixer levels. These are the expected output levels for all mixer products up to the tenth harmonic of the RF and LO signals. These expected levels are for the RF input level specified as the RF Reference Level, and are listed as dBc relative to the desired output level. In other words, the 1 x 1 spurious, or desired signal level (shown blank in the table), is by definition, 0 dB. The 0 x 0 spurious is also blank, as there is no 0 x 0 product. All spurious levels default to -150 dBc. Any levels entered may not be less than -200 dBc.

For a discussion of how these spurious levels are computed as the RF level changes, see the description of the Mixer Element.

Note that the LO level is assumed to be fixed.

RF Reference Level:

This is the RF input reference level at which these spurious levels are specified.

OK:

Pressing this button will accept the new mixer definition, and add the mixer, or replace it with the new definition, in the list of elements available in the element library.

Cancel:

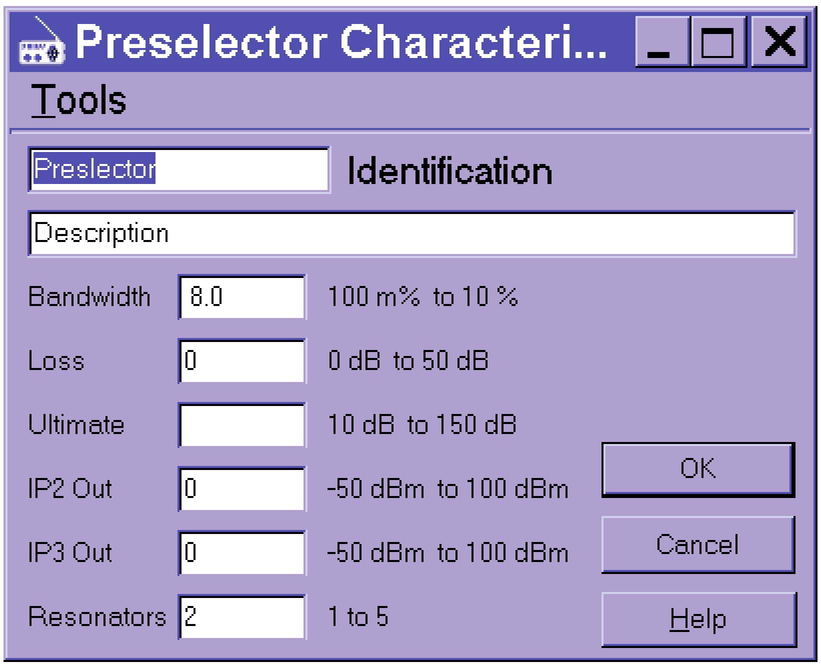
Pressing this button will abort this dialog box. If you were editing an existing mixer, it's entry in the element library will be unchanged. If this was a new mxier definition, it will discarded.

Help:

Displays this help page.

Note that this information is not presently used in this simulation.

8.1.11 Preselector Dialog



For information on the preselector filter element, see the Preselector element Description.

Tools:

This menu item allows the user to plot either the amplitude, or the delay response of the filter. These responses are based on the lowpass equivalent filter (see Lowpass Equivalent Filter discussion.)

Preselector Identification:

The identification consists of two strings. First is the name that will be assigned to this preselector element. In the "Module Definition" dialog, and any block lists, this preselector will be identified by the string "RF Preselector". The second string allows the user to enter a short description of the preselector, in this case "Double Tuned Preselector".

Note that the following preselector characteristics are all frequency independent.

Bandwidth:

Preselector passband bandwidth, expressed as a percentage, in engineering notation. At present, this bandwidth is loosely defined. In some analyses, it will be assumed to be the noise bandwidth.

Loss:

The loss of the preselector.

IP2 Out:

The second order intercept point of the preselector, at the output, expressed in dBm.

IP3 Out:

The third order intercept point of the preselector, at the output, expressed in dBm.

Poles:

The number of poles or resonators in the preselector. At present this value is not used by the program, but may be used at a later time to calculate rejection in the stopband.

DC Zeros:

The number of zeros at DC for the preselector filter. Because preselectors have rather broad bandwidths, the two skirts are normally not symmetrical, and is controlled to a large extent by the number of DC zeros. At present this value is not used by the program, but may be used at a later time to calculate rejection in the stopband.

OK:

Pressing this button will accept the new preselector definition, and add the preselector, or replace it with the new definition, in the list of elements available in the element library.

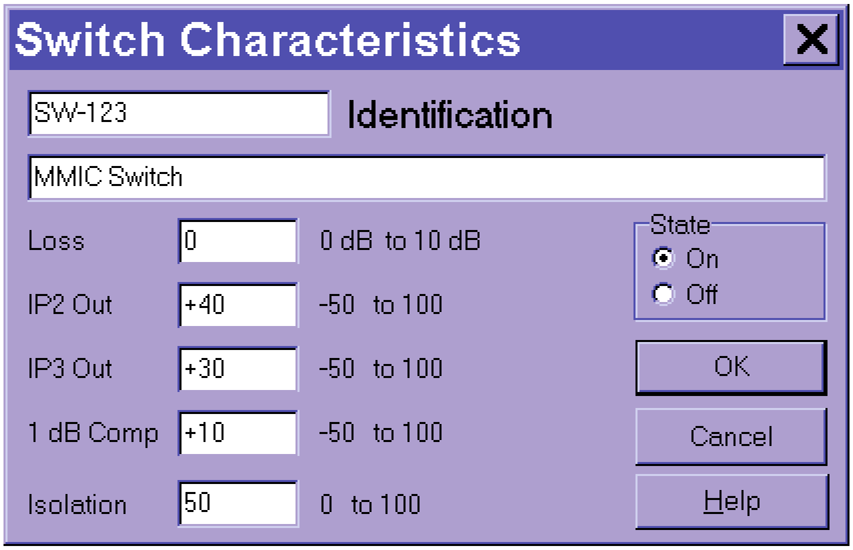
Cancel:

Pressing this button will abort this dialog box. If you were editing an existing preselector, it's entry in the element library will be unchanged. If this was a new preselector definition, it will discarded.

Help:

Displays this help page.

8.1.12 Switch Dialog



For information on the Switch element, see the Switch Element Description.

Switch Identification:

The identification consists of two strings. First is the name that will be assigned to this switch element. In the "Module Definition" dialog, and any block lists, this switch will be identified by the string "SW-123". The second string allows the user to enter a short description of the switch, in this case "MMIC Switch".

Note that the following switch characteristics are all frequency independent.

Loss:

The switch loss, expressed in decibels.

IP2 Out:

The second order intercept point of the switch, at the output, expressed in dBm.

IP3 Out:

The third order intercept point of the switch, at the output, expressed in dBm.

1 dB Comp:

The switch's 1 dB compression point, at the output, expressed in dBm.

Isolation:

The switch's off isolation, expressed in decibels.

State:

Selecting On or Off here will determine whether the switch loss or isolation will be used in block calculations. There is no automatic selection of the switch position in this simulation.

OK:

Pressing this button will accept the new switch definition, and add the switch, or replace it with the new definition, in the list of elements available in the element library.

Cancel:

Pressing this button will abort this dialog box. If you were editing an existing switch, it's entry in the element library will be unchanged. If this was a new switch definition, it will discarded.

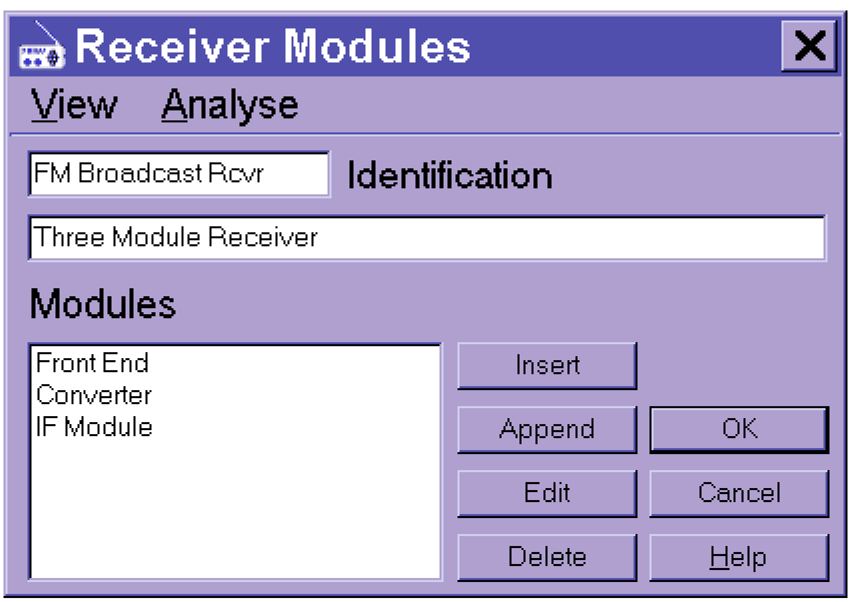
Help:

Displays this help page.

8.2 Module Dialogs

The following dialogs are used to define and edit the module defintions. This will include defining the module as a cascade of elements, and defining the frequency plan, and local oscillator configuration.

8.2.1 Receiver Modules Dialog



View:

This menu item allows the user to view the receiver archetecture as either a Receiver Module Diagram, or a Block Diagram of the elements.

Analyse:

This menu item offers a number of options for analyzing the block parameters of the receiver.

Identification:

The identification consists of two strings. First is the name that will Identify this Receiver, in this case as "FM Broadcase Rcvr". The second string allows the user to enter a short description of the receiver, in this case "Three Module Receiver".

Modules:

This contains a list of all the RF Modules presently defined. The RF Modules are listed in order from the front of the receiver toward the end of the receiver. When the receiver is analyzed the RF Modules will be cascaded in order.

Double clicking on a RF Module in this list will open up the Module Definition dialog, to allow editing the selected RF Module.

Insert:

Pressing this button will create a new RF Module, and open up the Module Definition dialog. When the RF Module dialog box is closed, the new RF Module will be inserted in front of the previously highlighted RF Module.

Append:

Pressing this button will create a new RF Module, and open up the Module Definition dialog. When the RF Module dialog box is closed, the new RF Module will be appended to the end of the RF Module list.

Edit:

Pressing this button will open up the Module Definition dialog, to allow editing the highlighted RF Module. Double clicking on the Module Name

Delete

Pressing this button will delete the presently highlighted RF Module.

OK:

Pressing this button will close the Receiver Modules dialog.

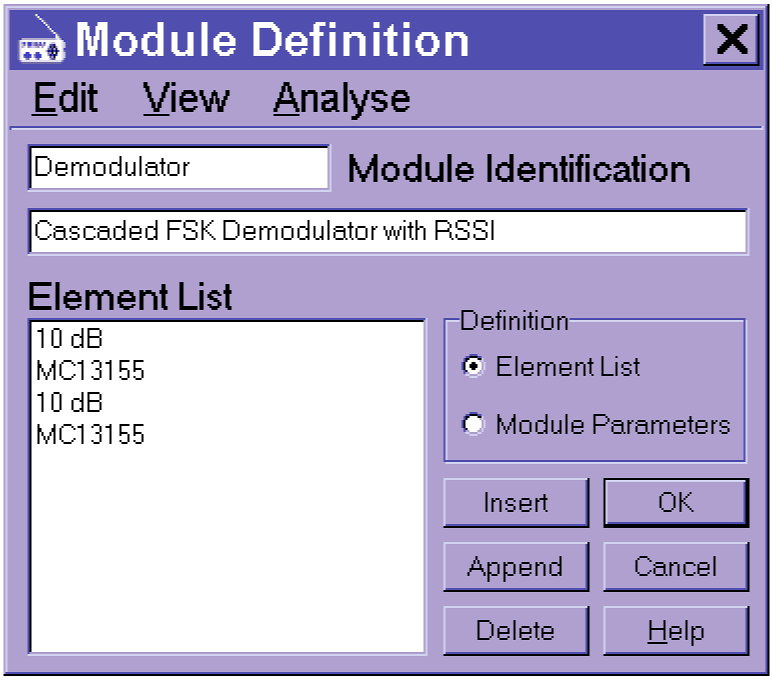
Cancel:

Pressing this button is identical to pressing the OK button. Any changes already made to the existing modules will be retained.

Help:

Displays this help page.

8.2.2 Module Definition Dialog



Edit:

This menu item allows the user to open any of four different dialog boxes to edit the Module Parameters (see Definition, below), or the frequency plan or local oscillator characteristics, if this module is a converter, or open the Edit Element dialog, for defining new Elements

View:

This menu item allows the user to view a block diagram of the module, with or without blocks for each Element.

Analyse:

This menu item offers a number of options for analyzing the block parameters of this module, or display the single signal spurious response, birdies, or LO leakage, if the module is a converter.

Module Identification:

The identification consists of two strings. First is the name that will be assigned to this Module. In the "Receiver Modules" dialog, this module will be identified by the string "RF Module". The second string allows the user to enter a short description of the module, in this case "RF Front End / Mixer".

Element List:

A list of the Elements to be cascaded in the module. They will be cascaded in the order displayed in the list.

Definition:

If the "Element List" radio button is selected, the Module performance will be calculated from the cascade of Elements shown in the Element List.

If the "Module Parameters" radio button is selected, the Module performance will defined by the Module Parameters dialog.

Insert:

Pressing this button will open the "Edit Element" dialog, allowing the user to chose an Element to be inserted in front of the highlighted element in the Element List.

Append:

Pressing this button will open the "Edit Element" dialog, allowing the user to chose an Element to be appended at the end of the Element List.

Delete:

Pressing this button will delete the highlighted element in the Element List.

OK:

Pressing this button will close the Module Definition dialog.

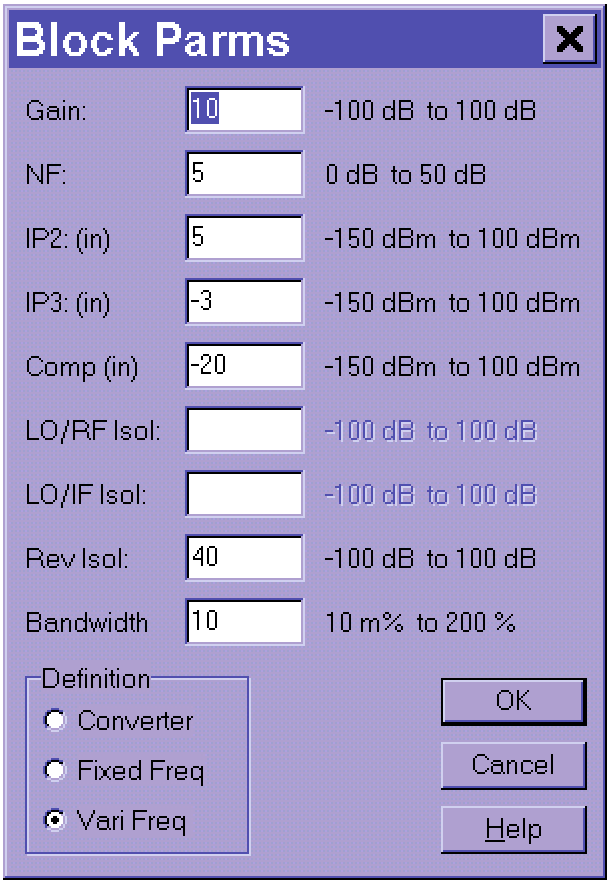
Cancel:

Pressing this button is identical to pressing the OK button. Any changes already made to the existing module will be retained.

Help:

Displays this help page.

8.2.3 Module Parameters Dialog



The parameters defined in the Block Parameters dialog will be used to define the block parameters of an RF module if the "Module Parameters" radio button on the Module Definition dialog is selected. All these parameters, except for bandwidth, are independent of frequency

Note that intercept and compression points are specified at the input of the module, where-as they are specified at the output for all elements.

Gain:

The module gain, expressed in decibels.

NF:

The module noise figure, expressed in decibels.

IP2 In:

The second order intercept point of the module, at the input, expressed in dBm. Note that the specified intercept point for the module is specified at the input, whereas intercept points for elements are specified at the output.

IP3 In:

The third order intercept point of the module, at the input, expressed in dBm.

Comp In:

The module's 1 dB compression point, at the input, expressed in dBm.

LO/RF Isol:

The module's LO to RF (Input) port isolation, expressed in decibels. This will only be enabled if the module is defined as a converter. This parameter is not presently used.

LO/IF Isol:

The module's LO to IF (Output) port isolation, expressed in decibels. This will only be enabled if the module is defined as a converter. This parameter is not presently used.

Rev Isol:

The module's reverse isolation, expressed in decibels. This will only be enabled if the module is not defined as a converter.

Bandwidth:

The module's bandwidth, expressed in engineering format. If the module is defined as fixed frequency or a converter, this is an absolute bandwidth. If the module is defined as variable frequency, it is a percentage bandwidth (referenced to the tuned frequency.) This bandwidth is loosely defined, but will be taken as the noise bandwidth during some simulations.

Definition:

The three radio buttons allows the user to define this module as either a converter, a fixed frequency module, such as a typical IF chain, or a variable frequency module, such as a tuned preselector.

OK:

Pressing this button will accept the new definition, and close the dialog.

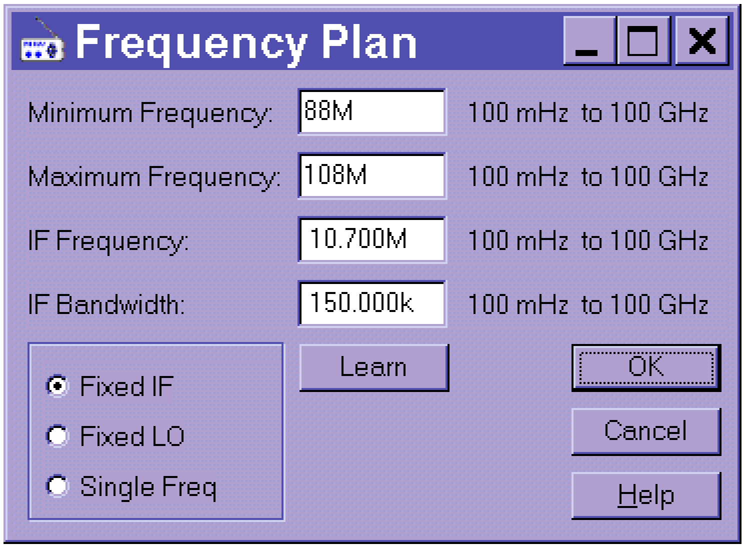
Cancel:

Pressing this button will abort this dialog box, leaving the module characteristics unchanged.

Help:

Displays this help page.

8.2.4 Frequency Plan Dialog



Minimum Frequency:

The minimum RF input frequency to which the converter will be tuned, entered in engineering notation.

Maximum Frequency:

The maximum RF input frequency to which the converter will be tuned, entered in engineering notation.

IF Frequency:

The center frequency of the intermediate output frequency, entered in engineering notation.

IF Bandwidth:

The bandwidth of the IF output, entered in engineering notation. This should normally correspond to the bandwidth of the IF chain following the mixer.

Conversion Type:

How the converter is configured. The standard configuration is Fixed IF where the LO tracks the RF signal frequency to maintain a constant IF frequency. Fixed LO is also know as block conversion, where an entire block of frequencies is converted to a wideband IF. Single Frequency is chosen if all tuning has been accomplished before this converter.

Learn:

Pressing this button will instruct the program to attempt to fill in the IF parameters by performing a quick look at the elements contained within this module.

OK:

Pressing this button will accept the new frequency plan, and close the dialog box.

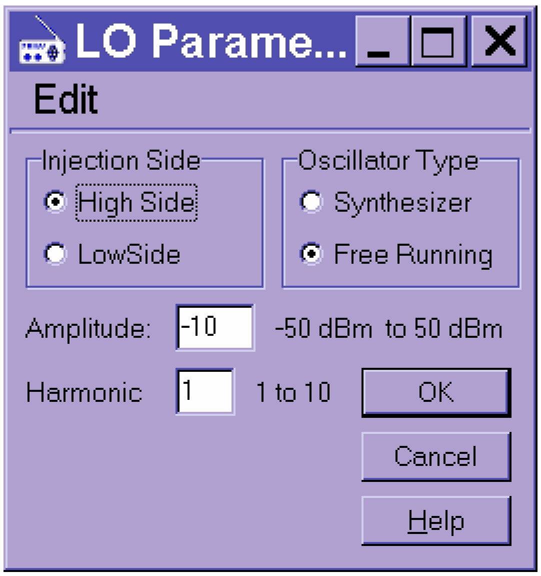
Cancel:

Pressing this button will abort this dialog box. The existing frequency plan will not be changed.

Help:

Displays this help page.

8.2.5 Local Oscillator Dialog



Edit Menu:

This single menu item is intended to allow the user to modify several different parameters of the local oscillator signal, such as noise, harmonics, and spurs. In addition, it will allow parameters to be defined for synthesizer operation. At present, selecting any of these sub-menu items will simply display a message that these items are under construction. Just like the highway department, we've put on the signs long before the work has started.

Injection Side:

Select the correct radio button to indicate whether this converter uses high or low side injection of the local oscillator.

Oscillator Type:

Select the correct radio button to indicate whether this oscillator is free-running (crystal, LC, SAW, etc), or a synthesized (PLL) source. At present this information is not used by this program. In the future it may be used to predict phase noise for the local oscillator.

Amplitude:

The amplitude of the LO signal into the mixer. This information is used for predicing LO leakage at the module or receiver input.

Harmonic:

In most cases we'll use the fundamental of the oscillator as the L.O. However, we may generate the LO at a lower frequency and multiply up. These subharmonics of the injected frequency will need to be included in the spurious analysis.

At present the harmonic number must be set to 1.

OK:

Pressing this button will accept the new LO definition, and close the dialog box.

Cancel:

Pressing this button will abort this dialog box. The existing LO definition will not be changed.

Help:

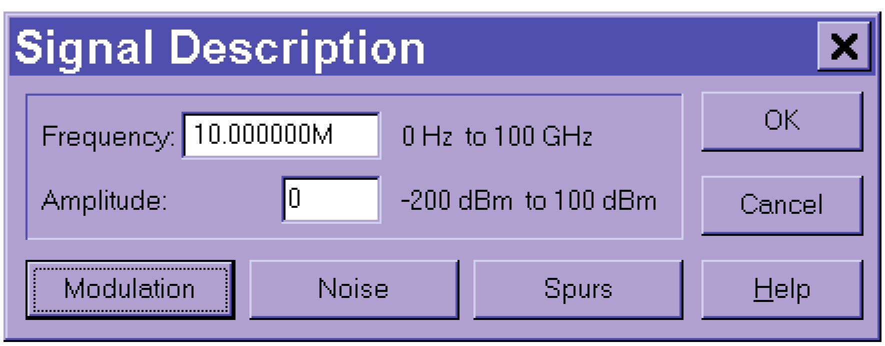
Displays this help page.

8.3 Signal Dialogs

The following dialogs are used to define the characteristics of signals, including the Input Signal, the signal to which the receiver has been tuned.

8.3.1 Input Signal Dialog

Selecing the Edit|Input Signal menu item from the simulator main window will open up a dialog allowing the parameters of the receiver input signal to be modified.

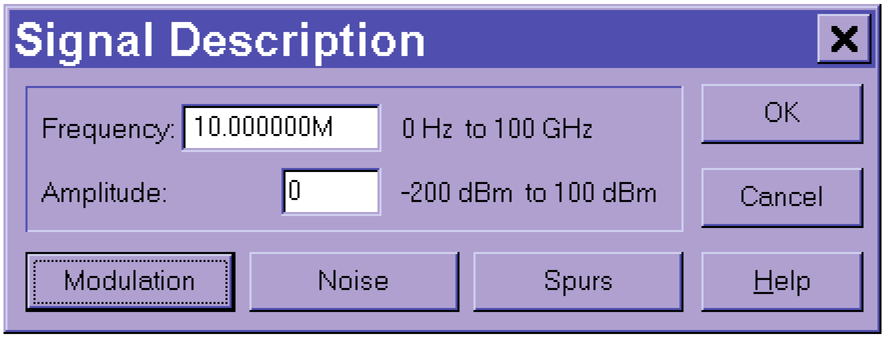


In particular, the frequency and amplitude can be entered directly. The modulation parameters may be modified by pressing the Modulation button.

Note that the tuned frequency is set in the receiver Front Panel dialog. Thus, the input signal may not be at the tuned frequency. In addition, the front panel dialog allows the user to set a range of input power levels for SNR and BER analysis, while the input signal dialog sets a specific power level for the input signal.

The Input signal dialog is one instance of the Signal Description Dialog.

8.3.2 Signal Description Dialog



Frequency:

The carrier frequency of the signal, specified in engineering notation.

Amplitude:

The amplitude of the signal, expressed in dBm. For a full carrier AM signal, this is the carrier level. For FM signals, it is the signal power. For all other signals it is the peak power level.

Modulation:

Pressing this button will display a dialog allowing the user to specify the modulation characteristics of the signal.

Noise:

Pressing this button will display a dialog allowing the user to specify the noise characteristics of this signal. At present it will just display a message box.

Spurs:

Pressing this button will display a dialog allowing the user to specify the spurious characteristics of this signal. At present it will just display a message box.

OK:

Pressing this button will accept the new signal description, and close the dialog.

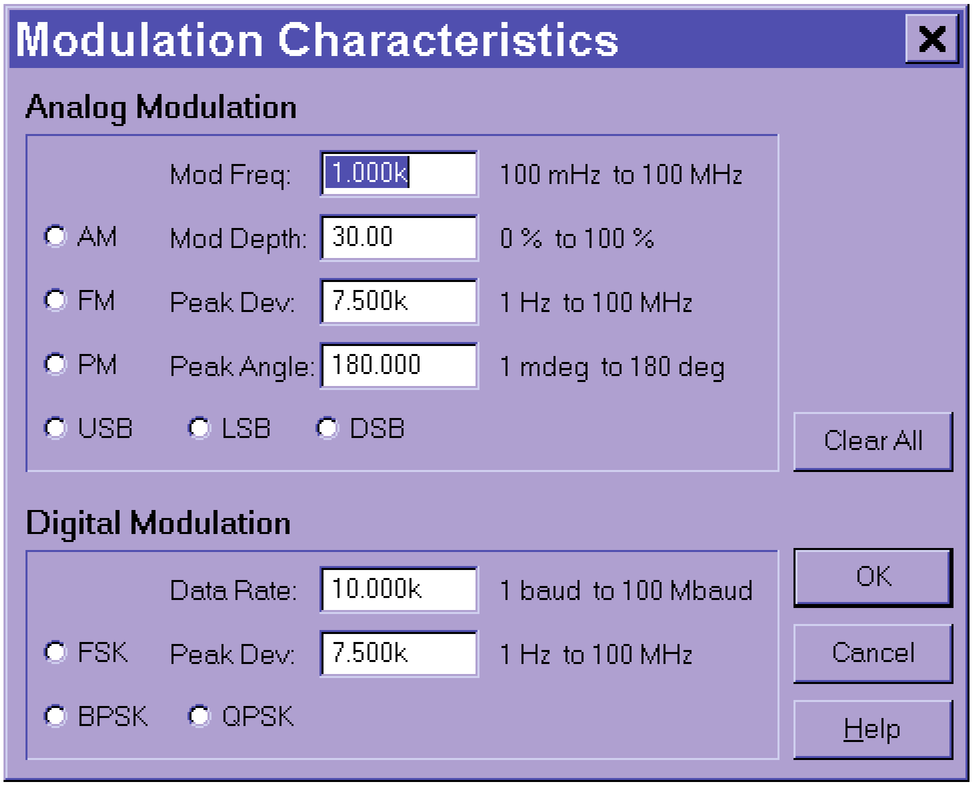
Cancel:

Pressing this button will abort this dialog box.

Help:

Displays this help page.

8.3.3 Modulation Dialog Dialog



Analog Modulation:

Selecting one of these radio buttons will select the associated analog modulation type.

Mod Freq: The frequency of the sinusoidal modulation waveform, expressed in engineering notation.

Mod Depth: The modulation depth of the sinusoidal modulation waveform, when the signal is AM, expressed in percent.

Peak Dev: The peak frequency deviation of the sinusoidal modulation waveform, when the signal is FM, expressed in engineering notation.

Peak Angle: The peak angular deviation of the sinusoidal modulation waveform, when the signal is PM, expressed in engineering notation.

Digital Modulation:

Selecting one of these radio buttons will select the associated digital modulation type.

Data Rate: The baud rate of the digital signal, expressed in engineering format.

Peak Dev: The peak frequency deviation of the data modulation waveform, when the signal is FSK, expressed in engineering notation.

Clear All:

Pressing this button will clear all the radio buttons, resulting in no modulation of the signal.

OK:

Pressing this button will accept the new modulation parameters, and close the dialog.

Cancel:

Pressing this button will abort this dialog box.

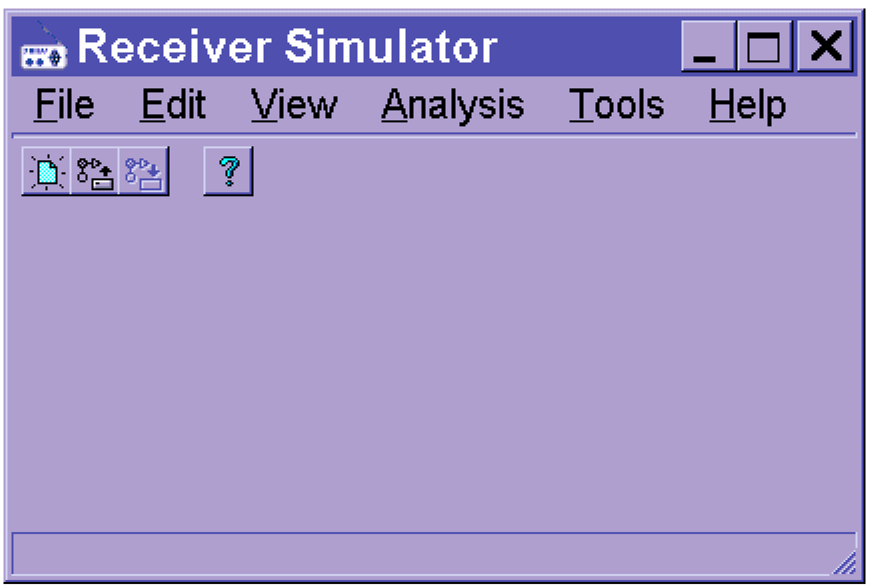
Help:

Displays this help page.

8.4 Receiver Characteristic Dialogs

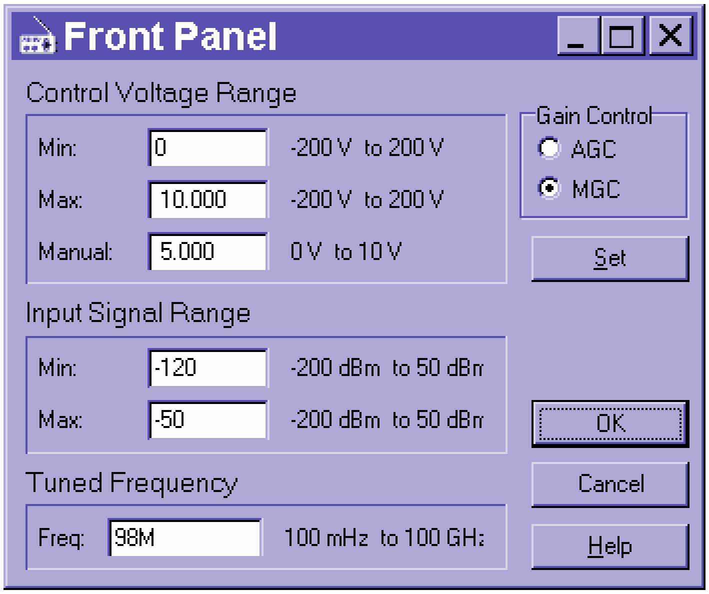
The following dialogs are used to define characteristics of the receiver, such as the tuned frequency, input signal level range, and the demodulator and AGC detector characteristics.

8.4.1 Main Simulator Window



The Main Simulator Window will open when the Simulator Application is first launched. It is described in the "Building a Receiver" section of this document.

8.4.2 Front Panel Dialog



Control Voltage Range:

Min: Minimum AGC voltage. During AGC voltage sweeps, the AGC voltage sweep will start at this limit.

Max: Maximum AGC voltage. During AGC voltage sweeps, the AGC voltage sweep will stop at this limit.

Manual: Use this edit box to set a fixed AGC voltage for analyses that do not sweep or set the AGC voltage. (For example, when calculating Block Parameters, this voltage will be used for all AGC Amplifier elements.)

Input Signal Range:

Min: Minimum input signal level. During input signal level sweeps, the input signal sweep will start at this limit.

Max: Maximum input signal level. During input signal level sweeps, the input signal sweep will end at this limit. .

Tuned Frequency:

Use this edit box to enter the frequency to which the receiver is presently tuned, in engineering format. Note that this is not neccessaryly the frequency of the input signal, which is defined in the input signal dialog. Many analyses will assume that a signal is present at the tuned frequency.

Gain Control:

Select either AGC or MGC to set automatic or manual gain control. If AGC is selected, the program will set a gain control voltage to establish the correct demodulator input signal level during analysis. If the MGC button is selected, the gain control voltage will be set to the Manual setting contained in the Gain Control Voltage pane of this window.

Set:

Pressing this button will set the manual gain control voltage to the value required to bring the input level just up to the level specified for the input to the AGC detector.

OK:

Pressing this button will accept the new front panel description, and close the dialog.

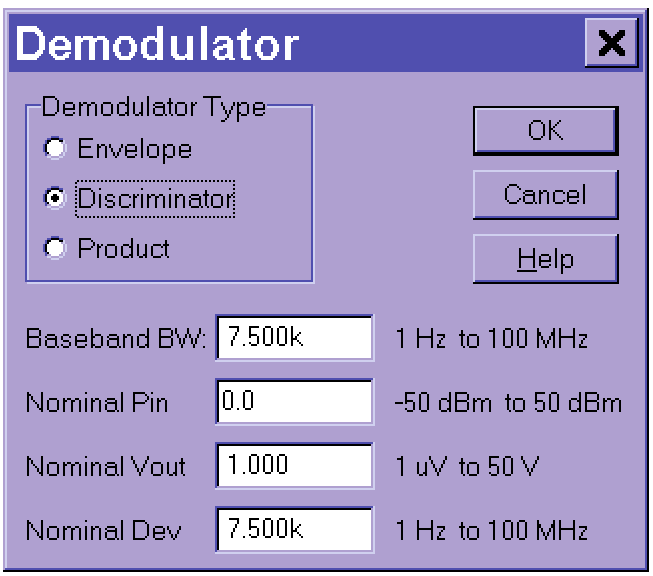
Cancel:

Pressing this button will abort this dialog box.

Help:

Displays this help page.

8.4.3 Demodulator Dialog



Demodulator Type:

Selecting a radio button here will specify the type of demodulator - Envelope (for AM signals only), Discriminator (for FM or FSK signals), and Product (for any type of amplitude modulation.) Note that the demodulator type selected must be compatible with the input signal modulation type.

Baseband BW:

The noise bandwidth of the baseband circuitry in the demodulator, specified in engineering notation.

Nominal Pin:

The input power at which the demodulator is designed to operate.

Nominal Vout:

The nominal output voltage from the demodulator, obtained when the input power is nominal. This parameter is not presently used in any analysis.

Nominal Dev:

The nominal input deviation at which an FM demodulator was designed to operate.

OK:

Pressing this button will accept the new demodulator description, and close the dialog.

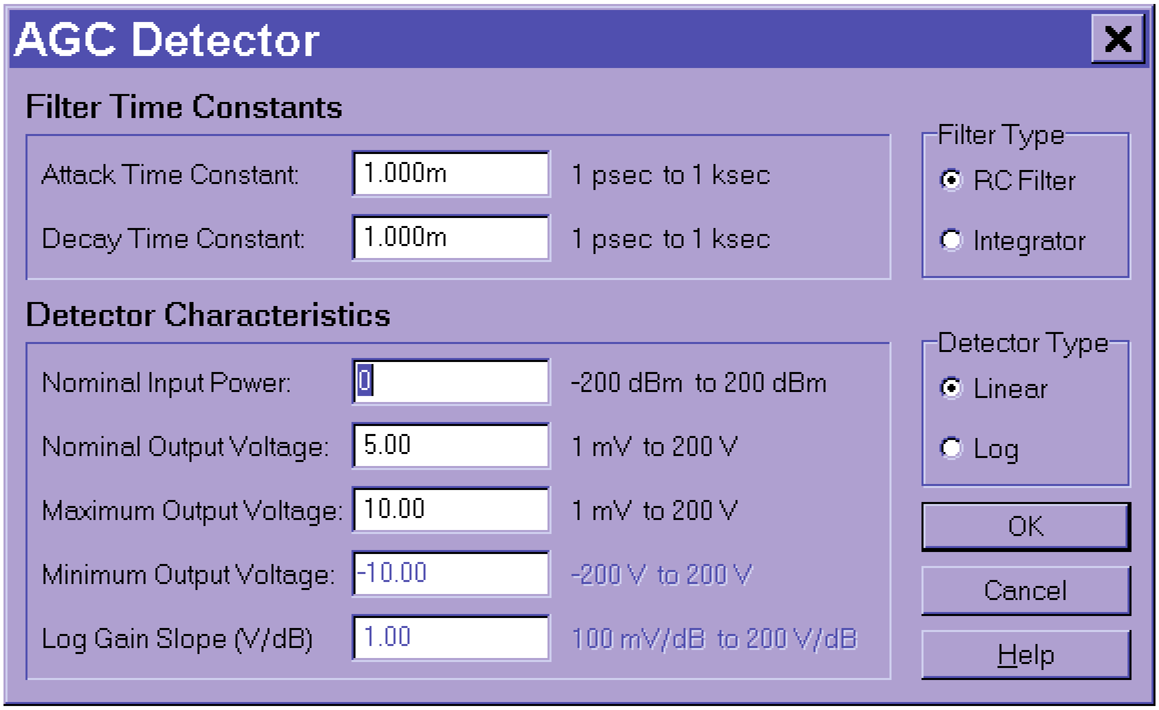
Cancel:

Pressing this button will abort this dialog box.

Help:

Displays this help page.

8.4.4 AGC Detector Dialog



The AGC Detector dialog allows the user to modify several parameters of the AGC detector. The filter type, detector type, and time constants will be used to analyse the transient characteristics of the AGC performance. This has not yet been incorporated into the program. The Detector Characteristics are presently used to set the gain control voltage when the receiver is simuated under AGC control.

Filter Time Constant:

Attack Time Constant:

The time constant for a signal appearing at the detector.

Decay Time Constant:

The time constant for a signal disappearing at the detector.

Detector Characteristics:

Nominal Input Power:

The nominal input power, where the AGC detector is developing the nominal output voltage.

Nominal Output Voltage:

The nominal output voltage, delivered when the input power is at it's nominal level.

Maximum Output Voltage:

The output voltage at which the AGC detector saturates.

Minimum Output Voltage:

The output voltage at which the AGC detector saturates in the negative direction. This is only meaningful for a logarithmic detector. A linear detector will never produce a negative voltage.

Log Gain Slope (V/dB):

The voltage change at the output of the log detector for a 1 dB change in the input power.

Filter Type:

Select the appropriate radio button to specify whether the filter is a simple RC filter, or a integrator.

Detector Type:

Select the appropriate radio button to specify whether the detector is linear or logarithmic.

OK:

Pressing this button will accept the new AGC detector description, and close the dialog.

Cancel:

Pressing this button will abort this dialog box.

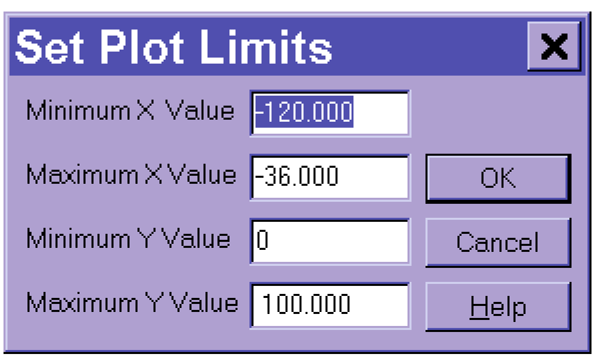
Help:

Displays this help page.

8.5 Analysis Dialogs

These dialogs are used for setting parameters in some of the plot windows.

8.5.1 Plot Limits Dialog



The Plot Limits dialog can be called up any time a plot is being displayed. It is called up using the

Configure|Limits menu item. It allows the user to set the displayed limits of the plot.

Maximum[Minimum] X[Y] Value:

These four edit boxes allow the user to set the lower and upper, X and Y limits for a plot. The data are entered in engineering format.

OK:

Pressing this button will accept the new limits, and close the dialog.

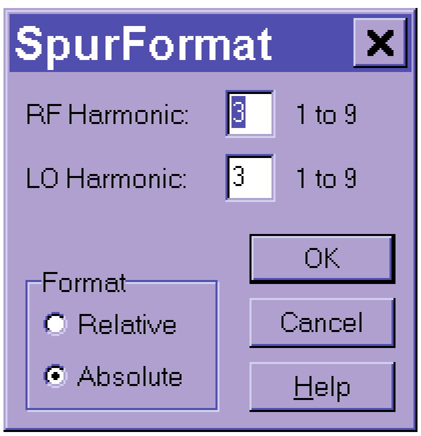
Cancel:

Pressing this button will abort this dialog box.

Help:

Displays this help page.

8.5.2 Spur Format Dialog



The Spur Format dialog can be called up from the Single Signal Spurious Plot window. It is used to set up the parameters and format of the Plot window. The user can select the maximum RF and LO harmonics to plot, and whether the plot is to be in absolute frequency, or relative to the tuned frequency.

RF Harmonic:

The maximum harmonic of the RF signal to consider when calculating spurious responses.

LO Harmonic:

The maximum harmonic of the LO signal to consider when calculating spurious responses.

Format:

Selecting Absolute will display a spurious chart with absolute frequencies as the Y axis. Selecting Relative will display a spurious chart with the Y axis relative to the tuned frequency.

OK:

Pressing this button will accept the new format, and close the dialog.

Cancel:

Pressing this button will abort this dialog box.

Help:

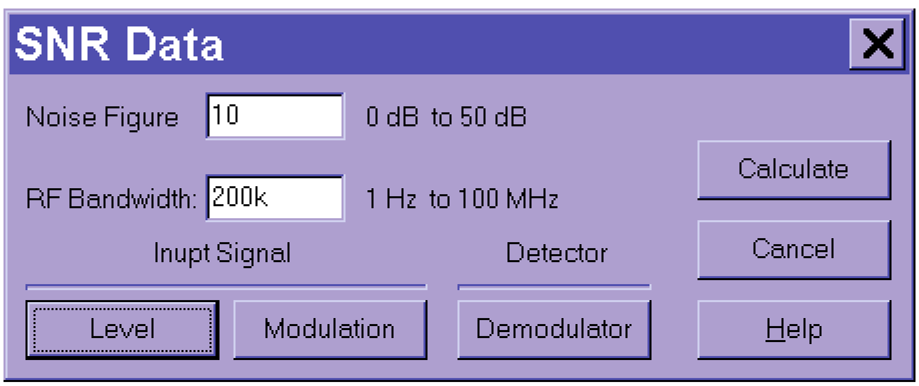
Displays this help page.

8.6 Tools

The following dialogs can be used to run tools for performing calculations. These tools include an SNR plot, BER plot, and attenuator calculator.

8.6.1 SNR Tool

Selecting the Tools|System|Calculate SNR menu item from the simulator main window will bring up a dialog window, allowing the user to enter parameters required to plot the SNR characteristics as a function of the input signal level.



Use of this tool allows the SNR plot to be created without enterring a receiver definition. However, if a receiver definition is presently loaded into the simulator program, any parameters that are redefined will affect the present receiver definition.

Noise Figure:

The noise figure entered into this edit box will be used as the receiver system noise figure. This will not affect the receiver definition.

RF Bandwidth:

The pre-detector bandwidth is entered into this edit box, in engineering format. This will not affect the receiver definition.

Level:

Pressing this button will bring up the receiver Front Panel dialog, allowing the input signal level range to be modified. Any changes to the Front Panel dialog will affect the present receiver definition. Note that other parameters in the Front Panel dialog will be disabled.

Modulation:

Pressing this button will bring up the receiver Input Signal Modulation dialog, allowing the input signal modulation to be modified. Any changes to the modulation dialog will affect the present receiver definition.

Demodulator:

Pressing this button will bring up the receiver demodulator dialog, allowing the demodulator type and baseband bandwidth to be modified. Any changes to the demodulator dialog will affect the present receiver definition. Note that other parameters in the demodulator dialog will be disabled.

Calculate:

Pressing this button will calculate and display a plot of the SNR characteristics of the receiver.

Cancel:

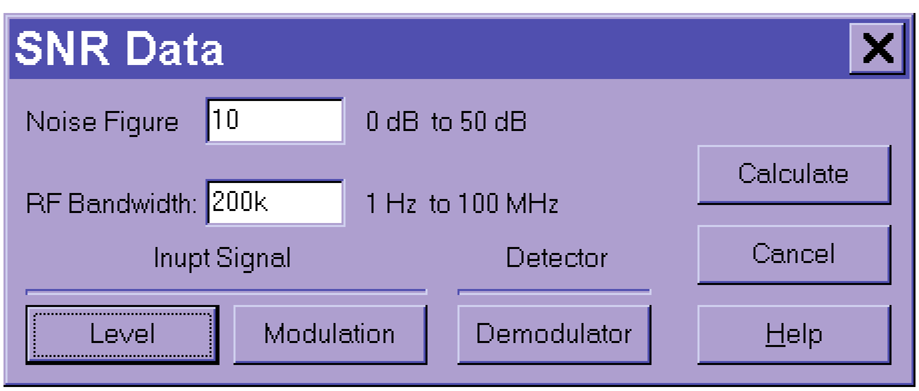
Pressing this button will abort the SNR tool.

Help:

Displays this help page.

8.6.2 BER Tool

Selecting the Tools|System|Calculate BER menu item from the simulator main window will bring up a dialog window, allowing the user to enter parameters required to plot the BER characteristics as a function of the input signal level.



Use of this tool allows the SNR plot to be created without enterring a receiver definition. However, if a receiver definition is presently loaded into the simulator program, any parameters that are redefined will affect the present receiver definition.

Noise Figure:

The noise figure entered into this edit box will be used as the receiver system noise figure. This will not affect the receiver definition.

RF Bandwidth:

The pre-detector bandwidth is entered into this edit box, in engineering format. This will not affect the receiver definition.

Level:

Pressing this button will bring up the receiver Front Panel dialog, allowing the input signal level range to be modified. Any changes to the Front Panel dialog will affect the present receiver definition. Note that other parameters in the Front Panel dialog will be disabled.

Modulation:

Pressing this button will bring up the receiver Input Signal Modulation dialog, allowing the input signal modulation to be modified. Any changes to the modulation dialog will affect the present receiver definition. Note that the modulation type must be a digital format in order to display a BER plot.

Demodulator:

Pressing this button will bring up the receiver demodulator dialog, allowing the demodulator type and baseband bandwidth to be modified. Any changes to the demodulator dialog will affect the present receiver definition. Note that other parameters in the demodulator dialog will be disabled.

Calculate:

Pressing this button will calculate and display a plot of the SNR characteristics of the receiver.

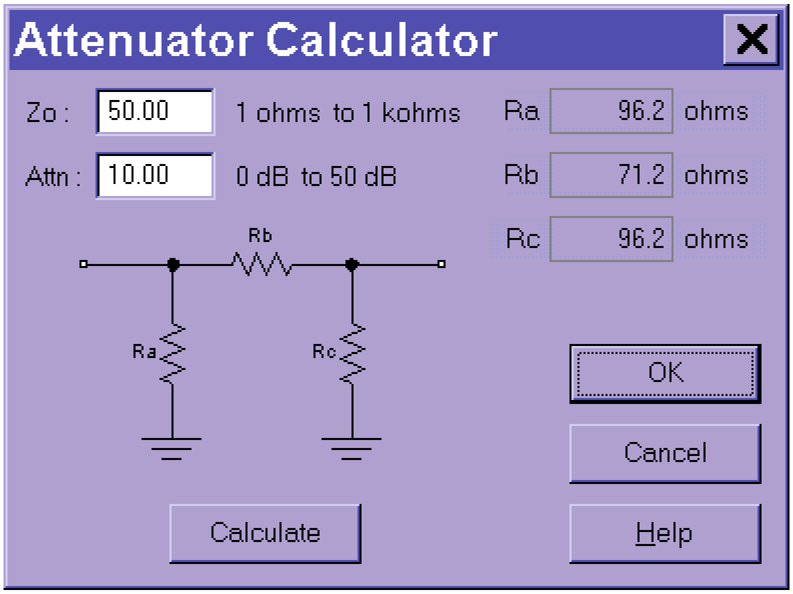
Cancel:

Pressing this button will abort the SNR tool.

Help:

Displays this help page.

8.6.3 Attenuator Calculator Dialog



The Attenuator Calculator dialog can be called up from either the Attenuator Dialog, or from the Tools|Components Submenu on the main receiver window. It is used to calculate the three resistor values for either a PI or T attenuation. The display above shows the dialog calculating the values for a PI attenuator. If a T attenuator has been requested (by selecting the appropriate menu item), the schematic and values will correspond to a T attenuator.

When the impedance or attenuation has been modified, a tab or return will calculate new resistor values.

Calculate:

Pressing this button will calculate and display new resistor values.

OK:

Pressing this button will accept the new limits, and close the dialog.

Cancel:

Pressing this button will abort this dialog box.

Help:

Displays this help page.

9 Receiver Theory

This section will define many of the characteristics that are of concern in a receiver design. These characteristics include noise performance, and spurious performance. Each characterisic will be defined, along with a discussion of it's affect on the receiver performance.

9.1 Noise Figure

All the Receiver Elements represented in this program will add undesired noise to any signals present in the signal path. This additional noise will degrade the signal by decreasing the signal to noise ratio at the output of the Element.

If the input signal to noise ratio for an Element is represented as Si/Ni, and the output signal to noise ratio is represented as So/No (less than Si/Ni because of the degradation caused by the Element), the noise factor can be calculated as:

$$F = \frac{S_i / N_i}{S_o / N_o}$$

The Noise Figure (NF) is just this same value, expressed in decibels.

The Noise Figure of a Receiver Element is either specified (as for an amplifier), or is calculated from characteristics of the Element - for example, the Noise Figure of an Attenuator Element is equal to the attenuation of that Element. A perfect Element would add no additional noise to the signal, and would therefore exhibit a Noise Figure of zero decibels. Any realizable element will add some additional noise to the signal, and must be characterized with a noise figure greater than zero decibels. As a consequence, each additional Element in the Receiver chain will further degrade the signal to noise performance. This degradation is reflected by an increasing Noise Figure as the noise contribution of each additional stage is included in the system performance calculation.

We can increase the signal to noise ratio at the output of the Element by increasing the signal level at the input to that Element. If the signal level is ten dB higher at the input, the noise degradation to the signal caused by this element is reduced substantially. Knowing this, we can improve the system signal to noise ratio (or equivalently, decrease the system noise figure) by adding a large amount of gain near the front of the Receiver (using a low noise amplifier), thereby reducing the signal to noise degradation occurring in later stages. There is a tradeoff, however, with system intermodulation performance, which is degraded by a large amount of gain near the front of the receiver.

As general rules of thumb, in applications where intermodulation performance is important (such as HF applications), the minimum signal level throughout the RF section of the receiver (preceding the narrowband IF filters) should be no more than ten dB above the input signal level (the cumulative gain at any point preceding the narrowband filters should not exceed ten dB.) In applications where the ability to recover low level signals near the noise level is important (generally VHF and UHF applications) the minimum signal level would be more on the order of twenty to thirty dB above the input signal level.

9.2 Intercept Points

All active receiver elements, such as amplifiers, mixers, and electronic switches, and some of the non-active elements, such as varactor tuned filters, will introduce some distortion to the desired signal. The most significant of these are the second and third order distortion products. While these distortion products can be caused by any of the above mentioned elements, we'll limit this discussion to amplifier distortion. The other elements will cause similar distortion products.

Second order distortion is caused by a non-symmetry in the amplifier characteristics. A single ended amplifier will limit on the positive signal peak because the amplifier current drops to zero. On the negative peak, it limits because the transistor saturates. These limiting mechanisms will most likely occur at different levels, and display different characteristics. Thus, a single ended amplifier is inherently non-symmetrical, and will introduce a somewhat predictable second order distortion. A perfectly balanced push-pull amplifier will exhibit a perfectly symmetrical characteristic, and thus will produce no second order distortion. An actual push-pull amplifier will not balance perfectly, and therefore produce a second order distortion product whose phase and amplitude can only be described on a statistical basis (assuming that the imbalance of the amplifier is known only on a statistical basis.)

Third Order Distortion is caused by limiting as the amplifier linearity falls off at the positive and/or negative extremes of the input signal. With a given amplifier, and a fixed bias, this characteristic should be fairly repeatable from amplifier to amplifier. And because the third order distortion is caused by a limiting characteristic, the phase of the distortion product is known, and repeatable.

9.3 Third Order Distortion

Third order distortion is particularly troublesome because it can generate undesired signals close to the signal to which the receiver is tuned. A common example is the standard third order intermodulation test, where two signals are supplied to the receiver, one at the adjacent channel, and the second one channel further away. These two signals then are separated from the desired channel by Δf and 2·Δf. One of the third order products generated by these two signals will fall onto the desired channel. The other product will fall three channels away.

Third order distortion products will increase by 3 dB for every 1 dB increase in the input signal levels. Thus the intermodulation ratio, which is the ratio of the distortion product to the desired signal, will decrease by 2 dB for every 1 dB increase in the input signal level. The third order intercept point is defined as the input (or output) level where the intermodulation product level would just equal the input (or output) signal level, if this 3:1 ratio would continue. (It does not, due to fifth, seventh, etc. order intermodulation products.) Thus the intercept point, intermodulation ratio, and signal level are related by the expression:

$$IP_3 = P_{in} + \frac{IMR}{2},$$

where IP_3 is the third order intercept point in dBm, P_{in} is the input power in dBm, and IMR is the third order intermodulation ratio, in dB.

Because the third order distortion is almost always caused by limiting characteristics, the third order distortion will almost always be out of phase with the fundamental signal. As a result, distortion products from different stages will usually add on a voltage basis. This will result in a three decibel decrease in the system intercept point if two stages cause identical level distortion products. The third order intercept point of N identical third order intercept points is usually considered to drop as 1/N (which must be converted to decibels.)

It has been suggested that signals used for measuring the third order intercept point be coherent, to assure that we are measuring a worst case intermodulation product. Since interfering carriers would not normally be coherent, this is an overly pessimistic test condition.

9.4 Second Order Distortion

The second order distortion product is not usually of as much concern as the third order, because two close signals cannot generate a second order distortion product that is near the two interfering signals. Instead, two adjacent signals will generate second order distortion products near the second harmonic of the two signals, and near zero frequency. Thus the second order distortion is primarily a concern only where the mixer following the amplifier has an input frequency range approaching an octave, or more. With mixers there is an additional problem with the second order distortion product if the I.F. frequency is somewhere around the second harmonic of the input signals. This should normally be avoided.

Second order distortion products will increase by 2 dB for every 1 dB increase in the input signal level. Thus the intermodulation ratio, which is the ratio of the distortion product to the input signal, will decrease by 1 dB for every 1 dB increase in the input signal level. The second order intercept point is defined as the input (or output) level where the intermodulation product level would just equal the input (or output) signal level, if this 2:1 ratio would continue. Thus the intercept point, intermodulation ratio, and signal level are related by the expression:

$$IP_3 = P_{in} + IMR,$$

where IP_2 is the second order intercept point in dBm, P_{in} is the input power in dBm, and IMR is the second order intermodulation ratio, in dB.

Often (particularly if the amplifiers are push-pull) the second order intermodulation distortion products will not add on a voltage basis. Instead, as mentioned earlier, the level and phase of each second order distortion product may be known only statistically. (The phase would normally be 0 or 180°, depending on the asymmetry in the amplifier characteristics.) Thus the second order distortion products will add on a statistical basis. The second order intercept point of N identical second order intercept points is usually considered to drop off as 1/√N (which must be converted to decibels.)

CHECK THIS OUT.

9.5 Second Harmonic Distortion

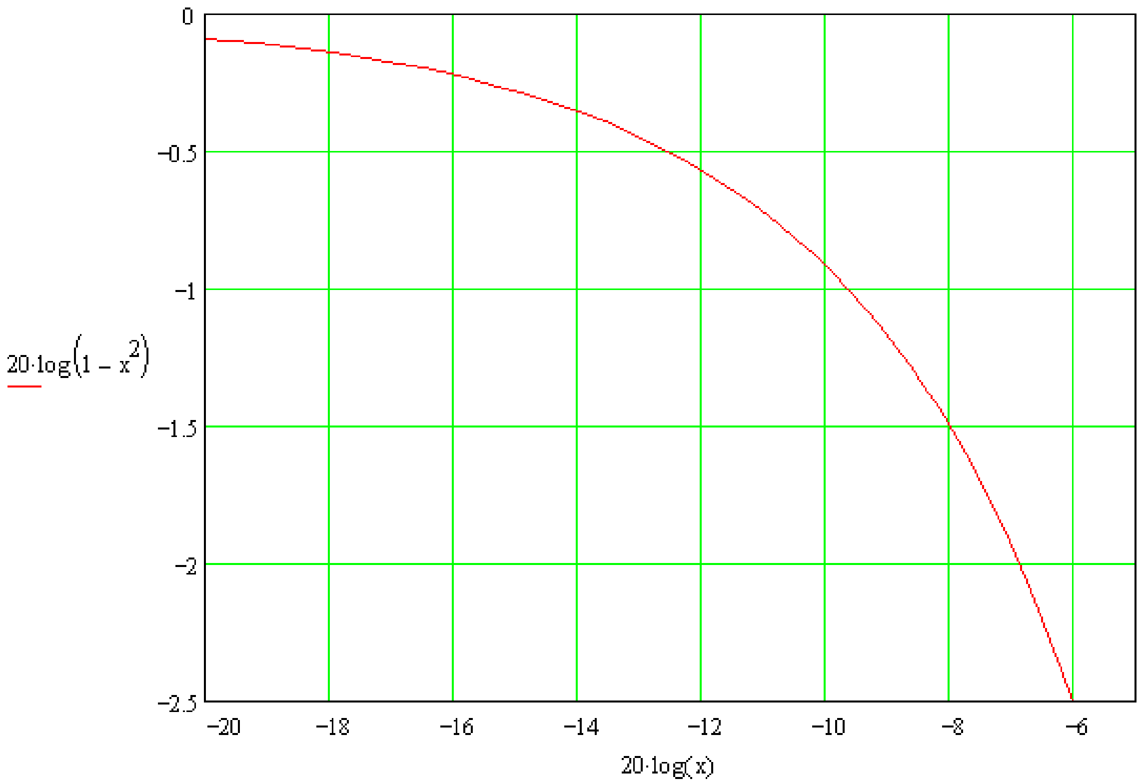
Another Second Order Distortion product is second harmonic distortion. In this case, a signal beats against itself, generating a signal at the second harmonic signal. Since the single signal is beating against itself, we develope a single second harmonic signal which - because the single signal is coherent with itself, will be six decibels higher than the other second order distortion products.

9.6 Compression

Compression is a close cousin of the third order intercept, as the primary contributor to both types of distortion is third order distortion occurring in the receiver.

Usually compression is not a large concern in receiver design, as the third order products become a problem long before compression. However, once the signal has passed the channel selection IF filter, we are no longer concerned about the third order distortion products, as we have now reduced the system bandwidth to a single channel. At this point we are still concerned with compression, as this can cause distortion to the envelope of the desired signal.

Based on a single term approximation - that the only distortion product contributing to the compression is third order, we can plot the expected compression characteristics.



In the above plot, the Y axis shows the compression in decibels. The X axis shows the single level in decibels below the third order intercept point. We can see that the 1 dB compression point should fall occur 9.5 dB below the third order intercept point.

9.7 Frequency Plan

Frequency Plan refers to the choice of IF and LO frequencies within a receiver. The proper selection of a frequency plan is necessary to mitigate the presence of spurious responses, frequencies where the receiver will respond to some frequency other than the tuned frequency. A proper frequency plan will also reduce the presence of birdies, frequencies where the receiver generates a signal at the final IF frequency, from some combination of local oscillator frequencies.

The most common example of an undesired spurious response is the image frequency. Here the receiver will respond to an undesired signal at the image frequency, which is separated from the desired signal by twice the IF frequency. Because the mixer responds equally well to the desired frequency, or the image (unless it's an image rejection mixer), the image signal will produce a signal just as large as an equal level signal at the desired frequency. For this reason image rejection must be provided by selectivity prior to the mixer.

Other spurious responses will be rejected to some extent by the mixer. High performance receivers will typically use double balanced diode mixers to keep the level of these undesired responses to a minimum. In addition, the LO and RF signals provided as inputs to the mixer must be clean, with harmonic levels held down with filters if necessary. Additional suppression of undesired spurious responses can usually be obtained by a proper selection of the frequency plan, and filtering prior to the RF input of the mixer.

Two items are of particular concern in the choice of the frequency plan:

IF Frequency

Injection Side

9.8 IF Frequency Selection

The typically receiver will convert the RF signal down to a lower IF frequency (down conversion). As the ratio of RF frequency to IF frequency increases, it becomes harder to obtain adequate image rejection, as the RF filter required to reject the image frequency becomes a smaller percentage bandwidth. Conversely, as the ratio of the RF frequency to IF frequency gets smaller, a series of cross-over spurious responses occur. These become problems when the tuned frequency is an integer multiple of the IF frequency.

As an alternative, the RF signal might be converted first to a higher IF frequency (up conversion). This is often the frequency plan chosen for HF receivers, where the IF frequency can be limited to a few hundred MHz, or less. A low IF frequency here can create spurious responses. In particular, the IF frequency should be more than twice the highest RF frequency tuned to avoid responding to second harmonic distortion in the mixer.

9.9 Injection Side Selection

Inject side refers to whether the local oscillator frequency is above the RF frequency (high side injection) or below the RF frequency (low side injection.) When up-conversion is employed, (IF frequency is greater than the RF frequency), high side injection is almost always used. When down-conversion is employed, either high side or low side injection can be used.

High side injection, with down conversion, displays a cross over spurious response when the IF frequency is half the tuned RF frequency. In this case, the second harmonic of the spurious signal mixes with the LO signal (the second harmonic of the spurious signal is above the LO frequency) to produce an output signal at the IF frequency.

Low side injection, with down conversion, displays a series of cross over spurious responses when the RF frequency is an integer multiple of the IF frequency. When the IF frequency is half the RF tuned frequency, the second harmonic of the LO signal mixes with the spurious signal (the second harmonic of the LO is above the spurious signal) to produce a signal at the IF frequency. If the LO has significant second harmonic content, the receiver will be very susceptible to this spurious response.

9.10 Spurious Responses

Spurious mixer responses can be divided into several catagories, or families. Some response are characteristic of a frequency plan. Others exist for all frequency plans. Some of these undesired responses that are common to all frequency plans are:

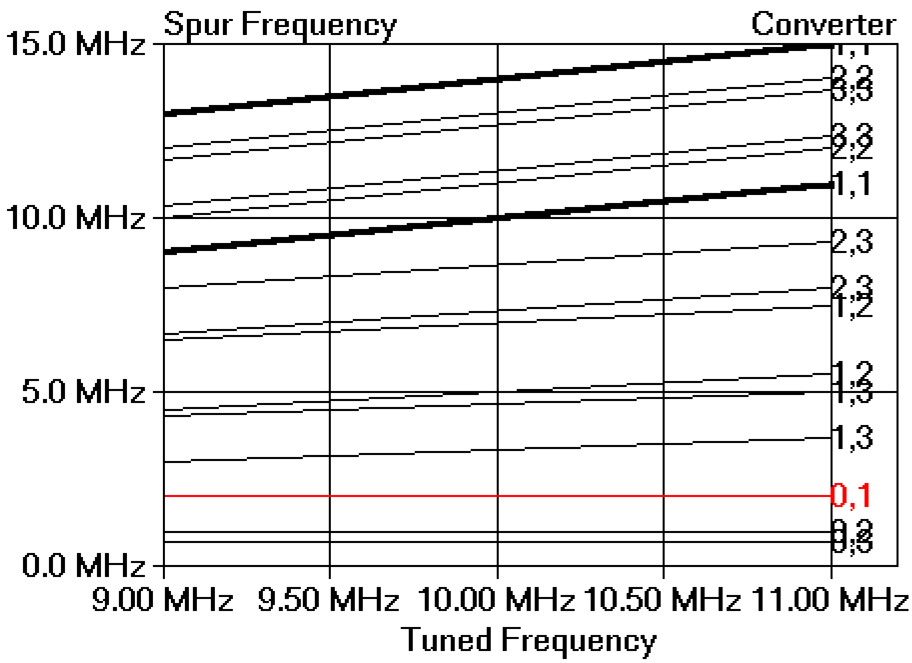
Image Frequency

IF Feedthrough

RF Harmonics

The Single Signal Spurious plot will display these spurious responses. In the following example we display the responses for a mixer that converts the RF input ragne of 9 to 11 MHz to an IF frequency of

2.0 MHz using high side injection.



The lower bold line is the desired signal. The upper bold line is the image response. Both lines are marked as "1,1".

Towards the bottom of the plot is the IF feedthrough (labeled "0,1"), and spurious responses at integer fractions of the IF frequency. These spurious frequencies are not a function of the tuned frequency.

Above the IF feedthrough are the RF harmonic spurious responses. The "1,2" response is at half the RF tuned frequency. The "1,3" response is at a third of the RF tuned frequency.

9.11 Image Frequency

Each mixer can be run with either high side, or low side injection. Similarly, there will always be two frequencies that will mix with the LO to produce a response at the IF. One is at the sum of the IF and LO frequencies (low side injection), and the other is at the difference of the IF and LO frequencies (high side injection.) The RF and LO frequencies are thus separated by a frequency equal to the IF frequency. The image frequency lies at an equal distance from the LO frequency, but on the opposite side.

Unless the mixer provides image rejection, the image response level will be equal to the desired signal response level, and all image rejection must be provided by RF filtering prior to the mixer.

With up conversion, the image filtering may be provided by a lowpass filter, eliminating the need for tuning (but with a requirement for improved signal handling, as the front end is now wide open to signals over the entire band tuned by the receiver.) With down conversion, the image filtering may be provided by a fix tuned bandpass filter, if the RF tuning range is small. If the RF tuning range is large, image filtering will require a tunable preselector that tracks the input tuned frequency.

9.12 IF Feedthrough

A spurious response of concern with any frequency plan is direct feedthrough of the IF frequency from the input. IF rejection is provided by a combination of the mixer (which provides isolation to input signal feedthrough) and filtering prior to the mixer.

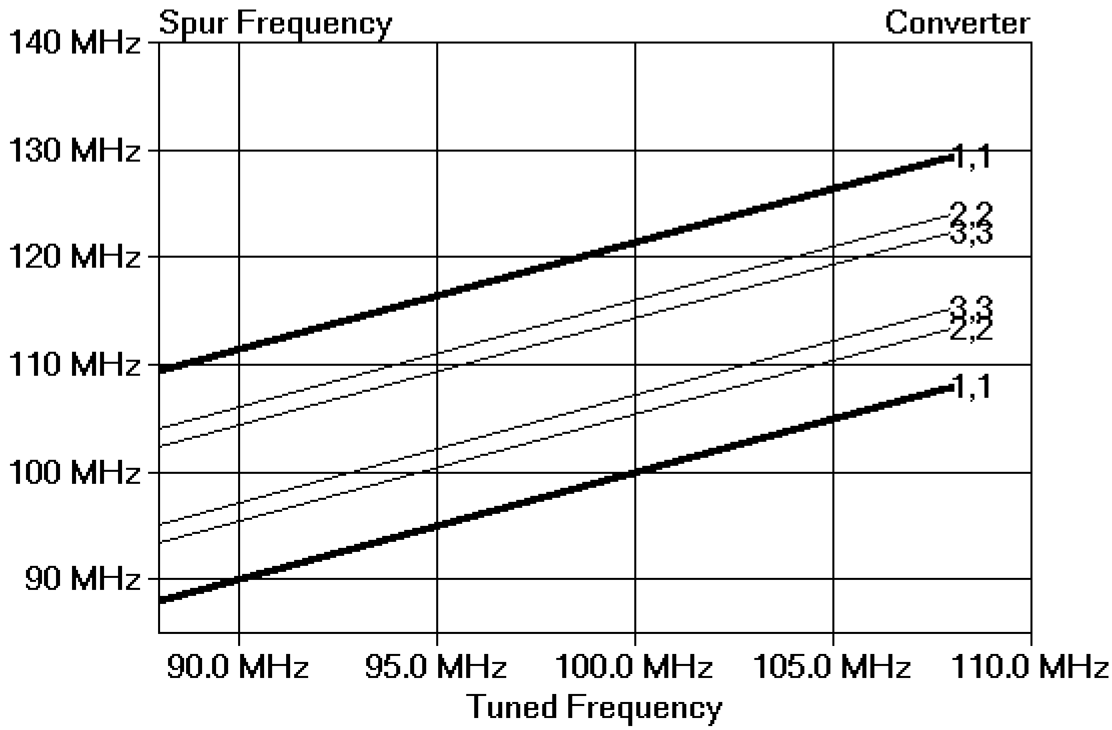
The IF Feedthrough is just one example of an entire family of spurious responses. This spurious response is at half the IF frequency. The second harmonic of this signal, generated in the mixer, will lie at the IF frequency. A similar situation exists for any spurious frequency that is an integer fraction of the IF frequency. In general, as the harmonic number goes up, the level of the undesired response goes down.

9.13 RF Harmonics

The RF harmonics are a family of spurious responses where a harmonic of the spurious frequency falls at the RF frequency. The worst case is the spurious response at half the tuned RF frequency. The mixer will provide some rejection to this response. Where up conversion with a simple lowpass filter is provided, all rejection must come from the mixer. Where a bandpass filter, or tuned preselector is provided prior to the mixer, additional rejection is provided.

9.14 IF Spurs

When the receiver employs down conversion, to a lower IF frequency, a family of spurious responses occur. that lie between the desired RF tuned frequency and the image frequency. They are commonly referred to as the IF spurs, because their spacing from the desired signal is determined by the IF frequency.



The plot above shows a portion of the spurious responses for a frequency plan that converts the FM broadcast band (88 - 108 MHz) down to an IF frequency of 10.7 MHz. The bottom bold line, labeled "1,1", is the desired response - a product of the fundamental of both the RF and LO signals. The top bold line, also a "1,1" response, is the image, twice the IF frequency (21.4 MHz) above the desired response.

Also shown are the "2,2" and "3,3" responses, due to the second harmonic of the RF and LO signals, and third harmonic of the RF and LO signals. The "2,2" is also known as the half IF spur, because it is located at half the IF frequency (5.35 MHz) above the desired signal, or half the IF frequency below the LO signal. Similarly, the "3,3" response is located at a third of the IF frequency below the LO signal. The pattern continues for as many harmonics as you need to consider.

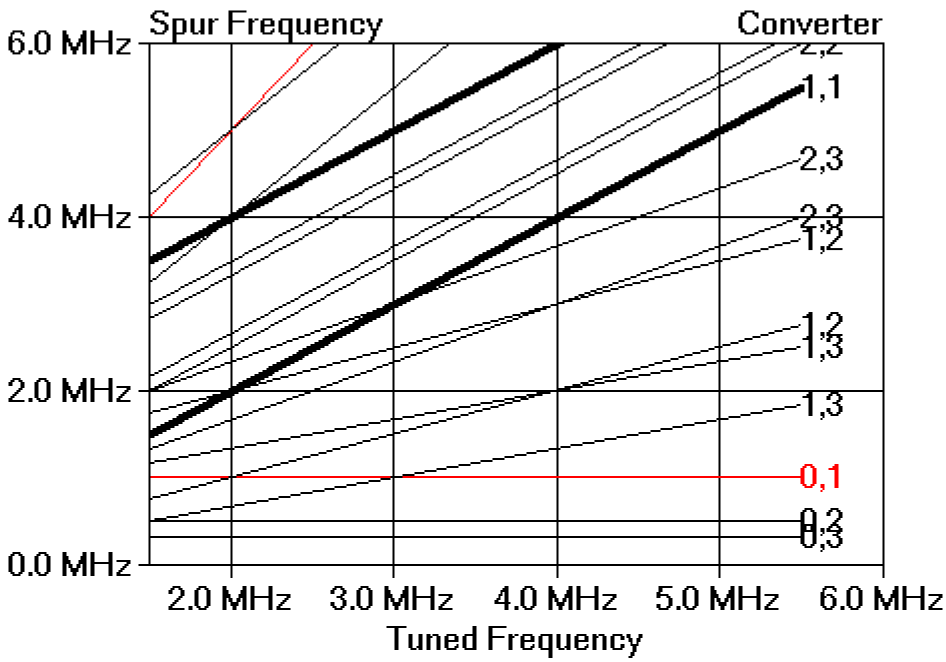
The worst case IF response (other than the image response) is the "2,2", or 2 by 2 response. As the harmonic numbers increase, the mixer response will in general go down, and the frequency separation will increase.

9.15 Crossover Spurs

When the receiver employs down conversion, to a lower IF frequency, a family of spurious responses occur, commonly called cross-over spurs, because the spurious frequency crosses over the desired RF frequency at certain ratios of RF / IF frequencies.

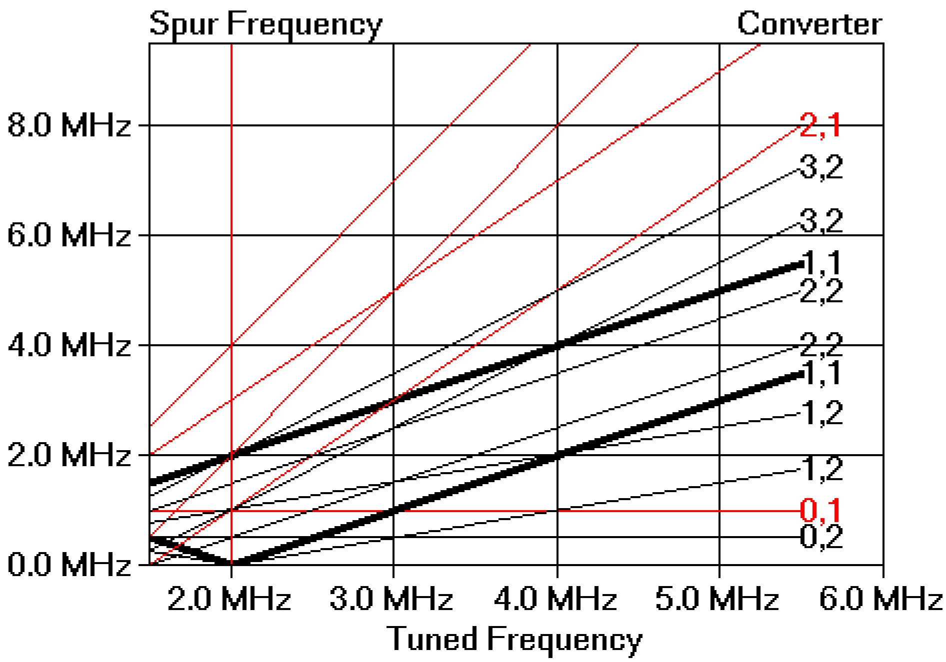
A special case of cross over spurs occurs for cases where the LO and RF harmonics differ by 1. As such they are sometimes called Able-Baker spurs. While they exist for both high-side and low-side injection, they are far more trouble when low side injection is employed. They are primarily a problem when the RF tuned frequency is some small integer multiple of the IF frequency.

9.16 Crossover Spurs - High Side Inj



The above spurious plot shows a frequency plan where RF signals in the range of 1.5 to 5.5 MHz are converted down to an IF frequency of 1.0 MHz, using high side injection. The lower bold line is the desired response. Two lines can be seen crossing over this desired response. The 1 x 2 response (second harmonic of the RF and fundamental of the LO) crosses over the desired response at a tuned frequency of 2.0 MHz, twice the IF frequency. Similarly the 2 x 3 response crosses over the desired responses at a tuned frequency of 3.0 MHz, three times the IF frequency. An entire family exist here with the RF harmonic always one greater than the LO harmonic. The worst case is most likely the 1 x 2 response, which can be a particular problem if the LO contains significant second harmonic content.

9.17 Crossover Spurs - Low Side Inj



The spurious plot above shows a family of crossover responses for the case of low side injection. In this case, the upper bold line is the desired response. A cross-over response occurs at 3.0 MHz. This is a 2 x 1 response, the fundamental of the spurious signal mixing with the second harmonic of the LO signal. Since this is the fundamental of the spurious signal, it will be rejected only by the amount of second harmonic rejection in the LO / mixer combination.

The next crossover response occurs at 4.0 MHz, the 3 x 2 response. As we continue upward in frequency, the harmonic numbers will continue to increase, reducing the level of the spurious response.

Several bad things happen at 2.0 MHz. A serious problem is revealed by the vertical red line at 2.0 MHz. When tuning 2.0 MHz, the LO frequency is 1.0 MHz, which is also the IF frequency. The LO will most likely enter the IF chain and saturate it, making reception of the desired signal impossible.

9.18 Equivalent Lowpass Filter

In order to model a bandpass filter, the response has to be calculated over a small frequency range around the center of the bandpass response. While this is not difficult for a frequency response calculation, it becomes very time consuming for a narrow band filter response in the time domain.

In order to simplify the response calculation, in both the time and frequency domain, this program will model a bandpass filter using it's equivalent lowpass filter, when possible.

In general, the equivalent lowpass filter will contain the same number of elements as the bandpass filter has resonators. Thus, a three resonator bandpass filter response will be modeled using a three element lowpass filter.

The lowpass filter bandwidth with be exactly half the bandwidth of the bandpass filter. Thus, if the lowpass filter response is taken as both the positive frequency, and the mirror image negative frequency response, it will display the same bandwidth as the original bandpass filter. The amplitude and group delay response of this mirrored response will also be identical to the response of a bandpass filter - if the filter were symmetrical.

Because we are using a lowpass filter response, any time domain calculations will be performed at baseband frequencies, rather than at the center frequency of the filter. This will increase the time step size considerably, decreasing the time required for completing the calculations.

Because the lowpass filter response is, by definition, symmetrical, this model will not model the affects of filter asymmetry on the filter response. In particular, there will be no asymmetry of the group delay response when the lowpass equivalent response is used to model the response of a bandpass filter. In general, this will become more noticable as the percentage bandwidth increases, and as the actual filter response becomes more asymmetrical as a result of the coupling type used in the filter.

10 Glossary

This glossary is an attempt to define terms used in this document.

10.1 Able Baker Spurs

Crossover spurs where the RF harmonic and LO harmonic numbers differ by 1. These can be particularly troublesome when low side injection is used, and the RF frequency is near a low integer multiple of the IF frequency.

10.2 AGC

Automatic Gain Control - A feedback system that uses the detected voltage to adjust amplifier gains to maintain a desired detector input signal level.

10.3 AGC Control Voltage

The control voltage used to adjust the gain of amplifiers in a receiver using an AGC loop.

10.4 AGC Detector

An AM detector used to develope an AGC voltage to adjust the gain in an AGC loop.

10.5 AGC Response

Refers to the response of an AGC loop. It usually refers to the speed of attack and decay.

10.6 AGC Attack

The response of an AGC loop to a signal appearing at the receiver input. May refer to the amount of time required to reach a stable output level.

10.7 AGC Decay

The response of an AGC loop when a signal is removed from the receiver input. May refer to the amount of time required to reach full gain.

10.8 Amplitude Modulation

Using a low frequency information signal to vary the amplitude of an RF carrier. It results in two sidebands carrying information, in addition to the carrier signal.

10.9 Analog Modulation

Any form of modulation where the modulating signal is analog.

10.10 Angular Deviation

When an RF signal is phase modulated, the Angular Deviation is the amount of phase change the occurs from the unmodulated carrier signal phase.

10.11 Bandwidth

Frequency limitation of a signal. It may refer to noise bandwidth, 3 dB bandwidth, etc.

10.12 Baseband

Processing that occurs after demodulation. The baseband bandwidth refers to frequency limitations (filtering) applied to the demodulated signal.

10.13 Baud Rate

Number of bits (data plus any overhead) per second. The minimum required frequency content of the data is half the baud rate.

10.14 Birdie

A frequency where some combination of receiver local oscillators results in the presence of a signal at the final IF frequency, creating the appearance of an undesired signal. Also know as a self quieting spurious signal.

10.15 Bit Error Rate

The fraction of bits processed that are recovered incorrectly, usually expressed for a number of bits given as a power of ten, such as 5/10^3 bits.

10.16 Bit Error Rate Plot

This program can plot Bit Error Rate for some combinations of modulation and detector. The plot is bit error rate on a log scale, vs. input signal level.

10.17 Block Conversion

Refers to a frequency plan where a block of input frequencies is converted to a block of IF frequencies using a fixed LO frequency. For example, the range of 10 - 12 GHz might be converted to an IF of 2 - 4 GHz with a 8 MHz LO.

10.18 Block Parameters

In this program, a receiver, RF module, or element can be represented by it's block parameters - gain, noise figure, 2nd and 3rd order intercept points, and compression point.

10.19 BPSK

Biphase-shift keying. A modulation format where the phase of an RF signal is either 0 or 180 degrees (inverted) depending on the value of the modulating bit.

10.20 Capture

An FM demodulator will tend to demodulate the largest signal present at it's input. Thus the largest signal is said to capture the demodulator. Similarly, a limiter will tend to respond primarily to the strongest signal present at it's input, again capturing that signal.

10.21 Carrier to Noise

A ratio of the desired unmodulated signal level to the undesired noise level at the input to a demodulator. Closely related is the signal to noise ratio.

10.22 Cascade

A system where the output of one block or module drives the input of another block or module. This program will calculate the block parameters of a cascade of receiver elements or RF modules.

10.23 Compression

A reduction in gain caused by an amplifier or mixer being driven by the input signal, beyond it's linear signal handling capability. Compression us usually specified at the output level at which the gain has dropped by 1 dB.

10.24 Converter

A block or stage that takes a band of frequencies at the input, and converts it to a frequency, or band of frequencies (block conversion) at the output. See frequency plan.

10.25 Crossover Spurs

A group of mixer single signal spurious susceptibilities where the spurious response frequencies cross over the desired frequency for some tuned frequencies. (Example)

10.26 Decibels

Gains and noise figure are usually refered to in decibels (dB), which is 10*log(x), where x is the ratio. If x is a ratio of some power to 1 mW, the resulting number is refered to as dBm.

10.27 Demodulator

A stage designed to recover the low frequency signal used to modulated an RF carrier. The resultant signal is at baseband.

10.28 Digital Modulation

Any form of modulation where the modulating signal is digital.

10.29 Discriminator

A discriminator is a demodulator that converts the instantaneous frequency to amplitude. It is used for demodulating FM and FSK signals.

10.30 Double Sideband

A signal that contains energy to both sides of the carrier signal (which may itself be suppressed.) Most modulation types are double sideband.

10.31 Double Sided Bandwidth

Refers to the RF bandwidth where both sidebands are present. It is at least twice the bandwidth of the modulation signal (although it may be much greater than that for FM signals.)

10.32 Down Conversion

A frequency plan where an RF signal is converted to a lower frequency IF.

10.33 Element

The basic building block for this program. Examples are amplifiers, attenuators, mixers, and filters.

10.34 Element Library

Contains elements defined for use in this program. May be accessed through the Edit Element dialog.

10.35 Engineering Notation

Engineering notation is a standard floating point number, appended with a character to indicate a power of 1000 (k for thousand, M for million, etc.)

10.36 Envelope Delay

The Envelope, or Group delay, is defined as derivative of the phase response as a function of frequency. The envelope delay is a measure of the time delay of the envelope of an AM modulated signal as it passes through a network.

10.37 Envelope Detector

A demodulator where the output signal is proportional to the instantaneous amplitude of the RF input signal. Used to demodulate standard AM.

10.38 Excess Noise

Noise added by a circuit. It adds to the noise present from thermal noise, and degrades the signal to noise ratio. See noise figure.

10.39 Fixed Frequency Module

An RF Module whose frequency is fixed. A standard IF is a fixed frequency module.

10.40 Fixed IF

Refers to a converter where the LO is variable, converting a range of RF frequencies to a fixed IF frequency.

10.41 Fixed LO

Refers to a converter where the LO is fixed, converting a range of RF frequencies to a range of IF frequencies.

10.42 FM Improvement

When high deviation is used in an FM signal, the signal to noise ratio improves at high signal levels (over a lower deviation signal.) This is known as FM improvement.

10.43 FM Threshold

For large signal levels, the signal to noise ratio at the output of the demodulator for an FM signal increases linearly with the input carrier level. At some low signal level the signal to noise ratio drops much faster as the input carrier level drops. The transition is known as the FM Threshold.

10.44 Free Running Oscillator

An oscillator who's frequency is set by a resonator at the oscillator frequency. It is not locked to an external reference.

10.45 Frequency Deviation

When an RF signal is frequency modulated, the Frequency Deviation is the amount of frequency change the occurs from the unmodulated carrier signal frequency.

10.46 Frequency Modulation

A modulation format where the frequency of the carrier is varied linearly with the instantaneous amplitude of the modulating signal.

10.47 Frequency Plan

The choice of IF and LO frequencies within a receiver. The proper selection of a frequency plan is necessary to mitigate the presence of spurious responses. A discussion of frequency plans can be found here.

10.48 Frequency Shift Keying

Frequency Shift Keying. FM with a digital modulation signal. The carrier frequency shifts between 0 and 1.

10.49 Gain

The output signal level for an element, module, or receiver, divided by the input signal level. Gain is usually expressed in decibels (dB). The gain for cascaded blocks or elements is equal to the sum of the gains for the blocks or elements when expressed in decibels.

10.50 Gain Controlled Amplifier

An amplifier who's gain can be controlled by adjusting a control signal. Used for AM modulated signals, that require linear amplification.

10.51 Harmonic

A signal at an integer harmonic of the desired signal, usually caused by distortion. LO and signal harmonics contribute to spurious responses in a receiver.

10.52 IF Feedthrough

The leakage of an undesired signal at the IF frequency of a receiver, into that IF, usually through leakage in a mixer.

10.53 Image Frequency

Any mixer will convert at least two frequencies to the IF frequency. One the sum of the LO and IF frequencies. The other is the difference. One is desired, the other is the image. The image is seperated from the desired signal by twice the IF frequency.

10.54 Image Rejection

Image rejection is a measure of the relative response of a receiver between a desired signal and it's image. Image rejection is usually obtained by a filter in front of the mixer, with the desired amount of rejection at the image frequency. Additional image rejection can be obtained by using an image rejection mixer.

10.55 Impedance Matching

In a receiver, stages connected together should display the same impedance at their junction. Mismatch in impedance can decrease gain, increase noise, and degrade spurious performance. Matching of a mixer must be considered at the desired and image frequencies, and at all frequencies where products may be formed.

10.56 Injection Side

A mixer uses high side or low side injection. High side refers to an LO signal higher in frequency than the RF input signal. Low side refers to an LO signal lower in frequency than the RF input signal. Choice of injection side can significantly influence the presence of spurious responses in the receiver.

10.57 Input Noise

The receiver will have input noise due to the thermal energy at the input. There will be additional apparent noise due to the finite noise figure of the receiver.

10.58 Input Signal

The desired input signal. In this simulator, several characteristics of the input signal can be set in the Input Signal dialog.

10.59 Integrator

This receiver can use an integrator filter in the AGC detector. With a constant input to the AGC detector, the output voltage will ramp up (or down) linearly with time. This filter is used because the DC gain is infinite, resulting in a constant demodulator output level.

10.60 Intercept Point

A hypothetical power level where the level of the undesired intermodulation product equals the level of the desired signals.

10.61 Intermediate Frequency

In a receiver the RF signal is usually converted down to a lower (intermediate) frequency for amplification. In some cases the RF signal may be converted up to a higher intermediate frequency. There may be several conversions to different IF frequencies.

10.62 Intermodulation Distortion

Distortion caused by a non-linear voltage or current characteristic, causing two or more signals to form undesired mixing products at other frequencies.

10.63 Isolation

The ability to keep a signal at one point in a receiver from reaching another point - Reverse Isolation, LO / RF isolation, LO / IF isolation are typical parameters for a receiver.

10.64 Limiter

FM receivers make no use of amplitude variations of the input signal. The presence of amplitude variations may in fact appear as noise to the demodulator. To remove amplitude variations on the signal, the signal is usually passed through one or more limits - stages designed to saturate in a well defined manner, to eliminate amplitude variations without changing the bias conditions of the limiter amplifier.

10.65 Linear Detector

The AGC detector may be a linear detector. This is a detector who's output voltage is proportional to the RF input signal voltage (or the square root of the input power.)

10.66 Local Oscillator

The local oscillator is a signal provided to a converter to convert the input signal to an IF signal. Dirty LO signals (noise or harmonics) can degrade the performance of a receiver.

10.67 LO Leakage

LO signal from the mixer will always be present at the module, or receiver input. This LO signal is present because the reverse isolation of the amplifiers is finite, and filters have limited rejection at the LO frequency. The isolation from the LO to the module or receiver input is the LO isolation, and the measured level of the LO signal(s) is the LO Leakage.

10.68 Logarithmic Detector

The AGC detector may be a log detector. This is a detector who's output voltage is proportional to the logarithm of the RF input signal level. Log detectors are used for equal attack and decay times.

10.69 Lowpass Equivalent Filter

A lowpass filter with a response that is the same as the one-sided response of a bandpass filter. The number of elements is the same as the number of resonators in the bandpass filter. See Lowpass Equivalent discussion.

10.70 Mixer

A circuit used to convert an RF frequency to a different IF frequency. The mixer must be provided with an LO signal equal to the sum or difference of the RF and IF signals.

10.71 Modulation

The process of varying some parameter of an RF carrier (amplitude, frequency, phase, or a combination) using a lower frequency signal that conveys information. Modulation may be analog or digital.

10.72 Modulation Depth

For AM modulation, refers to how far down the RF carrier voltage is reduced for a maximum negative excursion of the modulation signal. 100% modulation occurs when the RF voltage is cut off entirely at negative peaks in the modulation.

10.73 Noise Bandwidth

The equivalent ideal bandwidth of a filter based on the amount of noise that passes through. When calculating noise power, the filter noise bandwidth is multiplied by the level of the noise in dBm / Hz.

10.74 Noise Factor

Identical to Noise Figure except that Noise factor is a ratio, Noise figure is the Noise Factor expressed in decibels.

10.75 Noise Figure

A measure of noise added by an element, block, or receiver, expressed as a ratio of output noise added by the element, block or receiver, divided by the output noise due to amplified input thermal noise. Noise figure is expressed in decibels (dB).

10.76 Phase Locked Loop

In this simulation this refers to a Local Oscillator who's frequency is locked to an external reference.

10.77 Phase Modulation

A modulation format where the phase of the carrier is varied linearly with the instantaneous amplitude of the modulating signal.

10.78 Phase Noise

Refers to noise sidebands present on an RF signal. The noise represents frequency (or phase) modulation, because the oscillator is of a constant amplitude. Excess phase noise will compromise a receiver's performance.

10.79 Preselector

A narrowband RF filter (typically a bandwidth of a few percent of the center frequency). In this program the preselector is tunable, and will be automatically tuned to match the receiver frequency.

10.80 Product Detector

A demodulator where the output signal is the product of the IF signal and a local oscillator at the IF frequency. A product detector mixers the IF signal down to baseband.

10.81 QPSK

Quadrature phase-shift keying. A modulation format where the phase of an RF signal is either 0, 90, 180, or 270 degrees depending on the value of two modulating bits. QPSK can also be treated as two orthogonal BPSK signals.

10.82 RC Filter

A lowpass filter consisting of a single RC section. This receiver can use an RC filter in the AGC detector. With an RC filter, the output signal level will vary as the input signal level varies.

10.83 Roofing Filter

The IF stages of a modern receiver are usually high gain and broadband, resulting in a high level of noise over a broad bandwidth. This wideband noise can interfere with the proper operation of the demodulator circuitry.

In many cases an additional IF filter is included just prior to the detector circuitry, to reduce the amplitude of this wideband noise. This roofing filter is generally a fairly simple filter, often consisting of no more than two resonators.

10.84 RF Module

In this simulator, the RF Module represents a functional section of the receiver. It may be fixed frequency, as a typical IF, variable frequency, as a tunable preselector, or a convertor. It may be defined by block parameters, or contained elements. If a converter, it has an associated frequency plan and local oscillator.

10.85 RF Module List

The RF Module List is displayed in the Receiver Modules dialog. It contains a list of all the RF modules presently defined in the simulation.

10.86 Saturation

All amplifiers will eventually saturate - their output signal level will begin to increase more slowly than the input signal rises. Saturation causes the creation of harmonics, and distorts the envelope or amplitude of a signal.

10.87 Second Harmonic Distortion

A distortion product caused by a squared voltage or current term. The second harmonic is at twice the frequency of the input signal. The second harmonic distortion product is 6 dB higher than the second order distortion products for two input signals.

10.88 Second Harmonic Intercept Point

A hypothetical power level where the second harmonic level equals the level of the desired signal. The second harmonic intercept point is 6 dB higher than the second order intercept point.

10.89 Second Order Distortion

A distortion product caused by a squared voltage or current term. With two equal amplitude signals applied to a receiver, third order distortion products are produced at the sum and difference of the two desired signals.

10.90 Second Order Intercept Point

A hypothetical power level where the level of the second order products equals the level of the desired signals.

10.91 Self Quieting Spurs

Another name for Birdies.

10.92 Sideband

When a signal is modulated, the information is always carried by energy to the sides of the carrier. These are the sidebands. Each sideband will occupy at least as much spectrum as the modulating signal.

10.93 Signal Handling Capabliity

Any amplifier will distort if the input signal level rises high enough. This distortion defines the signal handling capability of the amplifer. Signal handling capability might be determied by intermodulation, or compression.

10.94 Signal to Noise

A ratio of the desired output signal level to the undesired output noise level. Closely related is the carrier to noise ratio.

10.95 Single Frequency

In this program, Single Frequency refers to a converter stage with a fixed RF and fixed IF frequency. This requires that any required tuning be accomplished prior to this converter stage.

10.96 Single Sideband

An amplitude modulated signal (AM) produces two sidebands, one on each side of the carrier. Because they carry identical information, one can be eliminated, along with the carrier that carries no information. The resultant signal is called single sideband (SSB), and must be recovered with a product detector.

10.97 Single Sided Bandwidth

Refers to the RF bandwidth where only one sideband is present. The single sided bandwidth is often the same as the baseband bandwidth. Most modulated signals occupy the double sided bandwidth.

10.98 Single Signal Spurious

An frequency where the receiver will respond to an undersired signal. The image frequency is an example of a single signal spurious susceptibility.

10.99 Single Signal Spurious Plot

A plot of the single signal spurious responses. It may include Image, IF feedthrough, RF Harmonics, IF spurs, and Crossover spurs.

10.100 Birdie Plot

A plot of the birdies, or self quieting spurs present in a receiver architecture. This is displayed as a function of the tuned frequency.

10.101 Spurious Responses

Spurious responses usually refer to two types of receiver responses.

Spurious susceptibility refers to spurious responses of the receiver to input signals at frequencies other than where the receiver is tuned.

Self quieting spurs, or birdies, refer to spurious signals generated by the receiver that the receiver responds to as a desired signal.

In addition, spurious responses may exist from the combination of multiple input signals.

10.102 Spurious Signals

Spurious signals usually refers to undersired signals accompanying a desired signal. These may include noise, or discrete spurious signals.

10.103 Synchronous Defector

Another name for a product detector.

10.104 Synthesizer

A circuit that synthesizes an RF signal from other RF signals. In this program a synthesizer is synonomous with a phase locked loop.

10.105 Third Order Distortion

A distortion product caused by a cubed voltage or current term. With two equal amplitude signals applied to a receiver, third order distortion products are produced as a signals on each side of the two desired signals, with the same spacing as the two desired signals.

10.106 Third Order Intercept Point

A hypothetical power level where the level of the third order products equal the level of the desired signals.

10.107 Time Constant

The time required for a voltage to slew up or down. For an integrator, the output slews an amount equal to the input in one time constant. An RC filter start slewing at the same rate, but the voltage rises or decays exponetially.

10.108 Ultimate Rejection

Many filters exhibit a rejection that increases towards infinity as the frequency moves further and further into the rejection band of the filter. This infinite rejection is not seen in practice, do to leakage around the filter, and imperfect elements in the filter. The maximum guaranteed rejection in the stopband is often specified as the ultimate rejection of the filter.

10.109 Up Conversion

A frequency plan where an RF signal is converted to a higher frequency IF.

10.110 Variable Frequency Module

In this program a Variable Frequency Module is an RF Module with some RF bandwidth (expressed as a percent of the tuned frequency) that is tuned in frequency to the same frequency as the receiver.

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