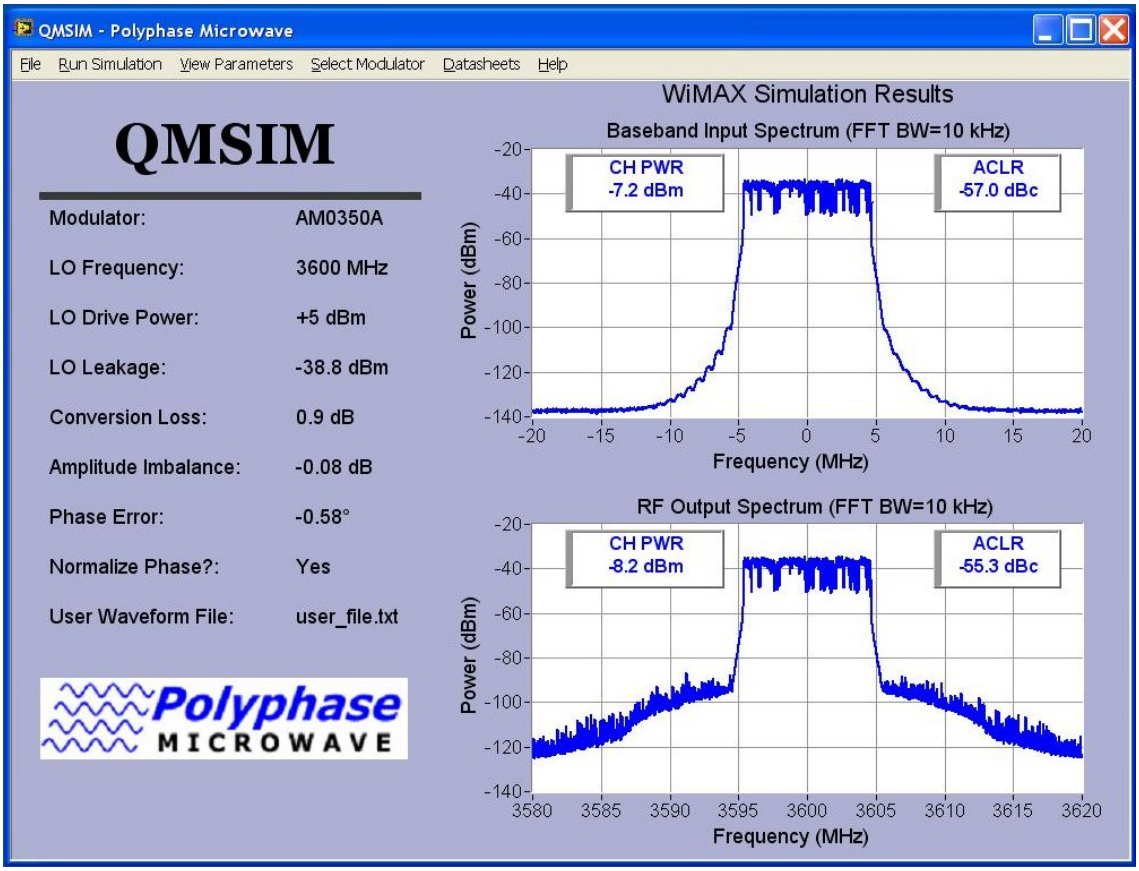
QMSIM

User Manual



Version 4.0

October 2010

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1. Introduction

QMSIM is a powerful simulation tool for the evaluation of Polyphase Microwave's entire line of quadrature modulators. Users can quickly simulate a modulator's RF output in response to standard I/Q waveforms or user-generated I/Q waveforms. QMSIM includes advanced behavioral models of 21 quadrature modulators covering 300 MHz to 17.5 GHz.

Users may choose from standard I/Q stimulus waveforms or load their own user-defined waveforms:

- Lower Sideband 1 MHz Tone
- Upper Sideband 1 MHz Tone
- Single Channel CDMA (IS-95)
- Single Channel W-CDMA (3GPP)
- WiMAX (802.16e)
- QPSK
- 16QAM
- 64QAM

Swept performance parameters for all modulators can be displayed vs. frequency:

- Conversion Loss
- P1dB Output Compression
- Input and Output IP3
- Amplitude Imbalance
- Quadrature Phase Error
- Sideband Suppression
- LO Leakage

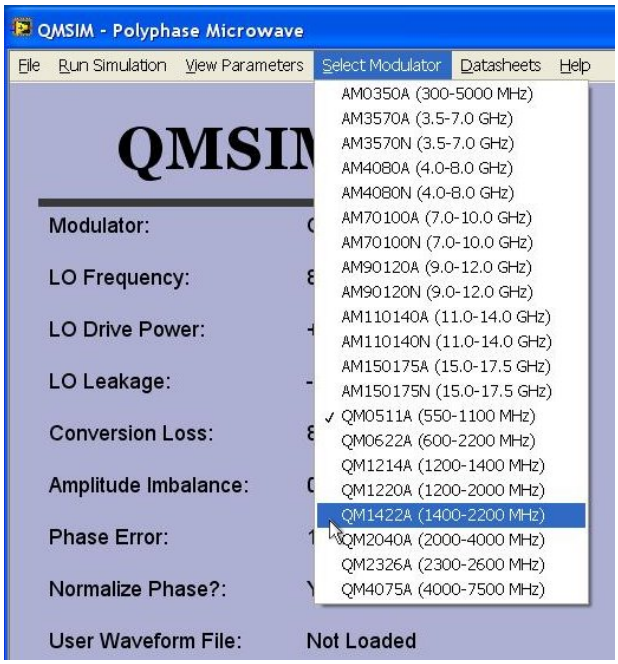
2. System Requirements

- PC compatible computer with Windows XP/Vista/7
- 200 Mbytes of free hard drive space
- 1024 Mbytes of RAM

3. Getting Started

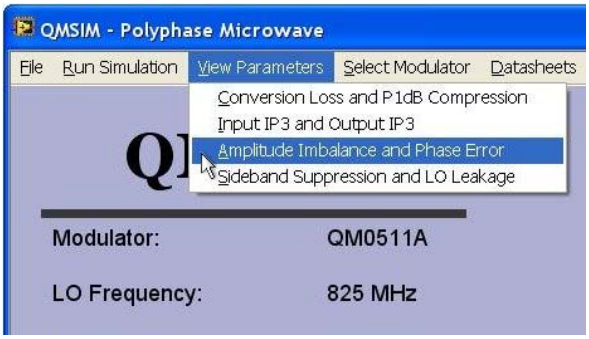
3.1. Selecting a Modulator

The desired RF operating frequency band will largely determine the best quadrature modulator for a given application. The QM series passive modulators feature the lowest output noise level (-174 dBm/Hz) and are optimized for common RF frequency bands. The AM series active modulators feature higher dynamic range with -162 dBm/Hz output noise. Select a quadrature modulator from the **Select Modulator** menu.



3.2. View Performance Parameters

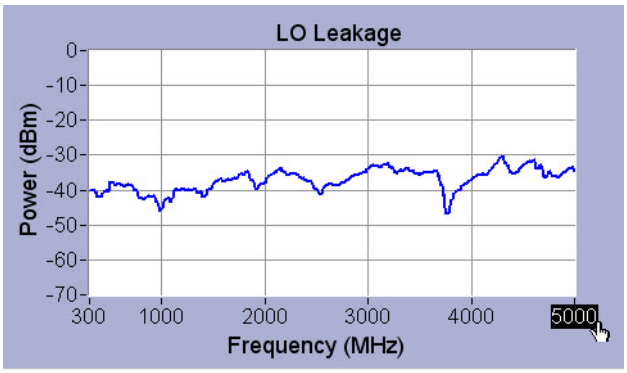
Common modulator performance parameters can be displayed with the **View Parameters** menu. Parameters are plotted vs. LO frequency and represent typical performance under standard conditions. QMSIM calculates all parameters by simulating the RF complex envelope of the modulator's behavioral model in response to 100 kHz I/Q baseband inputs.



3.3. Plotting and Viewing Results

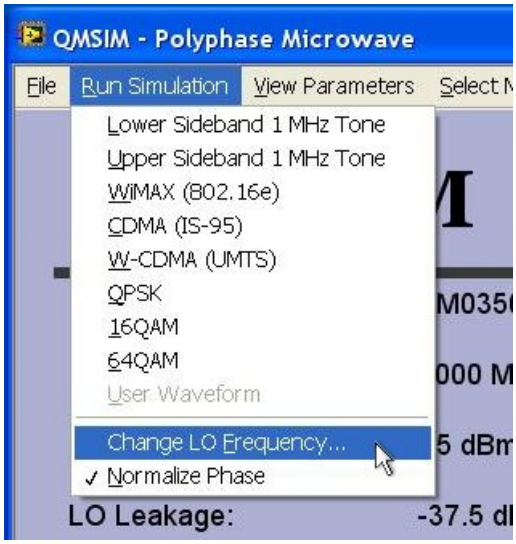
The right half of the main window is the plot display area. The left half of the main window displays the current simulator settings. When simulator settings are changed all plots are erased to prevent invalid results.

The X and Y scales can be changed by double-clicking a scale value and entering a new value with the keyboard. This allows the user to zoom into the area of interest.



3.4. Running a Simulation

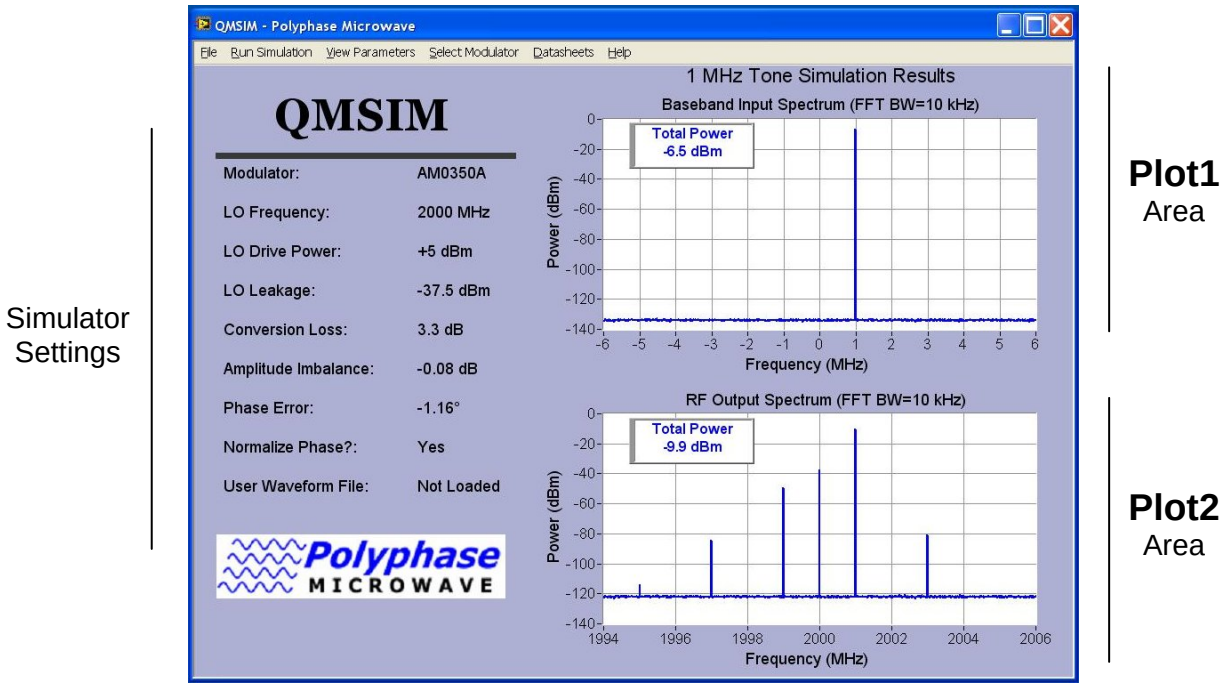
Simulations are performed at a single LO operating frequency. The current LO frequency is displayed in the left half of the main window. To change the LO frequency, select **Change LO Frequency…** from the **Run Simulation** menu and enter a new value in the dialog box.



There are eight standard I/Q stimulus waveforms available. Selecting the **USB 1 MHz Tone** simulation will open a dialog box that prompts the user for the desired I/Q signal amplitude.

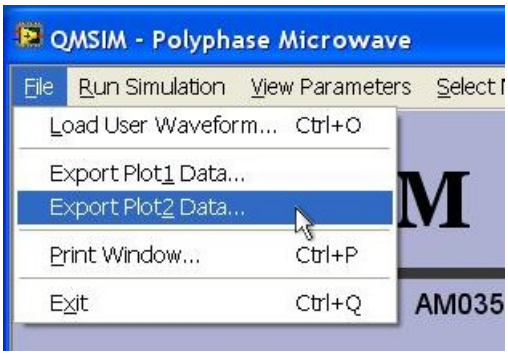
Once the value is entered, the simulator displays a progress window as the simulation is performed. When the simulation is complete, the results are displayed in the plot areas of the main window. The baseband spectrum of the input I/Q waveforms is displayed in the **Plot1** area. The modulator's RF output signal spectrum is displayed in the **Plot2** area.

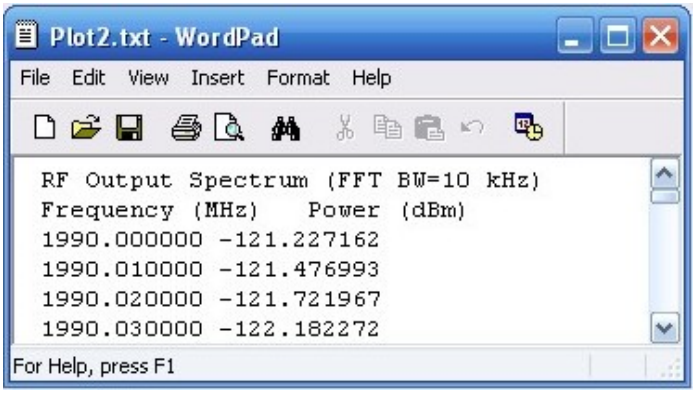
The total signal power of the spectrum is displayed in the upper left corner of the plot. Please refer to **§4** for more information about each available simulation.



3.5. Exporting Plot Data to a File

The user can export X and Y values of any plot to an ASCII file. Select the plot data to export under the **File** menu. A file dialog window prompts the user for a filename and location for the exported data.



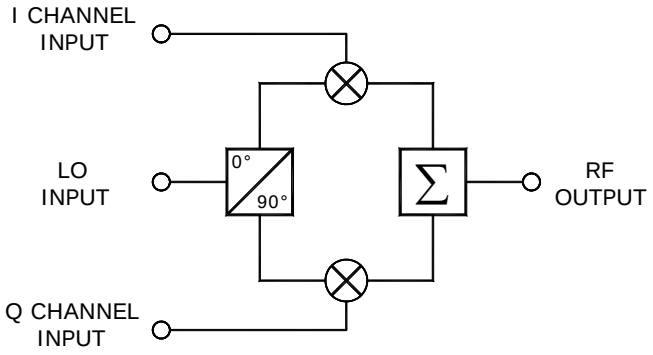


The exported data file format is ASCII text with two rows of header information followed by the tab-delimited data.

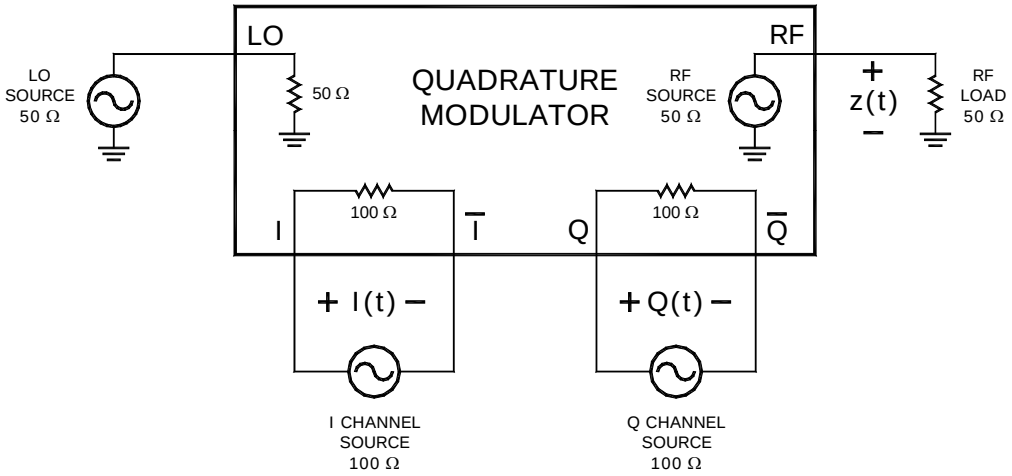
4. Simulation

4.1. The Physical System

The simulator engine within QMSIM allows the user to determine the RF output response of a quadrature modulator to any I/Q baseband stimulus at a fixed LO frequency. The simplified topology of a quadrature modulator is shown below.



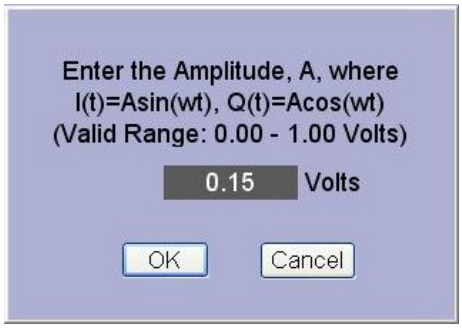
The AM and QM series modulators available from Polyphase Microwave incorporate differential I/Q interfaces. The baseband voltages I(t) and Q(t) used in QMSIM are defined as the voltages delivered by perfect 100 Ω differential sources into perfectly matched 100 Ω differential loads. The voltage and port impedance conventions used by QMSIM are shown below:



The real-valued RF output signal, z(t), is defined as the voltage across a 50 Ω load connected to the modulator's RF output port. Please see the Appendix for more information on the complex envelope notation used by QMSIM.

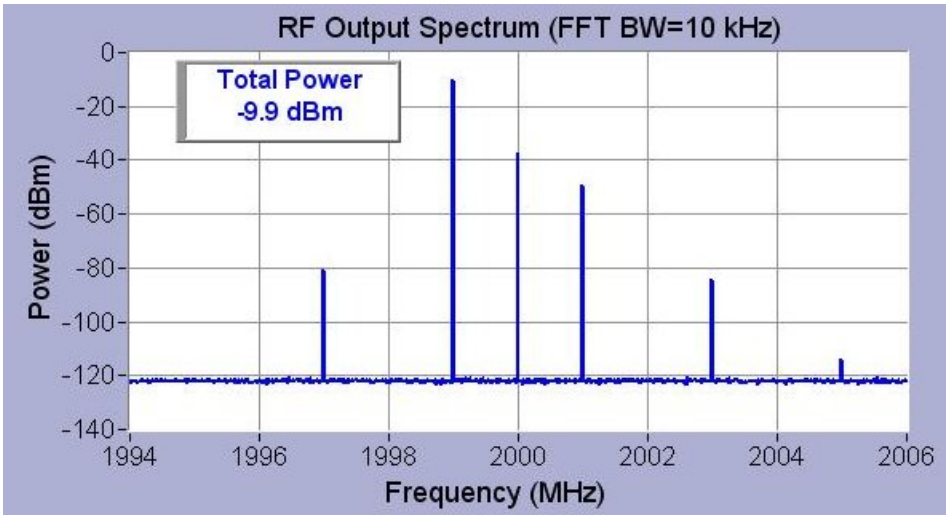
4.2. Lower Sideband 1 MHz Tone

When the **LSB 1 MHz Tone** simulation is selected from the **Run Simulation** menu, a window prompts the user to enter the signal amplitudes for I(t) and Q(t).



After the signal amplitude is entered, a window appears showing the simulator's progress. When the simulation is complete the results are displayed in the **Plot1** and **Plot2** areas of the main window.

The modulator's RF output spectrum will contain the desired lower sideband at 1 MHz below the specified LO frequency. LO leakage will be present at the simulation's LO frequency and the unwanted upper sideband will be 1 MHz above the LO frequency. Depending on the signal amplitude, higher order distortion products will be visible in both upper and lower sidebands.

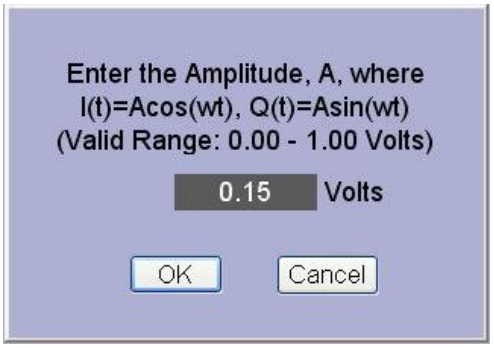


Noise – Additive white Gaussian noise is added to the input and output signals to set the actual noise levels present at the modulator's ports. Noise sets the lower limit of the modulator's dynamic range. The QM series passive modulators have output noise of –173 dBm/Hz (-133 dBm in 10 kHz FFT bandwidth). The AM series active modulators have an output noise level of -162 dBm/Hz (-122 dBm in 10 kHz FFT bandwidth).

The total power of the signal is displayed in the upper left corner of the plot. This power level includes all spectral components as would be measured by a perfect broadband power meter.

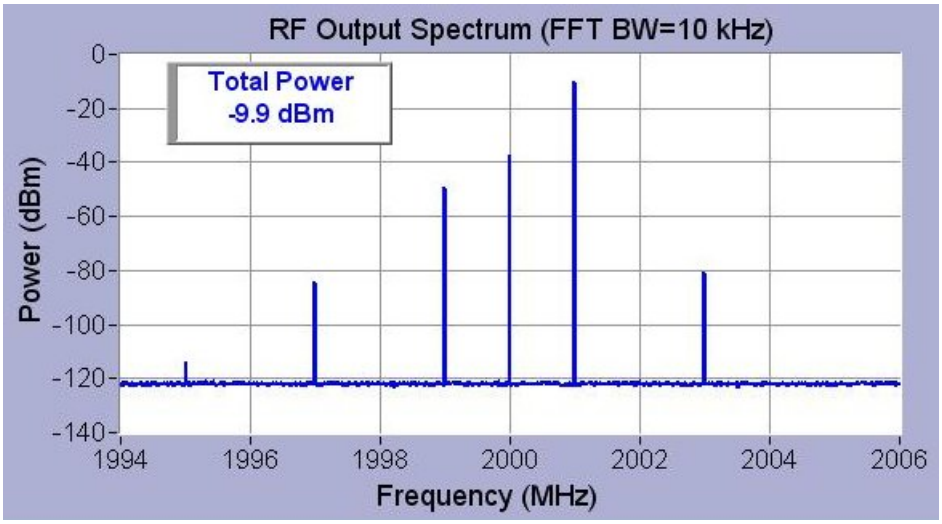
4.3. Upper Sideband 1 MHz Tone

When the **USB 1 MHz Tone** simulation is selected from the **Run Simulation** menu, a window prompts the user to enter the signal amplitudes for I(t) and Q(t).



After the amplitude is entered, a window appears showing the simulator's progress. When the simulation is complete the results are displayed in the plot area of the main window.

The modulator's RF output spectrum will contain the desired upper sideband at 1 MHz above the specified LO frequency. LO leakage will be present at the LO frequency and the unwanted lower sideband will be 1 MHz below the LO frequency. Depending on the signal amplitude, higher order distortion products will be visible in both upper and lower sidebands.

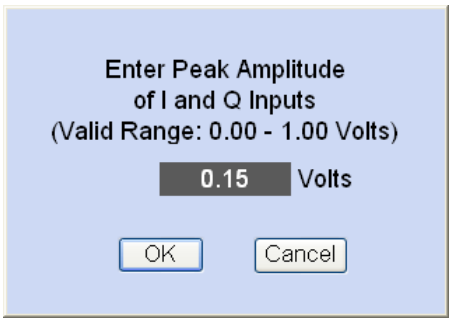


Noise – Additive white Gaussian noise is added to the input and output signals to set the actual noise levels present at the modulator's ports. Noise sets the lower limit of the modulator's dynamic range. The QM series passive modulators have output noise of –173 dBm/Hz (-133 dBm in 10 kHz FFT bandwidth). The AM series active modulators have an output noise level of -162 dBm/Hz (-122 dBm in 10 kHz FFT bandwidth).

The total power of the signal is displayed in the upper left corner of the plot. This power level includes all spectral components as would be measured by a perfect broadband power meter.

4.4. CDMA (IS-95)

When the **CDMA (IS-95)** simulation is selected from the **Run Simulation** menu, a dialog box appears and the user is prompted to enter a maximum I/Q signal amplitude.

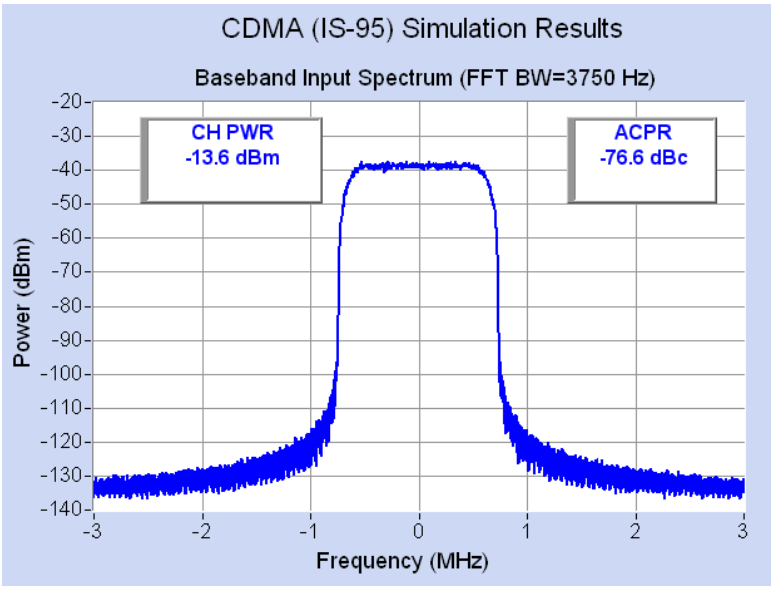


The simulator scales the I and Q waveforms to give the desired peak signal amplitude. For reference, a peak amplitude of 100 mV will result in a total baseband signal power of –17.2 dBm delivered to the modulator.

The IS-95 downlink waveform used by QMSIM has the following characteristics:

- One pilot channel with relative amplitude 1
- One sync channel with relative amplitude 0.5
- Six traffic channels each with relative amplitudes 0.5
- 1.2288 Msymbols/second
- 32768 symbols

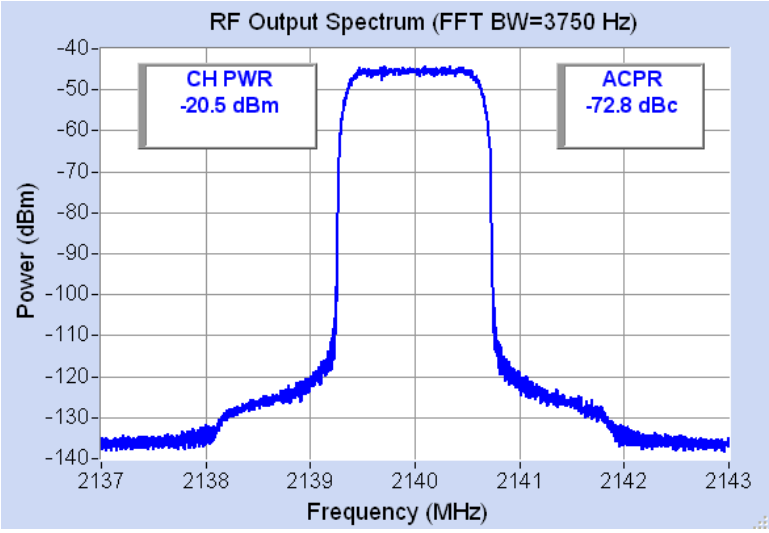
A progress meter will display the simulator's progress. The simulation results are displayed in the plot areas of the main window. The complex spectrum of the baseband stimulus is displayed in the **Plot1** area of the main window.



The channel power **CH PWR** of the complex baseband signal is displayed in the upper left of **Plot1**. The channel bandwidth for this measurement is 1.23 MHz centered at 0 Hz.

The Adjacent Channel Power Ratio **ACPR** of the complex baseband signal is displayed in the upper right of **Plot1**. The adjacent channel power is measured in a 30 kHz bandwidth at 885 kHz. The channel power for the ACPR calculation is measured in a 30 kHz bandwidth on the top of the carrier.

The modulator's RF output spectrum is displayed in the **Plot2** area of the main window. Depending on the signal level, LO leakage and/or spectral regrowth may be visible in the output spectrum.



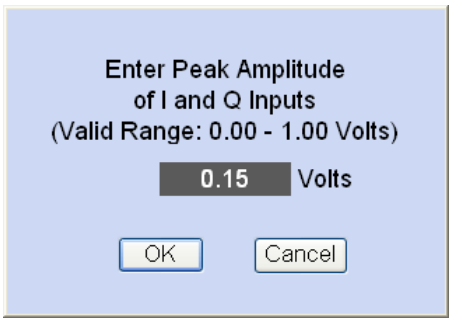
The channel power **CH PWR** of the RF output signal is displayed in the upper left of **Plot2**. The channel bandwidth for this measurement is 1.23 MHz centered at the channel frequency.

The Adjacent Channel Power Ratio **ACPR** of the RF output signal is displayed in the upper right of **Plot2**. The adjacent channel power is measured in a 30 kHz bandwidth at 885 kHz offset from the carrier frequency. The channel power for the ACPR calculation is measured in a 30 kHz bandwidth on the top of the carrier and does not include the LO leakage FFT bin.

Noise – Additive white Gaussian noise is added to the input and output signals to set the actual noise levels present at the modulator's ports. Noise sets the lower limit of the modulator's dynamic range. The QM series passive modulators have output noise of –173 dBm/Hz (-133 dBm in 10 kHz FFT bandwidth). The AM series active modulators have an output noise level of -162 dBm/Hz (-122 dBm in 10 kHz FFT bandwidth).

4.5. W-CDMA (3GPP)

When the **W-CDMA (3GPP)** simulation is selected from the **Run Simulation** menu, a dialog box appears and the user is prompted to enter a maximum I/Q signal amplitude.

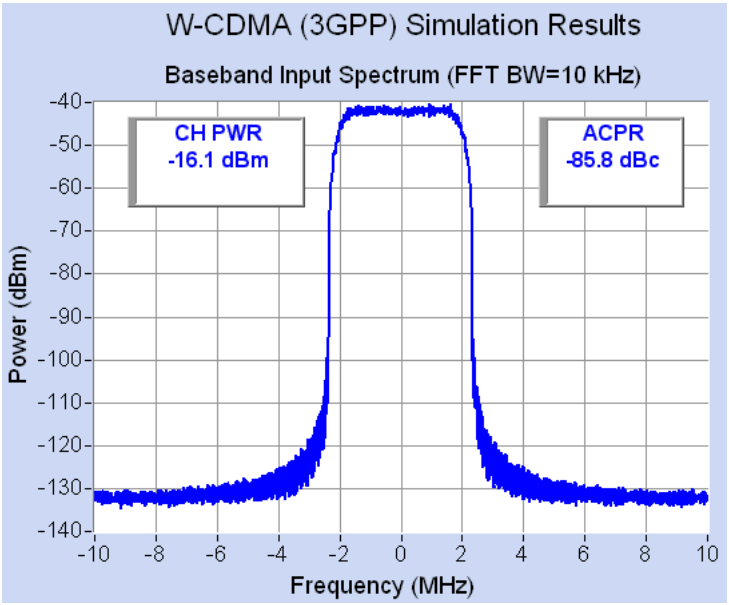


The simulator scales the I and Q waveforms to give the desired peak signal amplitude. For reference, a peak amplitude of 100 mV will result in a total baseband signal power of –19.7 dBm delivered to the modulator.

The 3GPP downlink waveform used by QMSIM has the following characteristics:

- One common pilot channel with relative amplitude 2
- One primary synchronization channel with relative amplitude 0.5
- One secondary synchronization channel with relative amplitude 0.5
- Three traffic channels each with relative amplitudes 0.5
- 38400 symbols at 3.84 Msymbols/second

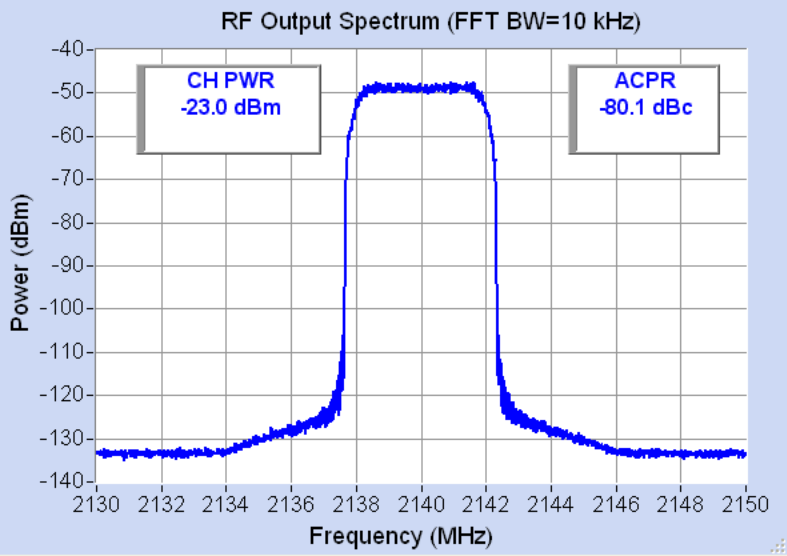
A progress meter will display the simulator's progress. The simulation results are displayed in the plot areas of the main window. The complex spectrum of the baseband stimulus is displayed in the **Plot1** area of the main window.



The channel power **CH PWR** of the complex baseband signal is displayed in the upper left of **Plot1**. The channel bandwidth for this measurement is 4.096 MHz centered at 0 Hz.

The Adjacent Channel Power Ratio **ACPR** of the complex baseband signal is displayed in the upper right of **Plot1**. The adjacent channel power is measured in a 4.096 MHz bandwidth centered at 5 MHz. The channel power for the ACPR calculation is measured in a 4.096 MHz bandwidth centered at 0 Hz.

The RF output spectrum is displayed in the **Plot2** area of the main window. Depending on the signal level, LO leakage and/or spectral regrowth may be visible in the output spectrum.



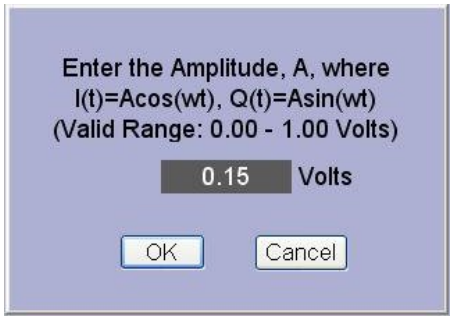
The channel power **CH PWR** of the RF output signal is displayed in the upper left of **Plot2**. The channel bandwidth for this measurement is 4.096 MHz centered at the channel frequency.

The Adjacent Channel Power Ratio **ACPR** of the RF output signal is displayed in the upper right of **Plot2**. The adjacent channel power is measured in a 4.096 MHz bandwidth centered at 5 MHz offset from the channel frequency. The channel power for the ACPR calculation is measured in a 4.096 MHz bandwidth centered at the channel frequency.

Noise – Additive white Gaussian noise is added to the input and output signals to set the actual noise levels present at the modulator's ports. Noise sets the lower limit of the modulator's dynamic range. The QM series passive modulators have output noise of –173 dBm/Hz (-133 dBm in 10 kHz FFT bandwidth). The AM series active modulators have an output noise level of -162 dBm/Hz (-122 dBm in 10 kHz FFT bandwidth).

4.6. WiMAX (802.16e)

When the **WiMAX (802.16e)** simulation is selected from the **Run Simulation** menu, a dialog box appears and the user is prompted to enter a maximum I/Q signal amplitude.

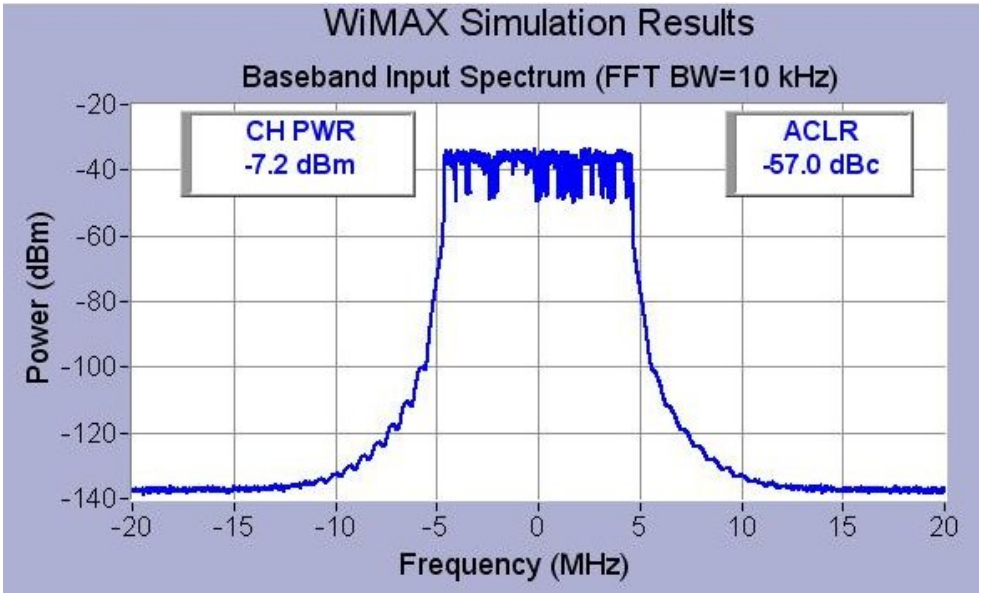


The simulator scales the I and Q waveforms to give the desired peak signal amplitude. For reference, a peak amplitude of 600 mV will result in a total baseband signal power of –7.2 dBm delivered to the modulator.

The WiMAX downlink waveform used by QMSIM has the following characteristics:

- Channel Bandwidth = 10.0 MHz
- FFT Size = 1024
- Frame Mode = TDD
- Frame Duration = 3.5 ms
- Cyclic Prefix = 0.125

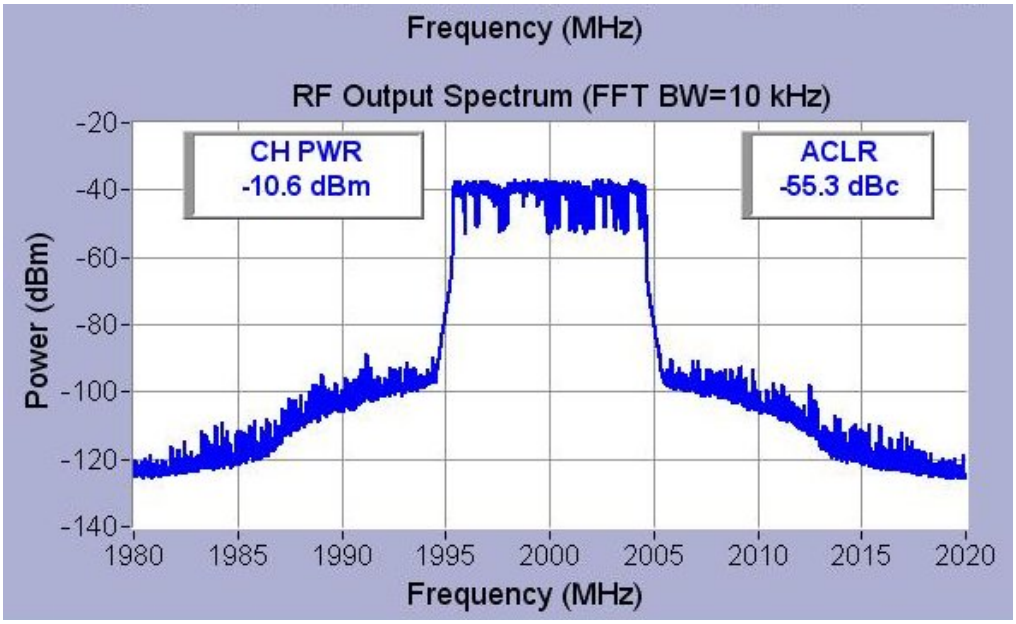
A progress meter will display the simulator's progress. The simulation results are displayed in the plot areas of the main window. The complex spectrum of the baseband stimulus is displayed in the **Plot1** area of the main window.



The channel power **CH PWR** of the complex baseband signal is displayed in the upper left of **Plot1**. The channel bandwidth for this measurement is 10.0 MHz centered at 0 Hz.

The Adjacent Channel Power Ratio **ACLR** of the complex baseband signal is displayed in the upper right of **Plot1**. The adjacent channel leakage ratio is measured in a 10.0 MHz bandwidth with 10.0 MHz channel spacing.

The RF output spectrum is displayed in the **Plot2** area of the main window. Depending on the signal level, LO leakage and/or spectral regrowth may be visible in the output spectrum.



The channel power **CH PWR** of the RF output signal is displayed in the upper left of **Plot2**. The channel bandwidth for this measurement is 10.0 MHz centered at the channel frequency.

The Adjacent Channel Power Ratio **ACLR** of the RF output signal is displayed in the upper right of **Plot2**. The adjacent channel leakage ratio is measured in a 10.0 MHz channel bandwidth and 10.0 MHz channel spacing.

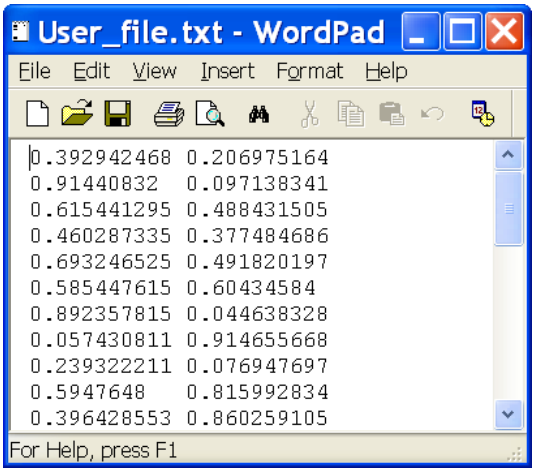
Noise – Additive white Gaussian noise is added to the input and output signals to set the actual noise levels present at the modulator's ports. Noise sets the lower limit of the modulator's dynamic range. The QM series passive modulators have output noise of –173 dBm/Hz (-133 dBm in 10 kHz FFT bandwidth). The AM series active modulators have an output noise level of -162 dBm/Hz (-122 dBm in 10 kHz FFT bandwidth).

4.7. User Waveforms

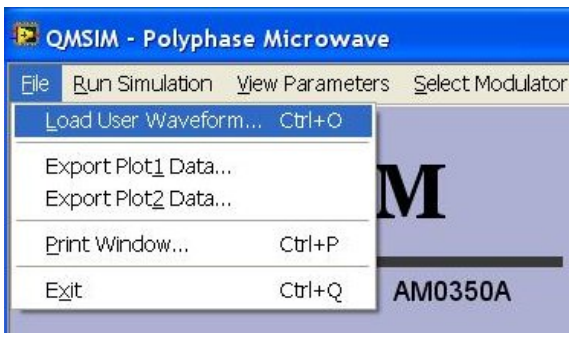
The most powerful feature of QMSIM is the ability to simulate a modulator's response to user-defined I and Q waveforms. This capability allows the user to simulate the modulator's response to I and Q signals used in the user's application. The simulation engine calculates the complex envelope of the modulator's RF output signal (see Appendix). The real and imaginary components of the RF complex envelope are displayed and can be exported to a file.

When creating user-defined waveforms, it is important to limit the frequency bandwidth of the I and Q signals. The behavioral models used by QMSIM are "memoryless" and become less accurate as the I and Q signal bandwidths increase beyond 20 MHz. The minimum time increment for I and Q baseband signals is therefore 50 ns.

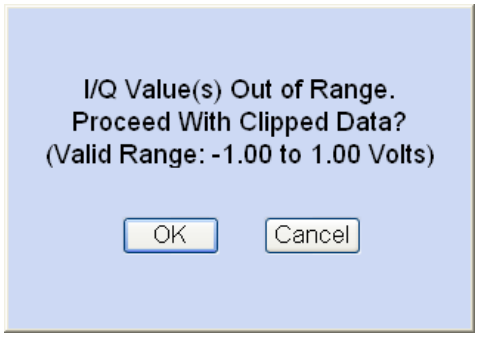
File Format – The user waveform file format recognized by QMSIM is tab-delimited ASCII text with EOL characters separating rows of I and Q voltages. This is the format that results when a spreadsheet containing a column of I samples and a column of Q samples is saved as a tab-delimited text file. Units for I and Q samples are in Volts.



Once a waveform file is created, load the file by selecting **Load User Waveform…** from the **File** menu. The file dialog window prompts the user to select a user waveform file.

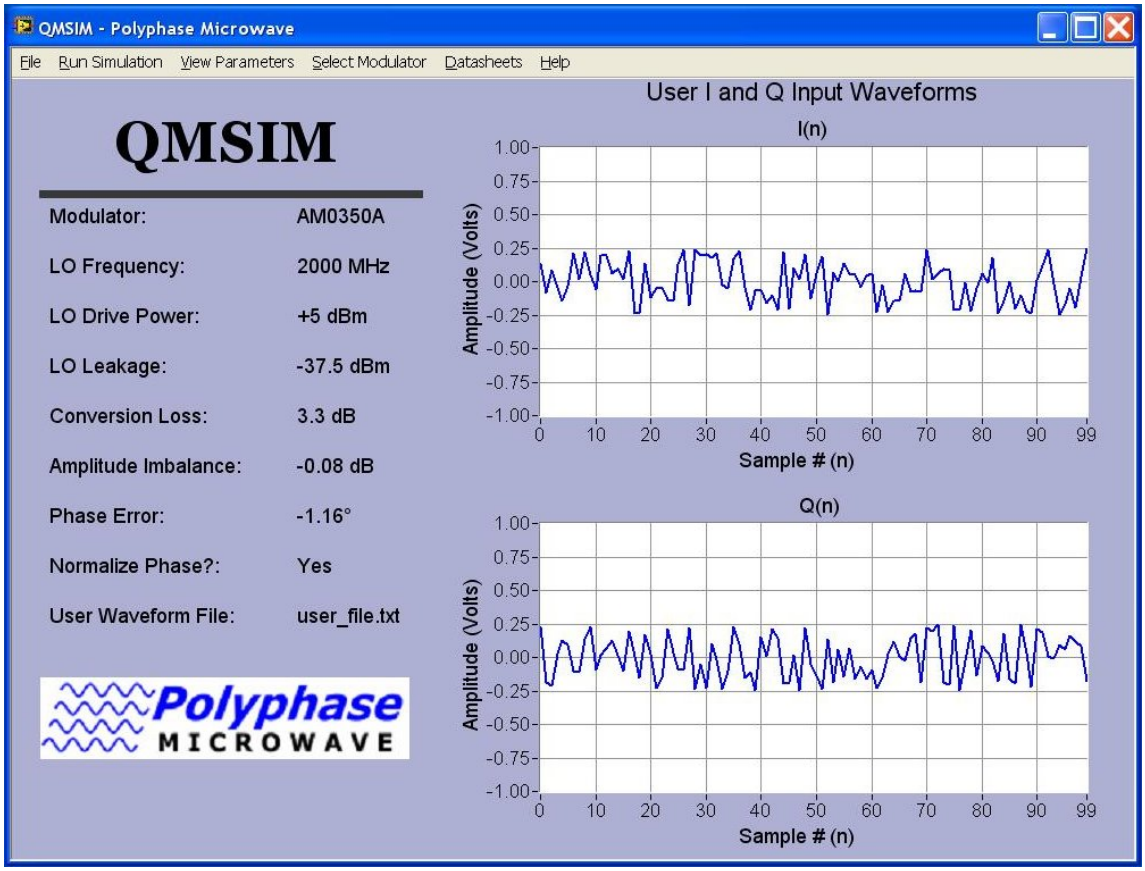


When a file is selected, QMSIM verifies that the file is in the correct format. An error window will appear if the file format is not recognized. If the format is correct, QMSIM then verifies that the voltages are in the valid input range of –1.00 to +1.00 Volts. If signals contain samples outside of this range, the user is asked if the out of range samples should be clipped at +/- 1.00 V.

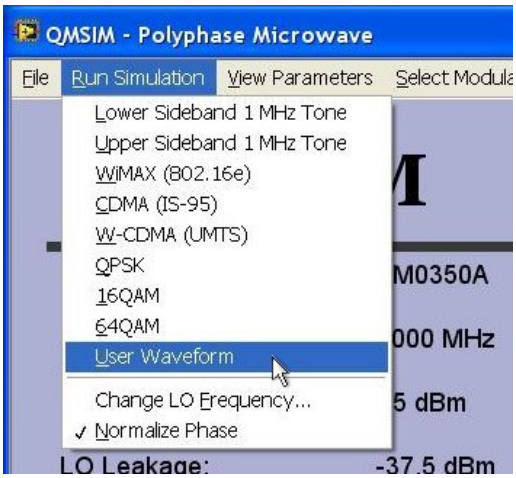


If the user cancels the operation, the user file is not loaded.

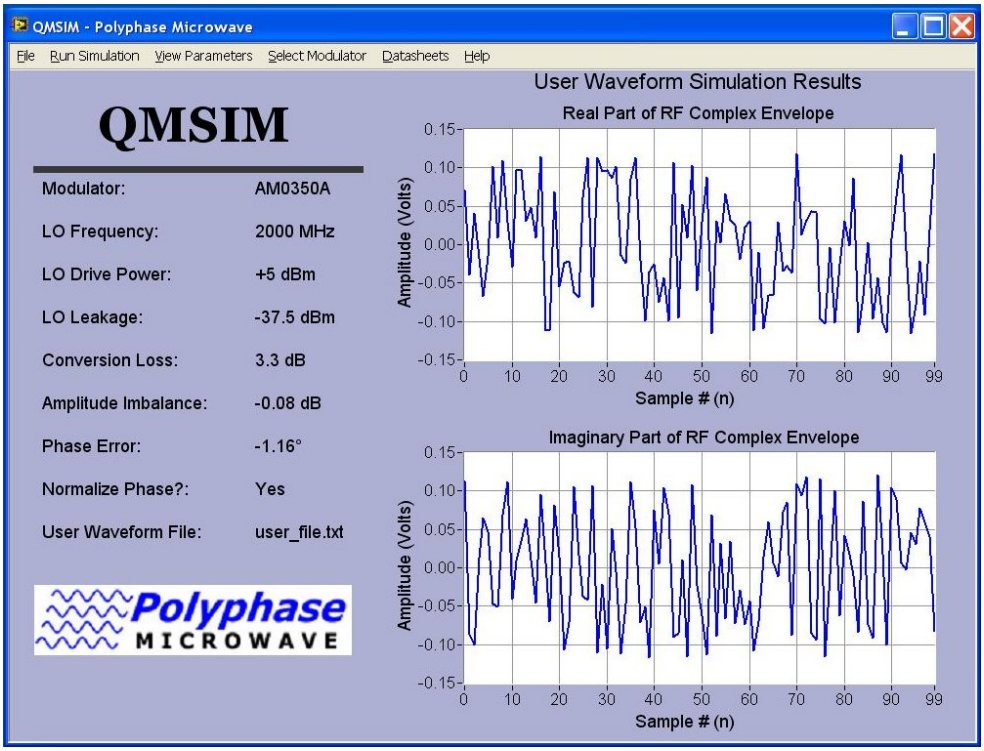
After valid I and Q waveforms are loaded into memory they are displayed in the plot areas of the main window. The user should verify that the waveforms were loaded correctly before proceeding. The simulator displays the loaded user waveform file name in the settings area of the main window.



To begin the simulation, select **User Waveform** from the **Simulate** menu.



A progress window shows the simulation progress for long waveforms. When the simulation is complete, the real part of the modulator's RF complex envelope is displayed in **Plot1**. The imaginary part is displayed in **Plot2**. Please refer to the Appendix for more information on the RF complex envelope notation used by QMSIM

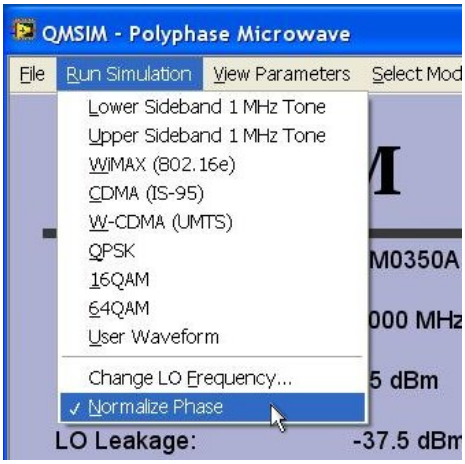


Noise – Not added for user simulations.

The RF complex envelope simulation results may be exported to a file for further analysis by other software tools.

4.8. Phase Normalization

The phase of the RF complex envelope generated during a user waveform simulation is normalized by default.



Phase normalization adjusts the phase of the modulator's RF output such that the I channel baseband input signal produces a linear response on the real axis of the RF complex envelope. When phase normalization is turned off, the phase of the RF output complex envelope is expressed as relative to the phase of the LO input signal. Since all receivers must remove an arbitrary phase rotation, it is recommended that the phase be normalized unless the user must know the phase of the RF output signal relative to the phase of the LO signal.

Appendix – RF Complex Envelope Representation

QMSIM uses the RF complex envelope representation to express the results of user waveform simulations. The RF complex envelope is also known as the complex baseband representation of bandpass signals.

The complex envelope representation of the modulator's output RF signal is defined as

$$\tilde{z} = \tilde{I} + j\tilde{Q} = Ae^{j\phi} \tag{1}$$

where

$$A = \sqrt{\tilde{I}^2 + \tilde{Q}^2} \tag{2}$$

and

$$\phi = \arctan(\tilde{Q}, \tilde{I}) \tag{3}$$

The modulator's RF output signal can be obtained from the complex envelope representation by

$$z(t) = \sqrt{2}\Re\left[Ae^{j(2\pi f_c t + \phi)}\right] \tag{4}$$

resulting in

$$z(t) = \sqrt{2}\tilde{I}\cos(2\pi f_c t) - \sqrt{2}\tilde{Q}\sin(2\pi f_c t) \tag{5}$$

$z(t)$ is the real time-domain signal present at the RF port of the modulator centered at frequency f_c. It has amplitude A and phase ϕ.

The units of $\tilde{I}$ and $\tilde{Q}$ are in Volts. The power of the RF output signal, $z(t)$, is therefore

$$Power(dBm) = 10\log_{10}\left(\frac{\tilde{I}^2 + \tilde{Q}^2}{.05}\right) \tag{6}$$

QMSIM produces $\tilde{I}$ and $\tilde{Q}$ when a user waveform is simulated. $\tilde{I}$ and $\tilde{Q}$, the real and imaginary parts of the modulator's RF complex envelope, should not be confused with I and Q, the baseband stimulus.

