

An ADS Bench for Generating Multi-Carrier 3GPP WCDMA ACLR Test Signals

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Generating test signals using simulation software lets engineers create 'real world' signals—including the effects of filtering and clipping—without the need for the hardware of an entire base station

Multi-carrier Wideband WCDMA signals are required for testing 3G wireless base stations. This article shows how to create a source able to generate those signals, using the Agilent Technologies Advanced

Design System 2001 (ADS 2001) environment. Innovative solutions are proposed to reduce the simulation time, and the source is capable of clipping. Possible applications are also discussed.

3GPP Frame Structure

The physical channels have a three-layer structure. A super frame consists of 72 radio frames. A radio frame has a 10 ms duration and consists of 15 time slots. Each time slot consists of a number of symbols dependent on the type of channel. A symbol consists of a number of chips equal to the spreading factor for the physical channel used.

For the 3GPP system, the final spreading rate is 3,840,000 giving a chip period of 0.260417 μ s.

A rapid calculation indicates that a radio frame consists of 0.01 s x 3.84 Mchips/s = 38,400 chips, or in other words, 15 time slots of 2560 chips.

3GPP Test Model 1

3GPP specification TS 25.141-v4.1.0 [1] specifies various test models for base station testing. The Test Model 1 shall be used for ACLR measurements.

This test model consists of 64 Dedicated

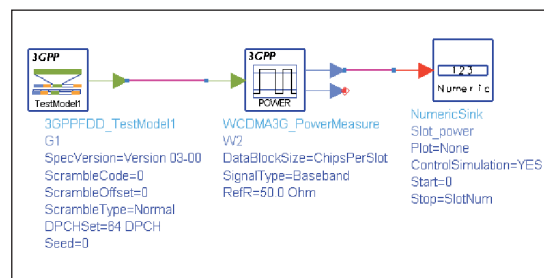


Figure 1 · ADS test bench for mean power per slot measurement.

Physical Channels (DPCH), with a spreading factor of 128, distributed randomly across the code space, at random power levels and random timing offsets so as to simulate a realistic traffic scenario that may have high PAR (Peak to Average Ratio). Variants of this test model containing 32 and 16 DPCH are also specified but will not be considered for this study.

It is important to notice that the timing offsets cover a complete radio frame. Table 6.2 in the specification document [Ref. 1] gives the DPCH timing offsets. The maximum offset is 149 x 256 Tchips. So the different offsets are spread over a time length of almost 150 x 256 Tchips. This can be written as 15 x 2560 chips or 15 time slots, i.e. one radio frame.

Implementation of 3GPP Test Model 1 in ADS 2001

Special care must be taken when using the Test Model 1 for ADS simulations. During the first radio frame, the dedicated physical channels are computed according to the specified timing offsets. This is equivalent to switching on the channels progressively during the first radio frame. So the power is also progressive-

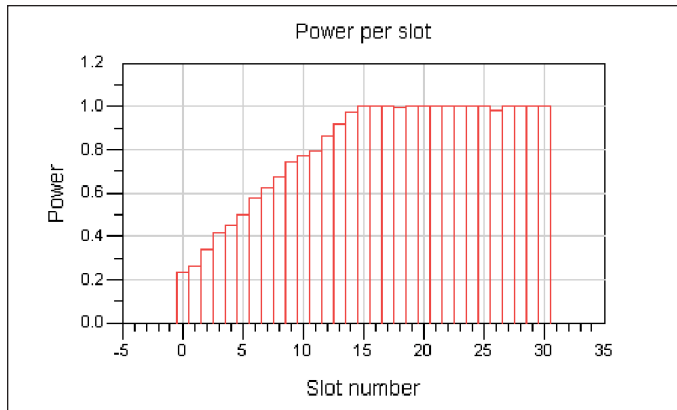


Figure 2 · Average power per slot.

ly increasing during the first radio frame.

This can be better understood by looking at the mean power in each time slot. For this purpose, a simple test bench is used (Figure 1). A specific component, WCDMA3G_PowerMeasure, from the ADS 3GPPFDD 10-99 Measurement library [2] is used to measure the average power in the time slots. The simulation is run over 30 time slots. The results are presented in Figure 2.

Based on these results, it becomes obvious that for measurements requiring a stable source power versus time, the simulation must run over two radio frames since the data generated during the first one can't be used.

Simulation Time Optimization

An innovative solution can be used to reduce the simulation time. Considering that the data from the first radio frame are useless, it is judicious to save only the data generated during the second radio frame in a file. This file is then used as a source. Not only the number of data read from the file is half of the data generated by the 3GPPFDD_TestModel1 component during two radio frames, but also it is much faster to read a file than to compute the data inside the 3GPPFDD_TestModel1 com-

ponent. The reduction in simulation time using this method is even greater for benches using several test models, as it is the case for a multi-carrier source. Another advantage of this solution is that the data can be easily accessed for statistical computations or any other manipulation, such as clipping or pre-distortion.

One obvious way to implement this would be to use a NumericSink component to write the numeric data in the dataset and a NumericSource component to read them. Unfortunately, a bug in ADS 2001 prevents the software from correctly reading data blocks with more than 5,000 entries. This problem was reported to Agilent Technologies and should be solved in the 2002 version of ADS.

To overcome this issue, another solution is proposed. The data are written in text files with the Printer component from the Sinks Library. Even though this component can write complex arrays, this feature is not used since the ReadFile component—from the Numeric Sources library—can only read data in the real format. Hence, the I and Q data are written in two separate text files. An additional advantage of using text files is that the data are not indexed as they are when written in a dataset. This makes it easier to manipulate the data. To simplify the schematics, the sub-network 'I_Q_write' is created (Figure 3). It allows to chose the first slot and the number of slot to write. An offset can also be added. This feature will be useful to handle the timing offset mandatory in the case of multi-carrier test signal as specified in the 3GPP specification [1] as described later. Similarly, another sub-network, 'I_Q_read,' is created to read the I and Q data from the text files (Figure 4).

A bench is created to generate the raw I and Q values for four sources. It simply uses a 3GPPFDD_TestModel1 to generate the data and the previously described I_Q_write sub-network to save the I and Q values in text files. This is repeated four times since we are using a maximum of four sources. The scrambling code are chosen in accordance with paragraph 6.1.1.6.3 of the 3GPP specification [1]: "Where multiple repetitions of the Test Model

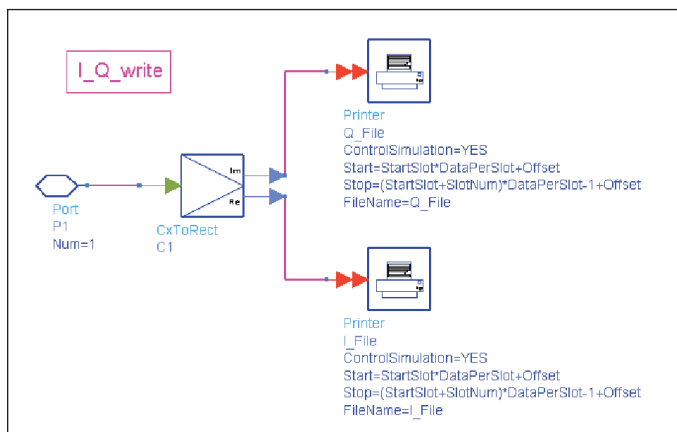


Figure 3 · The I_Q_write sub-network.

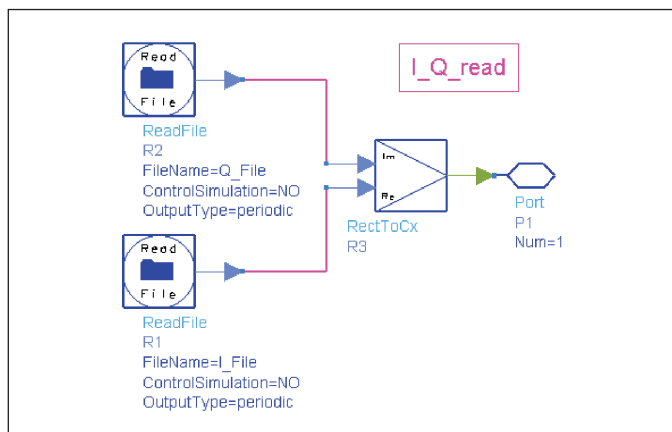


Figure 4 · The I_Q_read sub-network.

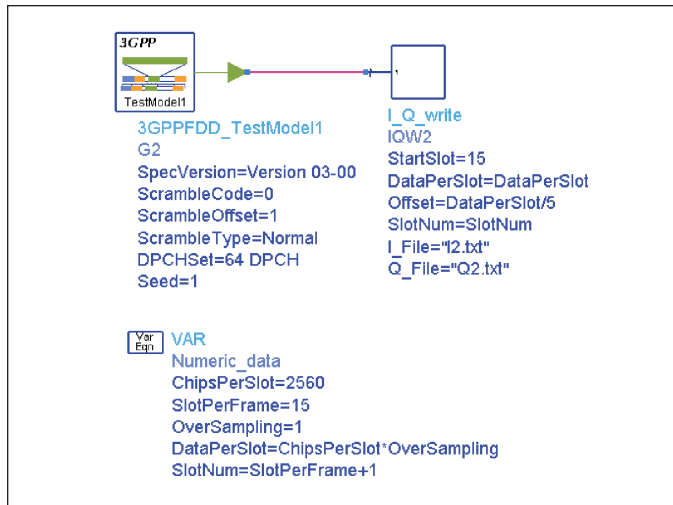


Figure 5 · Parameters used to write the 16 slots data.

signals are being used to simulate a multi-carrier signal the scrambling code for the lower frequency is 0. Carriers added at successively higher frequencies use codes 1, 2, ... and their frame structures are time offset by 1/5, 2/5... of a time slot duration. “This time offset is managed with the Offset parameter of the I_Q_write sub-network.

The number of points to write depends on the final application. In this study, we write the data corresponding to a whole radio frame but it should be noted that if the goal is, for example, to perform a spectrum analysis, the number of points written can be limited to the number of points used by the spectrum analyzer to perform its FFT, therefore minimizing the size of the text files.

By carefully defining the parameters of the I_Q_write sub-networks, only the data from the second radio frame are written in the files. In fact, 16 slots are written, i.e. one radio frame plus one extra slot. This is to anticipate that the data will have to go thru the pulse shape filter. This FIR filter requires having a certain number of points entering so that it can generate the first valid data at the output. This extra slot will be used for this purpose. The number of data written in each file is thus 16 times 2560 i.e. 40960. Figure 5 shows the portion of the bench used to write the data generated by the second source. It can be checked that the power per slot is now constant over the radio frame that is saved in the text files, as shown in Figure 6.

Signal Statistics

Some parameters like peak and RMS values are of particular interest for signals like W-CDMA. CCDF curves are also commonly used. A bench is created to easily get access to this information. It is based on the WCDMA3G_CCDF component from the 3GPPFDD 10-99 Measurement library [2]. This component calculates the

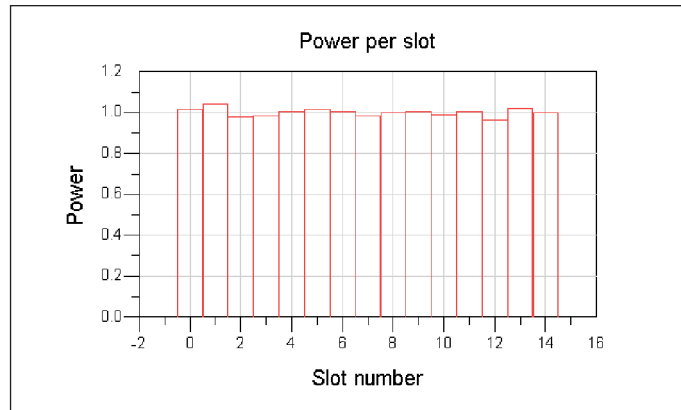


Figure 6 · Power per slot for the written data.

peak power of 99.9% probability but not the absolute peak value. This value can't be used as the reference for clipping since it represents an already clipped signal. A branch is thus added in the bench to calculate the absolute peak value in the radio frame—the highest magnitude of I + jQ. This bench is saved as a sub-network named Baseband_stat (Figure 7). Another bench is then built using four times a combination of the I_Q_read and Baseband_stat sub-networks.

The CCDF computed for the four sources is presented in Figure 8. It should be noticed that the four sources have similar average power but different peak values. This is confirmed by checking the absolute peak value—the highest magnitude of I + jQ—in the radio frame as shown in Figure 9. If we clip the signals with a reference to each ones peak value, we end with different average power and thus the four tones would have different power levels. To overcome this, the average peak value is used as the reference in the clipping module for all four sources.

Clipping and Filtering

Clipping is commonly used to reduce the peak to average ratio of the signal. A bench is designed to perform

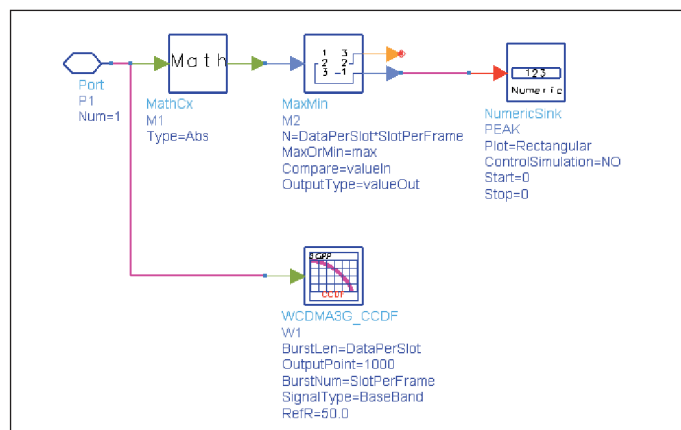


Figure 7 · The Baseband_stat sub-network.

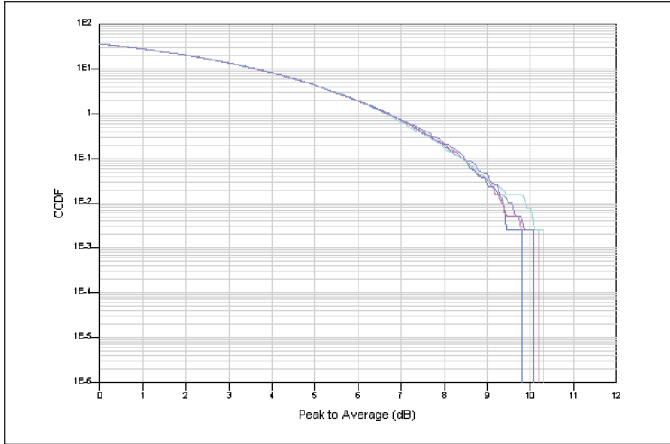


Figure 8 · CCDF plots of the four sources.

BS1.PEAK[0]	BS2.PEAK[0]	BS3.PEAK[0]	BS4.PEAK[0]
3.115	3.260	3.298	3.216

Figure 9 · Peak value in the radio frame

clipping on the previously generated data. It is shown in Figure 10. This circuit limits the magnitude of the complex voltage at its input to a given value. The equivalent mathematical function is:

$$V_{out} = V_{in} \quad \text{if} \quad |V_{in}| \leq A$$

$$V_{out} = V_{in} \times \frac{A}{|V_{in}|} \quad \text{if} \quad |V_{in}| \geq A$$

where V_{in} is the complex voltage at the input of the clipper, V_{out} is the complex voltage at the output of the clipper, and A is the clipping level—maximum allowed magnitude at the output of the clipper.

This can be written as:

$$V_{out} = \frac{V_{in}}{|V_{in}|} \times \min(|V_{in}|, A)$$

The “min” function is performed using a limiter available in the Numeric Special Functions library.

This clipper is used in a bench to generate the clipped data. In order to check the correct behavior of the clipper, the CCDF curve is plotted for different clipping levels: 100% (no clipping), 67% and 50% (Figure 11).

Filtering

The characteristics of the transmit pulse shape filter are described in paragraph 6.8.1 of [3]. It is a root-raised

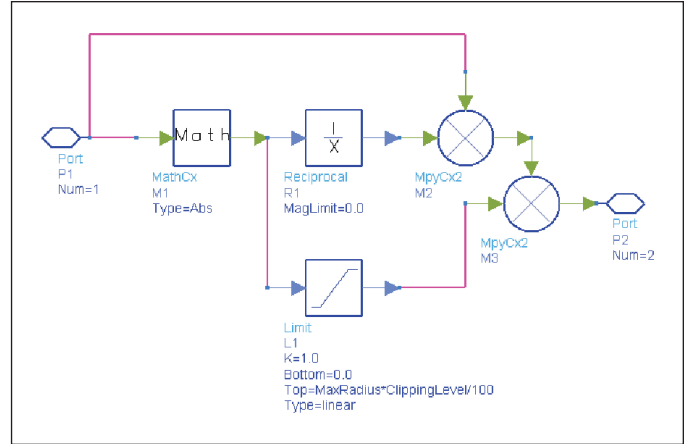


Figure 10 · Schematic of the clipper.

cosine with a roll-off factor of 0.22 in the frequency domain. Such a filter can easily be implemented in ADS 2001 using the complex raised cosine component—RaisedCosineCx—from the Numeric Communications library. This component implements a pair of FIR filters with a raised-cosine or square root raised-cosine frequency response. The real part of the complex input goes through one filter to become the real part of the output signal. Similarly, the imaginary part of the input goes through the other filter to become the imaginary part of the output signal [2].

It also allows over-sampling of the data by setting the Interpolation parameter. Over-sampling is necessary to get enough bandwidth for spectrum analysis. Considering that the signal bandwidth covers 20 MHz of band in the case of four adjacent carriers and that we want to analyze a 20 MHz band below and above the signal, a total bandwidth of 60 MHz must be available for spectrum analysis. The over-sampling ratio is thus computed as 60/3.84 and rounded to 16.

The sharpness of the filter—and thus the quality of he

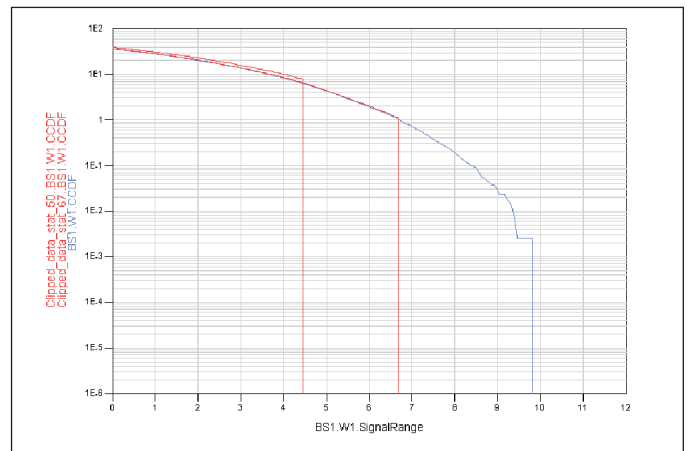


Figure 11 · CCDF plot of the clipped data.

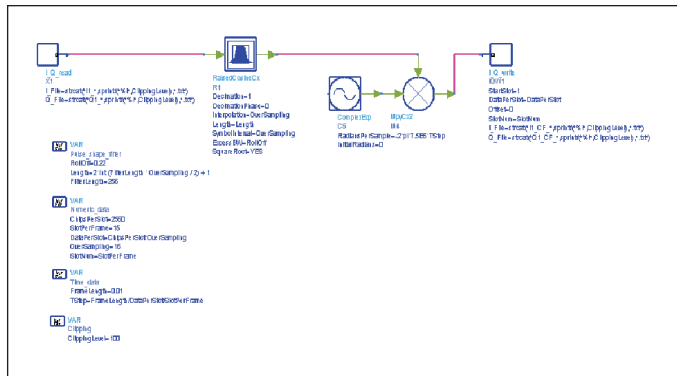


Figure 12 · Filtering and frequency offset.

source—is determined by the Length parameter. In order to obtain a symmetric impulse response, the Length parameter is forced to an odd value. More information can be found in the description of this component in the ADS documentation [2]. This is done by computing the parameter Length as:

$$Length = 2 \times \text{int}(\text{FilterLength} \times \text{OverSampling} \div 2) + 1$$

The parameter FilterLength is set to a power of 2. A value of 256 gives excellent filter sharpness resulting in ACLR better than 100 dBc.

In order to get the right frequency spacing between the carriers, a baseband frequency offset is also implemented. To obtain a centered spectrum in the case of four carriers, the first carrier is offset by -7.5 MHz, the second by -2.5 MHz, the third by +2.5 MHz and the fourth by +7.5 MHz. A baseband signal containing the four carriers is thus simply obtained by adding the complex data corresponding to the four carriers. Multiplying the data by a complex exponential performs the frequency offset. Figure 12 shows the filtering and frequency offset for the first carrier as well as the values assigned to the different variables.

The CCDF of the filtered signal can be plotted for dif-

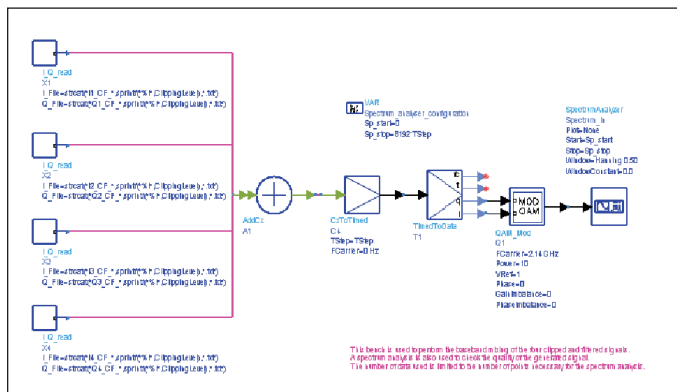


Figure 14 · Carriers mixing and I-Q modulation.

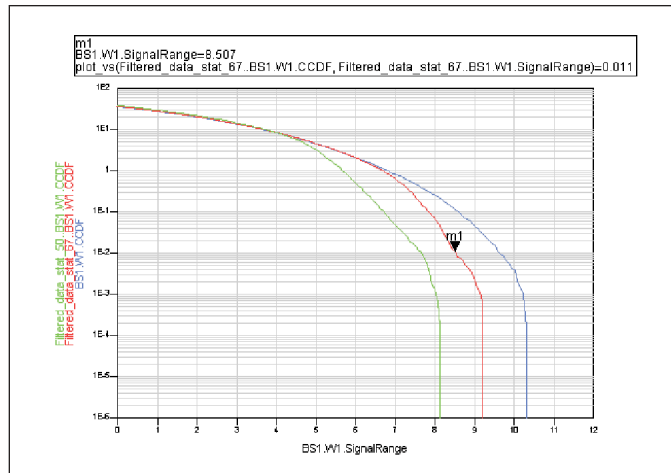


Figure 13 · CCDF of the filtered signal.

ferent clipping levels. On Figure 13, the blue curve represents a non-clipped signal, the red one is with clipping at 67% and the green one is with clipping at 50%. The marker m1 indicates the well-known value of 8.5 dB at 0.01% probability with clipping at 67%. This clipping level is commonly used by Motorola for actual testing of W-CDMA products, as displayed in the data sheet of the MRF21125 transistor [4].

Another bench (Figure 14) is built to perform the signals mixing, I-Q modulation and spectrum analysis. As mentioned earlier, the mixing is as simple as a summation of the baseband frequency offset data. The modulation uses a QAM modulator with an RF frequency of 2.14 GHz. The spectrum of the signal obtained is shown in Figure 15.

At this level, any combination of signals and tone spacing can be performed and the base-band data can either be written in text files. This allows to perform the I-Q modulation in a circuit envelope simulation as will be seen later. The bench shown in Figure 14 is thus modified accordingly. The components used for modulation and spectrum analysis are removed and replaced by an

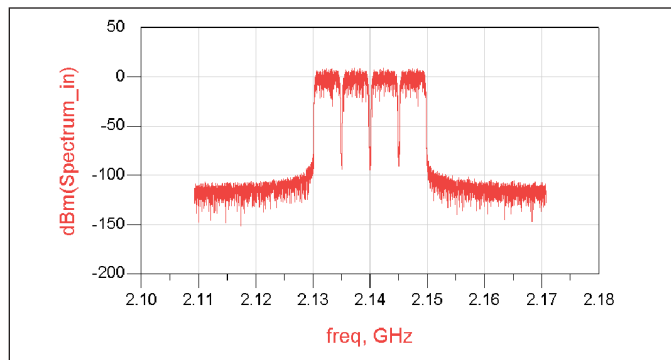


Figure 15 · Spectrum of the signal generated by the source.

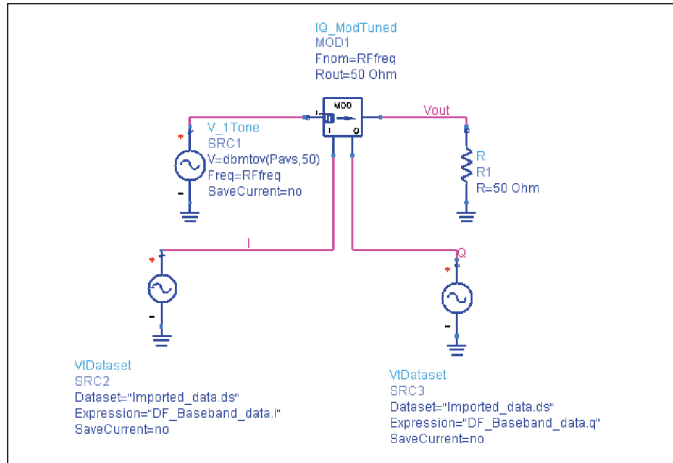


Figure 16 · The I-Q modulation in a circuit envelope simulation.

I_Q_write sub-network connected at the output of the complex adder. Another alternative is to write the baseband data in a data set after converting them to time domain data and using TimedSink components.

Applications Examples

One obvious application of such a source is to perform ACLR measurements as suggested in the examples provided by Agilent Technologies. In the “Examples” folder, the WCDMA3G_BS_Tx_prj shows how such a bench can be implemented. It is of course necessary to modify the ACLR_FilterBank sub-network to take into account the use of several carriers. The bench performing the mixing of the carriers can be modified to generate other signals, 2 or 3 carriers, and other tone spacing. These measurements require circuit co-simulation.

Another approach of interest is to use these data in a circuit envelope simulation. The main advantage is to avoid running resource demanding circuit co-simulations. This method is of course also valid if the text files are generated with any other software.

As an example, a simple circuit envelope bench is created using an I-Q modulator and two VtDataset components to read the data from a dataset (Figure 16). This dataset can either be generated with the previously described Ptolemy benches or created using the Instrument Server tool. In the later case, a simple manipulation in a spreadsheet transforms the text files in the MDIF format.

The spectrum can then be plotted (Figure 17) and one can see that it is the same as the one obtained with the Ptolemy simulation, except that the x-axis frequency is an

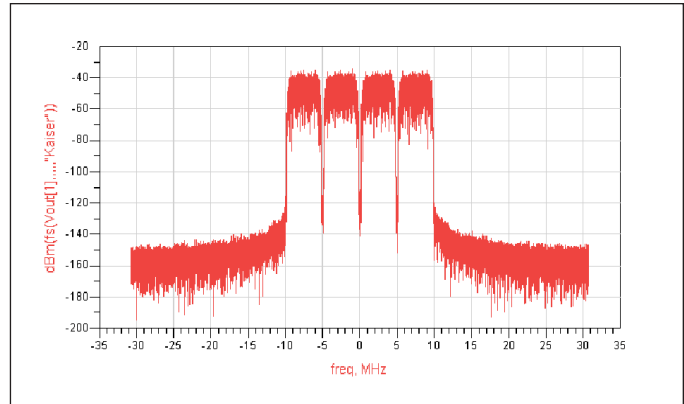


Figure 17 · Spectrum of output voltage in the circuit envelope simulation.

offset of the RF frequency as it is always the case with circuit envelope simulations.

Summary

An innovative way of designing a multi-carrier 3GPP source in the ADS 2001 environment was described. Emphasis was given on compliance with the ETSI 3GPP specifications. Reduction of the simulation time is also a key achievement. This source gives system and power amplifier designers a powerful tool for simulations with complex envelope modulations like W-CDMA. The solutions presented also apply to other complex modulations. Complete systems can be simulated with real life signals, which reduces development time.

References

1. 3GPP TS 25.141 V4.1.0 (2001-06), 3rd Generation Partnership Project; Technical Specification Group Radio Access Networks; Base station conformance testing (FDD) (Release 4)
2. Advanced Design System 2001, Signal Processing Components, August 2001, Agilent Technologies (www.agilent.com)
3. 3GPP TS 25.104 V4.1.0 (2001-06), 3rd Generation Partnership Project; Technical Specification Group Radio Access Networks; UTRA (BS) FDD; Radio Transmission and Reception (Release 4)
4. The data sheet can be found at: www.motorola.com/rf

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