

# System Simulation for RF Link Budget Analysis

Featuring Cadence AWR Software

This white paper examines how a more rigorous link budget analysis of an entire system can be determined through simulation, and how performing link budget analysis enables designers to address losses, gains, and power levels to meet the operational requirements of the radio communications system.

## Contents

Overview .....	2
RF Link Budget Analysis and System Planning.....	3
An Integrated Tool for Frequency Planning, Budget Analysis, and More ....	5
Predicting Critical Metrics for Wireless RF Links.....	9
RF Planning Speeds System-Level Analysis .....	14
Conclusion .....	18



## Overview

Cadence® AWR® Visual System Simulator™ (VSS) communications and radar systems design software provides an RF link budget analysis capability that enables designers to account for all the gains and losses in a telecommunication system – from the transmitter, through the medium (free space, cable, waveguide, fiber, and more), to the receiver (Figure 1). By accounting for the attenuation of the transmitted signal as it propagates through the communication channel, system designers can determine the required signal strength and antenna gain necessary to overcome all feedline and miscellaneous losses in order to ensure an appropriate quality of signal for successful data transmission.

### RF Budget Analysis

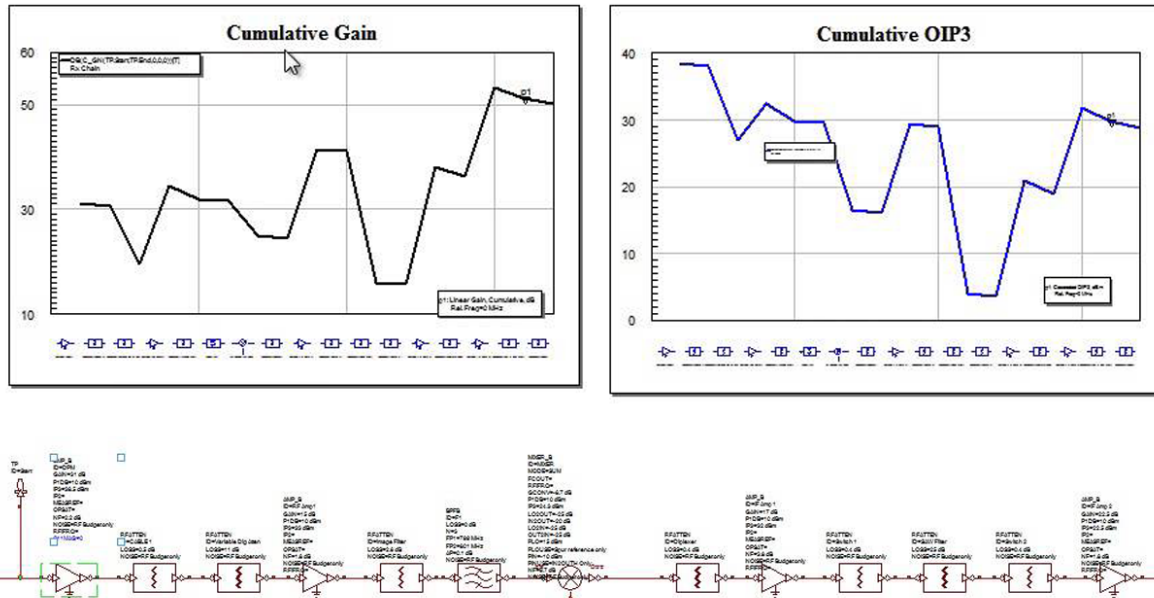


Figure 1: A simple link budget equation takes the form:  $\text{Received Power (dB)} = \text{Transmitted Power (dB)} + \text{Gains (dB)} - \text{Losses (dB)}$

For free space propagation, as it occurs in satellite communications, there are no noticeable reflections and only one major RF path. In contrast, transmitted signals in terrestrial systems may reach the receiver via a number of different paths (multipath propagation) due to signal reflections off buildings, trees, and other objects, resulting in phase and amplitude variations among the received signals. If the signals arrive in phase with the direct signal, then the reflected signals will tend to reinforce the direct signal. If they are out of phase, then they will tend to cancel the signal. If either the transmitter or receiver moves, then the signal strength will be seen to vary as the relative strengths and phases of the different signals change, which is often addressed with a simple link margin to account for the channel losses (worse-case fading).

Increasingly, communication standards are incorporating more sophisticated channel models to account for multipath losses. While link budget calculations are an essential step in the design of radio communications systems, their growing complexity requires a more robust approach to this type of analysis than a simplistic spreadsheet accounting for loss and gain.

## RF Link Budget Analysis and System Planning

A primary motivation for using an RF/microwave communication system simulator is to establish the right system architecture and formulate suitable specifications for each of the underlying components. Accomplishing this goal helps companies to reduce time to market by eliminating iterations and rework, and to reduce system cost by ensuring that components are not over-specified and thus unnecessarily expensive. The sooner the engineering team has an accurate understanding of system performance before committing to hardware, the faster they can move the product into manufacturing and ultimately into the hands of the consumer.

The AWR VSS software's RF budget analysis capability enables designers to calculate cascaded performance of the RF link. Traditional RF/analog system analysis commonly requires several tools to achieve a complete analysis of end-to-end performance. For example, the engineering team may use one tool for error vector magnitude (EVM) measurements and another for calculating cascaded noise figure (NF) and output third-order intercept (OIP3). With AWR VSS software, engineers now have an efficient and comprehensive platform for making RF cascade calculations at interior points of the RF link to perform all common linearity measurements such as EVM, within a single system workspace that supports co-simulation with circuit-level design. Working in one environment provides a seamless flow of information between traditional systems engineers and RF/analog engineers.

### System-Level Architectural Planning Tool to Aid Initial RF Design

The AWR VSS software's RF architect (RFA) system-level planning and specification tool enables RF communication system engineers to quickly create and verify the initial specifications of a radio design. It includes the innovative RF budget (RFB) technology that helps to streamline the product development process by providing the ability to make conventional RF cascaded measurements such as gain, NF, OIP3, and image noise along a communication link. The ability to identify potential pitfalls early in the design process at the system-level design phase saves design cycle time and speeds time to market.

The RF Inspector (RFI) tool, also part of the RFA technology, is a frequency-domain simulation tool that helps determine the root cause or heritage of any intermodulation product of an RF link and includes the effects of conversions, harmonics, and intermodulation. In addition, it accounts for thermal noise and phase noise effects. This enables users to isolate the sources of unwanted interferers and to better architect their RF systems.

AWR VSS software, inclusive of the RFA, RFB, and RFI tools, enables engineering teams to further analyze and simulate designs by incorporating complex modulation sources and receivers with the RF link created in the RFA tool, while at the same time using the full suite of AWR VSS software's capabilities, including EVM, eye diagrams, and bit error rate (BER).

### Radio Frequency Planning Wizard

Whether developing satellite communication, cellular, or military radio links, the radio frequency planning (RFP) wizard add-on to AWR VSS software is an essential part of the design process in that it provides greater insight into unwanted signals or spurs generated in a specific bandwidth. In addition to analyzing spurs generated by a lineup of mixers for instance, the RFP tool examines the entire RF lineup of common components (amplifiers, mixers, filters, and more) found in radio communication links and can be built up from a selection of commercially available parts or behavioral models.

#### Features at a Glance

- ▶ Seamlessly integrated within AWR VSS software
- ▶ Provides insight into unwanted signals or spurs in a specified bandwidth
- ▶ Analyzes spurs generated by a lineup of mixers
- ▶ Examines the entire RF lineup of common components in RF links
- ▶ Provides first cut of cascaded measurements for:
  - NF, 1db compression point (P1dB), signal-to-noise ratio (SNR), third-order intermodulation (IM3), and more
- ▶ RF link automatically translates to a AWR VSS software system diagram for yield analysis and optimization

The RFP tool delves deeper than common spreadsheet analysis calculations and displays clear results with several options when viewing simulations. For example, a tabular result of in-band and out-of-band signals can be generated in real time as a frequency of interest is swept. In addition to showing the particular power levels and frequencies of the signals, the root causes of the signals can also be displayed, and mixer spur charts and traditional spectrum plots can be viewed. Furthermore, RFP gives engineers the first cut of cascaded measurements such as NF, P1dB, SNR, and IM3, as well as spurious-free dynamic range (Figure 2).

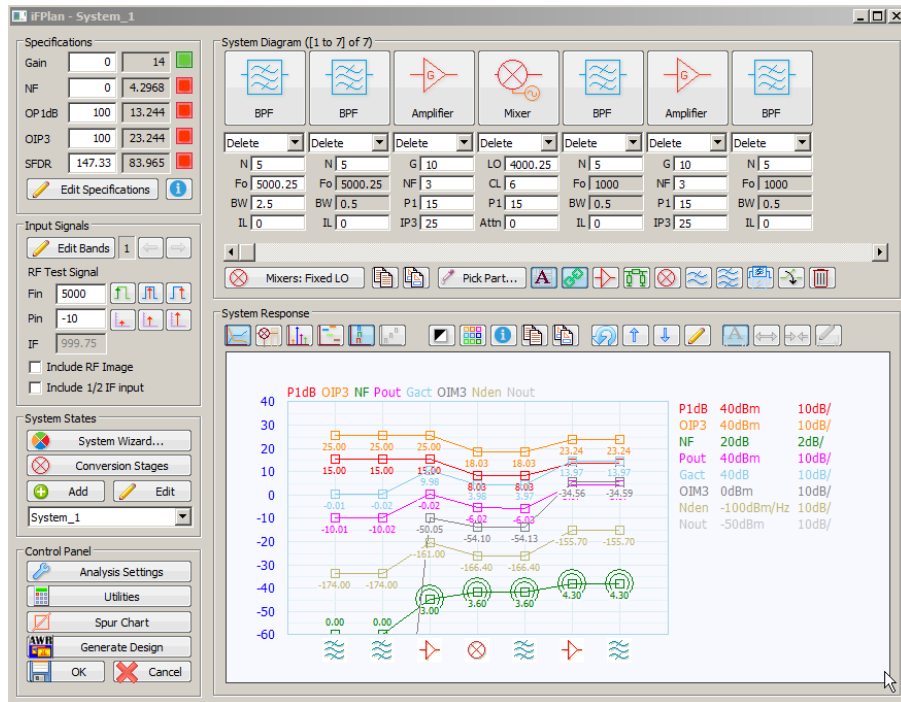


Figure 2: RFP interface showing system response and measurements

Seamlessly integrated into AWR VSS software, the RFP tool launches from a single mouse click to construct the RF link and automatically translate it to a system diagram (Figure 3). AWR VSS software can then be used to account for mismatch between components and noise at image frequency, and run yield analysis and optimization. Engineers then have a choice of modulated signals and can perform, for example, EVM, adjacent channel power ratio (ACPR), and BER measurements.

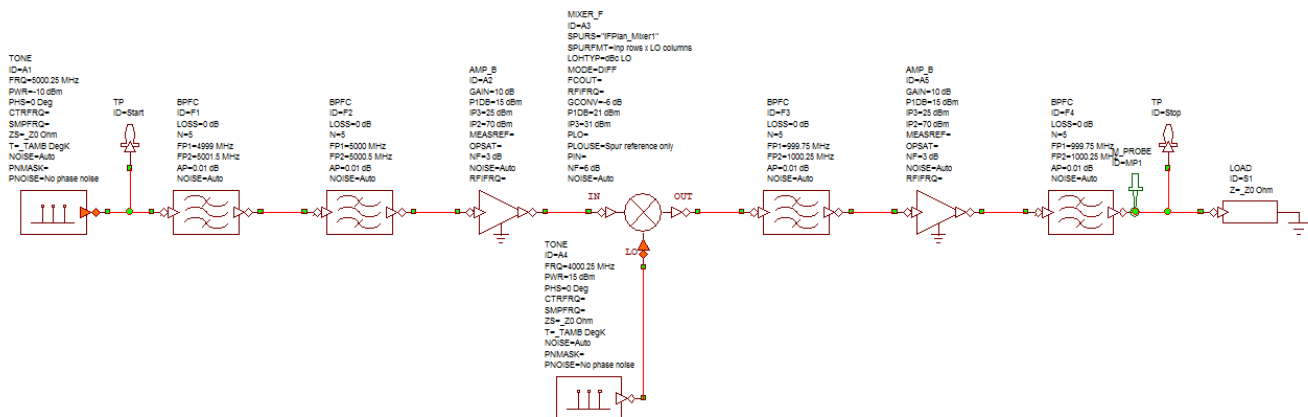


Figure 3: RFP automatically renders the resultant system within the AWR VSS software's schematic

## An Integrated Tool for Frequency Planning, Budget Analysis, and More

In the recent past, system designers may have addressed budget analysis, spur searching utilities, and frequency planning with the help of spreadsheets or hard-coded algorithms. These “home brew” approaches are limited in functionality and/or breadth and support for new capabilities, and operate using a text-based (spreadsheet) user interface that hinders engineering productivity. Few designers today have the time required to build their own design utilities or manage aging spreadsheets to meet the growing requirements of today’s communication systems. AWR VSS software, on the other hand, offers end-to-end system design, while also embracing legacy approaches with the incorporation of spreadsheet views.

### Frequency Planning

The AWR VSS software’s frequency planning utility uses an input/output signal frequency and power specifications with the goal of designing a system that transports the signal of interest from the input port to the output port using the minimum number of frequency translations (along with the simplest synthesizer architecture) and the lowest-cost filter technology. More filters and more complex synthesizers translate directly into higher cost, volume, and weight.

There are two aspects of frequency planning. The first, which is akin to a design tool, uses spur charts and related algorithms, and the second, which is closer to a verification process, is commonly known as spur searching. The latter accounts for both mixer-generated spurs and those generated by nonlinear building blocks in the system that are found in the main signal path, as well as in the mixer synthesizer subsystems.

Equation (1) shows the classic mixer equation:

$$\omega_{\text{mix}} = \pm n * \omega_{\text{lo}} \pm m * \omega_{\text{rf}}$$

This equation defines both wanted and unwanted mixing products generated by the process of frequency translation using a mixer driven by a local oscillator. This seemingly innocuous equation understates the complex picture of unwanted signal growth or generation, and describes the signal growth of a single frequency translation block. With complex systems that contain multiple frequency translations, the potential for unwanted signal creation grows alarmingly.

A typical spur chart (Figure 4) displays the output signals as a function of input frequency for  $n$  and  $m$  values in the mixer equation. In Figure 4, these values have been constrained to a maximum magnitude of  $n$ -Max and  $m$ -Max. The chart then shows that the input and output frequencies have been normalized to the local oscillator (LO) frequency. Tables typically accompany such plots to define the relative magnitudes of the mixing products using mixer spur tables derived from mixer manufacturers’ data sheets, measurements, or simulations.

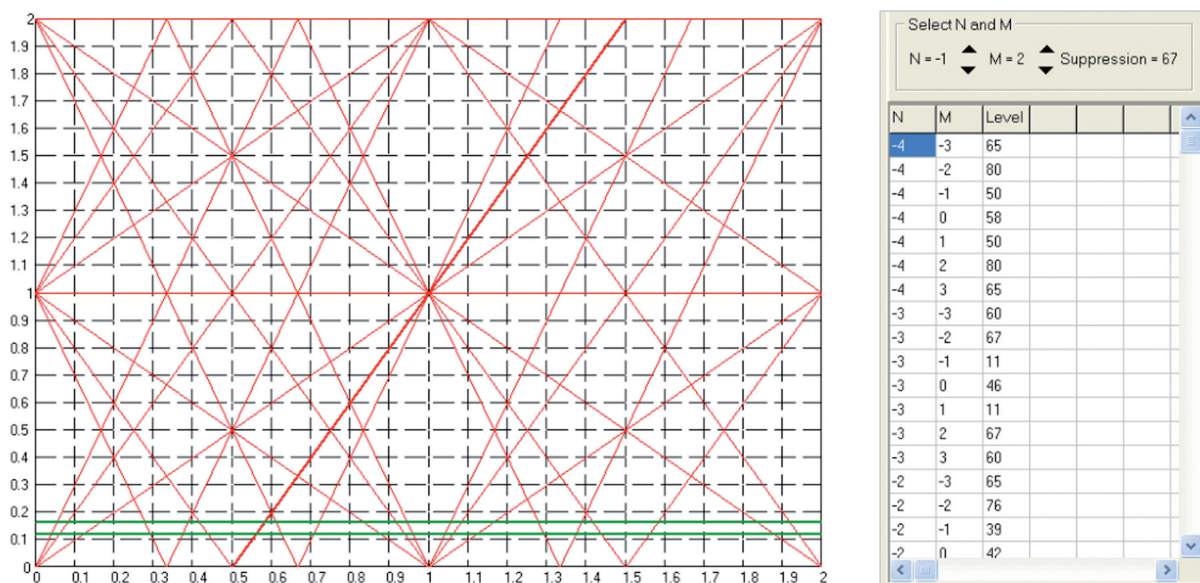


Figure 4 Spur chart and spur chart suppression table

While spur charts like this demonstrate the existence of spurs, some designers prefer to display the results using a spectral plot, such as that in Figure 5. In this case, the spur equations are enhanced to add the loss and filtering action of the input and output filters.

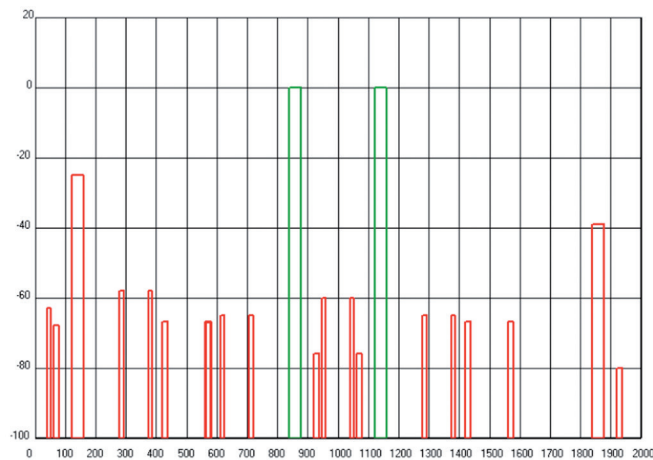


Figure 5: Spur spectral plot

In Figure 4, the two horizontal lines represent the output filter characteristics. The filter has infinite order: the low- and high-frequency band transitions between stopband and passband are infinitely steep. The green rectangles in the spectral plot (Figure 5) are the lower sideband and upper sideband conversion products, so the input filter is open to all signals. The spectral plot is referenced to the input signal and the LO frequency has been set to 1000MHz for simplicity.

Spur charts enable system designers to make judgments about how to allocate LO frequencies, the filter orders at different points in the system, and the number of conversions required. Signal loss is introduced with each frequency conversion (frequency translation) and the filters employed to constrain signals. If the frequencies are low enough for the use of active devices in the mixer design, some gain may be possible. To overcome loss, extra gain stages are required, which increases the possibility of generating distortion products.

After defining the mixer architecture, the number of mixing stages, and the amplification required to raise the input power to deliver the required output power, a general spur search can be performed. The primary algorithm employed for spur searching tracks signals through the system blocks and at the location of each new spur or signal, setting up a parent/child relationship, with the child's heritage stored in memory. In Figure 6, AWR VSS software clearly shows a set of spurs.

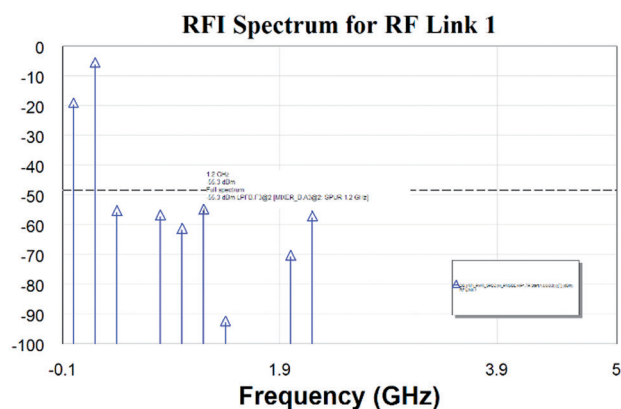


Figure 6: Spur search results

The annotation associated with one of the spurs can also be seen in the plot in Figure 6, which describes the spur frequency, power, and parent (spur source). This information can be expanded to show a comprehensive description of the heritage of a particular spur. A user-defined power threshold can be set, below which new spurs are ignored. A practical approach would be to ignore spurs that fall below the system noise floor.

In Figure 7, the comprehensive data is displayed after selecting a specific spur in Figure 6. The partial heritage of the signal of interest is shown, along with the data associated with the unwanted tones. This allows designers to address unwanted spurs with changes to components that can be easily identified as the source of unwanted signals resulting from their nonlinear behavior.

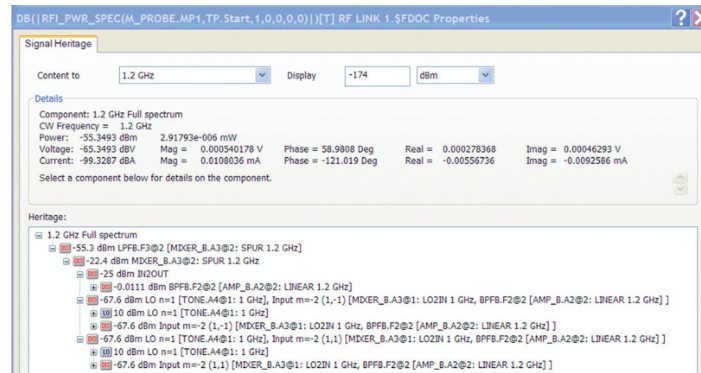


Figure 7: Heritage information of the spur search results

## Budget Analysis

Spreadsheets have traditionally been the approach of choice for performing budget analysis. They can easily capture the effects of channel defects such as noise and two-tone intermodulation, define the system block properties, and structure the information in a linear fashion. A more obvious reason for their popularity is that they are widely and readily available to most people.

However simple and ubiquitous the spreadsheet approach may be, it has several disadvantages, the most notable of which are difficulty in making changes to topology and lack of linkage between the frequency planning and spur searching tools that should accompany the budget analysis. These three views of the system architecture (frequency planning, spur searching, and budget analysis) must be synchronized manually by the designer, which is nearly impossible in a spreadsheet. A schematic diagram, which has long been the first choice of circuit designers, is the preferred way to capture system topology and block diagrams.

The schematic or diagram generated by AWR VSS software captures the intent of the system designer in a visually expressive manner. However, because the spreadsheet remains well-suited for presentation during peer reviews, AWR VSS software offers spreadsheet views to complement its budget tools (Figure 8).

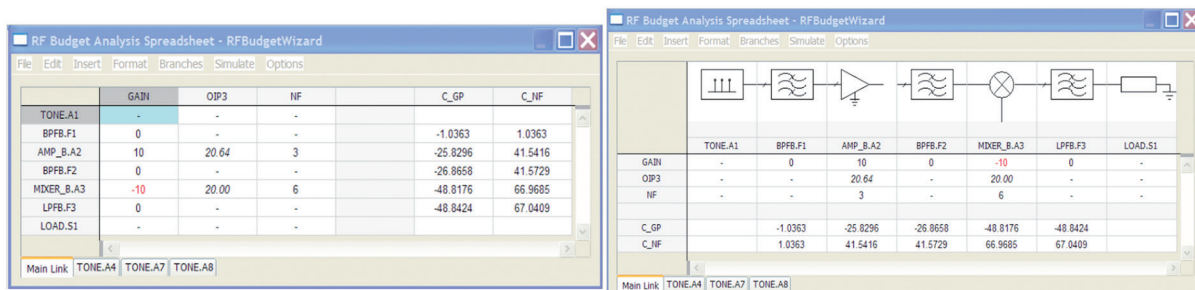


Figure 8: Spreadsheet display of budget information within AWR VSS software

One objective of the budget tool is to define the location of the gain control blocks, either the static beginning of life (BOL) adjustments made in the factory, or automatic gain control (AGC) blocks to account for variations in signal magnitude (target range, distance from antenna). For the BOL gain adjustments, knowledge of the spread in system gain is necessary – a measurement that is not simple when using spreadsheets.

For these types of simulations, the VSWR interactions between the blocks are accounted for, along with first-order parameter changes. Unlike the spreadsheet approach, a true parameter sensitivity analysis can be conducted. Another important consideration when designing systems is accounting for image noise, which is most often overlooked when using spreadsheets for system design. The system algorithm within AWR VSS software accounts for image noise, which enables designers to make rational judgments about filter order and the bandwidth of the pre-mixer filter to minimize noise figure degradations. For some applications, image noise cannot be suppressed, but the designer must still account for all noise sources in these calculations.

A versatile approach to system design requires that the figures of merit that define each block eventually be substituted with simulation data derived from circuit tools, and measured data when available. This makes the system simulation more accurate, because the calculations are based on real system block data (circuit data) and not figures of merit.

Within the Cadence AWR Design Environment® platform, AWR VSS software is tightly integrated with Cadence AWR Microwave Office® software, enabling circuit simulation of amplifiers, oscillators, and mixers to be automatically linked to the system simulation. This makes it possible to replace block descriptions such as gain and NF as circuit data becomes available.

The link between circuit and system tools effects the way designers interact and share design ideas. The aim of using a system tool integrated with a circuit tool is to promote a more productive discussion between these two groups. Alternative system design approaches can result in the over-engineering of systems that reach the production stage, which leads to excessive R&D effort and overly complex and expensive solutions. Conversely, systems that are under-engineered can provide unacceptable performance when they are finally deployed.

## Case Study: Power Amplifier

Figure 9 shows the combination of system and circuit tools using a simple test of a power amplifier as an example.

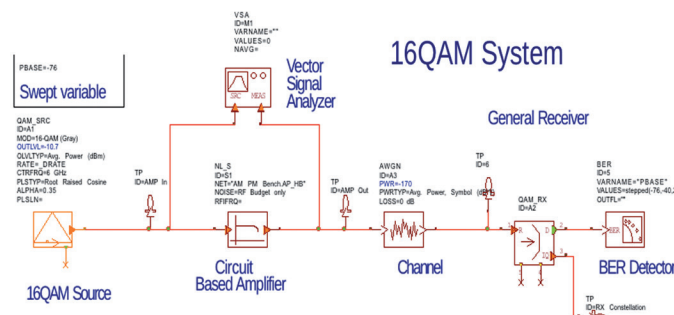


Figure 9: Amplifier testbench with 16-QAM modulation

The amplifier is actually defined using measured data. In this example, the measured data is being used by the Cardiff model, although nonlinear data such as S-functions or X-parameters could have been used as well. The spreadsheet approach works well for spot frequencies or narrowband systems in which the system block parameters are constant over frequency.

The budget analysis tools in AWR VSS software support the simulation of wideband systems such as electronic counter-measure (ECM) applications over multiple octaves. The example in Figure 10 shows the NF simulation over a finite bandwidth. The system block data is provided by data files that capture NF, gain, two-tone, and IP3 point data over a user-specified frequency range. This data can be provided either by simulation or from measurements.

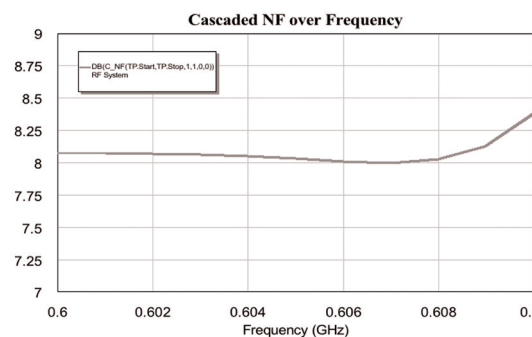


Figure 10: An NF simulation over a finite bandwidth

System design entails budget planning, frequency planning, and spur searching. AWR VSS software enables a single system diagram to capture the system topology and system block parameters, enabling a smoother, more productive, and problem-free design flow. It also provides spreadsheet views to complement its graphical user interface, so designers need not abandon this type of presentation. In addition to its system tools, The AWR VSS software's integration with AWR Microwave Office software provides system and circuit designers with a robust method of sharing information at all stages of the system design, from initial architectural decisions through to the prototype phase, reducing the time and materials cost risk of over- or under-engineering.

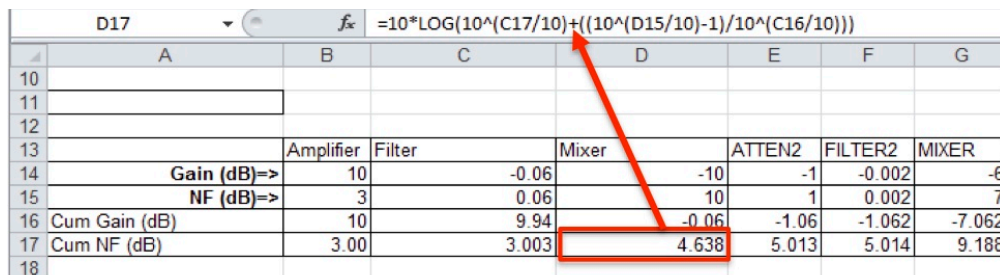


## Predicting Critical Metrics for Wireless RF Links

Understanding and correctly predicting cellular, radar, or satellite RF link performance early in the design cycle has become a key element in product success. The requirements of today's complex, high performance wireless devices are driving designers to assess critical measurements – NF, P1dB, IM3 distortion versus output power (IM3dBc), and SNR—long before manufacturing begins. Traditional modeling methods such as rules of thumb and spreadsheet calculations (Friis equations) give limited insight on the full performance of an RF link in next-generation wireless products. This section highlights the use of specialized RF system simulation software to accurately predict critical metrics for wireless RF links.

### Simulation Software: A Novel Approach

Traditionally designers have used spreadsheets (Figure 11) to do calculations such as cascaded NF, P1db, compression point, and/or IP3 point of an RF link. As wireless devices become more and more pervasive and complex, the limitations of spreadsheets become more apparent. Spreadsheet responses are based on standard equations and therefore do not typically account for mismatch between components or noise at image frequency. In addition, spreadsheets do not normally support data files such as S2p and spur tables, nor do they support yield analysis or optimization—techniques that are becoming increasingly important in order to produce high performance devices at a competitive price.



	A	B	C	D	E	F	G
10							
11							
12							
13		Amplifier	Filter	Mixer	ATTEN2	FILTER2	MIXER
14	Gain (dB)=>	10	-0.06	-10	-1	-0.002	-6
15	NF (dB)=>	3	0.06	10	1	0.002	7
16	Cum Gain (dB)	10	9.94	-0.06	-1.06	-1.062	-7.062
17	Cum NF (dB)	3.00	3.003	4.638	5.013	5.014	9.188
18							

Figure 11: Traditional use of the spreadsheet as a system tool

With AWR VSS software, designers can start from a spreadsheet interface to define the components (mixer, amplifier), whether file- or circuit-based, go on to define the circuit measurements such as cascaded NF and P1db, and also automatically generate a system diagram (Figure 12). This method provides far greater insight into what is happening. RF behavioral, circuit-based, and file-based models are available in AWR VSS software that account for VSWR effects and frequency dependence, as well as support yield analysis and optimization.

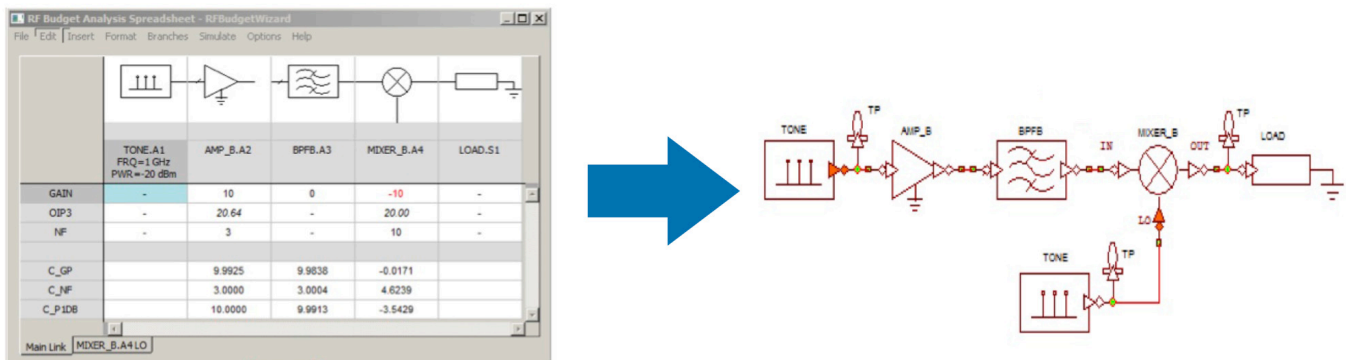


Figure 12: System simulation software tools start from a spreadsheet interface and automatically generate a system diagram

### Accounting for PSD at the Input of a Mixer

This example presents a typical design that accounts for noise power spectral density (PSD) at the input of a mixer.

As Figure 13 shows, the RF link starts with the continuous wave (CW) source, followed by the amplifier, the filter, the attenuator, and finally the conversion. Looking at the LO path, there is a CW tone, an attenuator, a model representing a cable, the amplifier, and then it goes directly into the LO. When the analysis is run in the AWR VSS software, a significant difference in the cascaded NF can be noted between the traditional spreadsheet, which shows 4.64dB, and the specialized software, which shows 11.45dB.

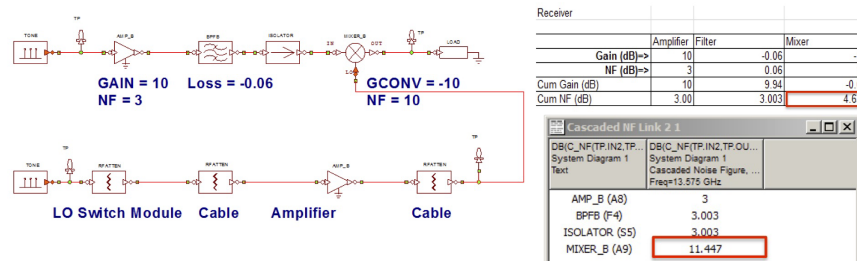


Figure 13: RF link and LO path of a mixer design, the spreadsheet and simulation software show significantly different cascaded noise figures (red boxes)

What’s happening to this link that is causing the discrepancy? The math was done correctly and entered into the spreadsheet, so the expectation is that the NF should be 4.6dB. The design was built and the analysis done, but the AWR VSS software’s simulation does not return anything close to 4.6dB. Why? The AWR VSS software is much more sophisticated than a spreadsheet and has lots of capabilities and measurements, so the next step would be to try doing a further analysis of the LO link.

The analysis done here is to make the PSD measurement at the very beginning of the LO link. It can be seen in Figure 4 that the PSD at the input of the mixer’s LO is -138.6dBm/Hz. This is due to the fact that there is an amplifier prior to the LO input of the mixer. When there is gain and NF in the amplifier, what does that do to thermal noise? The NF goes up, as shown in Figure 14. Typical spreadsheet equations do not account for this, so while designers can follow the book and do everything right, the AWR VSS software’s tool provides greater insight on the link.

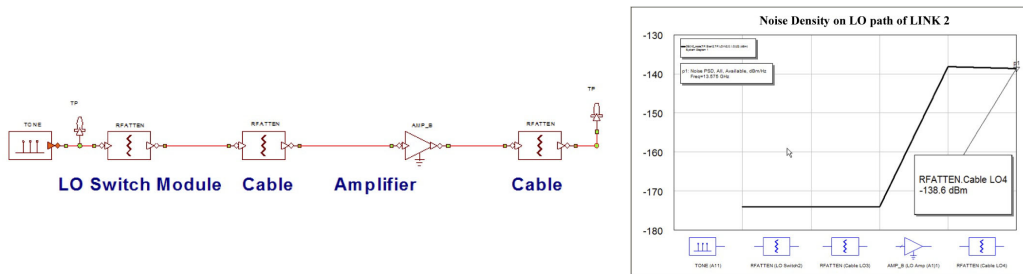


Figure 14: The noise density analysis of the PSD at the beginning of the link is -138.6dBm/Hz due to thermal noise

What’s the solution to this problem? Place a filter after the amplifier and, as shown in Figure 15, the noise density at the input of the mixer goes down to 174dBm/Hz and the software gives the expected measurement of 4.63dB.

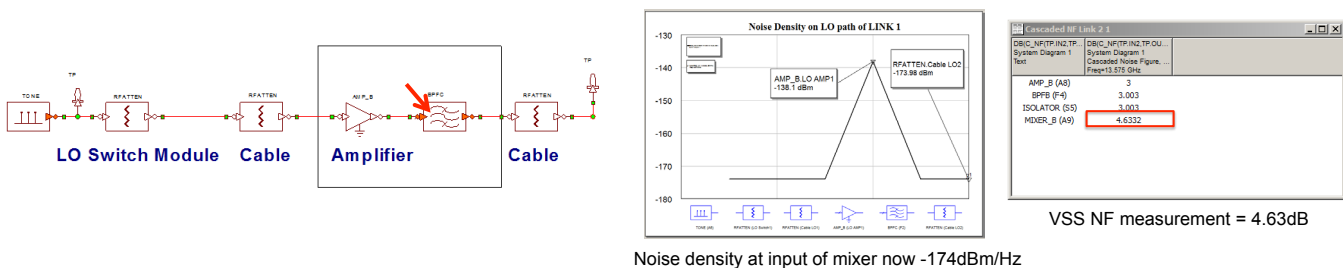


Figure 15: Upon placing a filter after the amplifier, the noise density at the input of the mixer goes down to 174dBm/Hz and the software gives the expected measurement of 4.63dB

### Accounting for Reflections

The second example shows how the behavioral filter can be replaced with an actual circuit implementation (Figure 16). The analysis is done and the S-parameters examined, specifically the S<sub>11</sub> and S<sub>21</sub>. Going down to the circuit level, what happens if a particular component level is switched or if the inductance of one of the inductors in this filter is tuned? As the S<sub>11</sub> response in the reflection is changed, once again the impact on NF can be seen (Figure 17). The filter's response changes with inductance value, and the resulting NF of the link fluctuates as well. Changes in S<sub>11</sub> and S<sub>21</sub> result in changes in cascaded measurements.

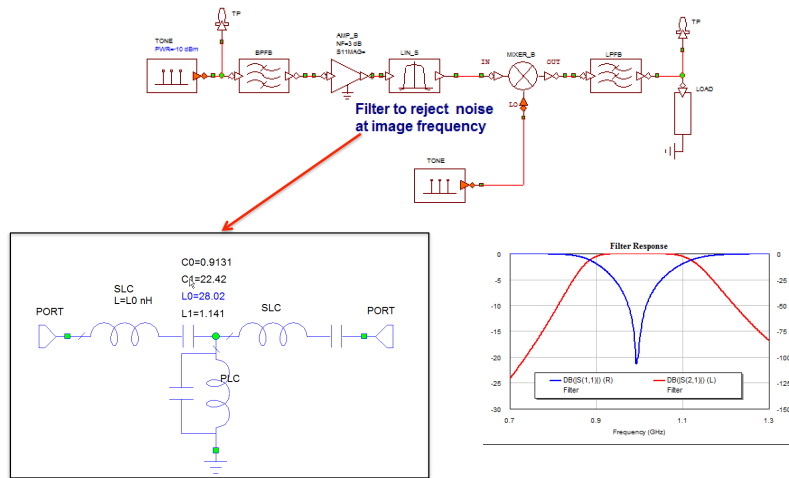


Figure 16: The behavioral filter is replaced with an actual circuit implementation

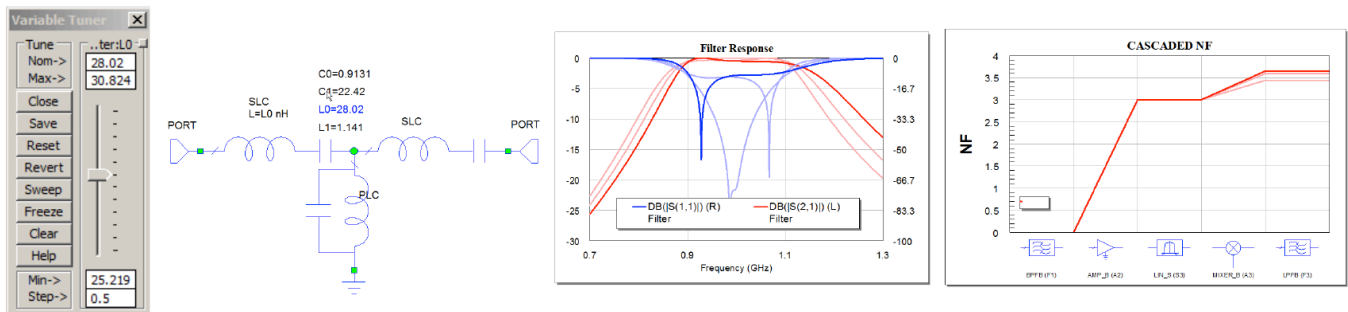


Figure 17: The filter's response changes with the inductance value and the resulting noise figure of the link fluctuates; changes in S<sub>11</sub> and S<sub>21</sub> result in cascaded measurement changes

Two cases have now been demonstrated where the AWR VSS software's simulation tool has differentiated from the typical spreadsheet. In the first case, the PSD running through the LO path causes the NF to go up due to the higher PSD in thermal, and in the second case, tuning or optimizing on the inductance value and changing the S<sub>11</sub> changes the NF.

### Accurate Measurement for Spurs

The final example (Figure 18) is a little more complicated. The goal here is to measure the ratio of a IM3 product to the carrier IM3dBc.

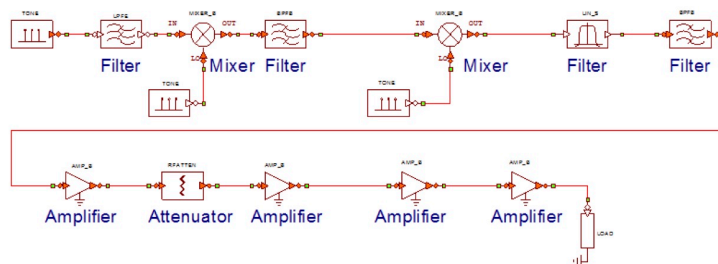


Figure 18: The desired measurement of the IM3 product to the carrier IM3dBc

First, the typical spreadsheet process is used to define the components, and then the system is built in the software using a tool such as AWR VSS software's RFB budget analysis (Figure 19).

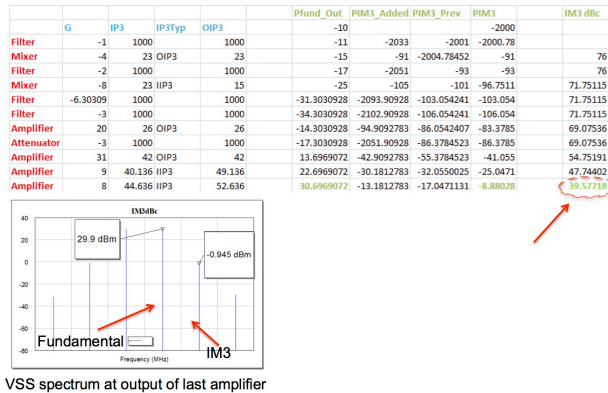


Figure 19: Spreadsheet calculation for IM3dBc versus AWR VSS software measurement

Once again, it can be seen that AWR VSS software does not agree with the standard spreadsheet measurement. The spreadsheet calculation is 39.577dBm and the AWR VSS software's calculation is 30.845dBm (29.9dBm - 0.945dBm). Why do the two methods differ?

Looking more closely, IM3 product is measured at the output of the second mixer and compared to the spreadsheet (Figure 20). In the software, the intermodulation product is -92dBm, and the spreadsheet is calculating -97dBm. Only the ratio of that tone to the product is being measured. To get to -97dBm, the previous value for the is -101dBm, and -105dBm has been voltage combined to get to -97dBm. The software is calculating -92dBm—what is going on?

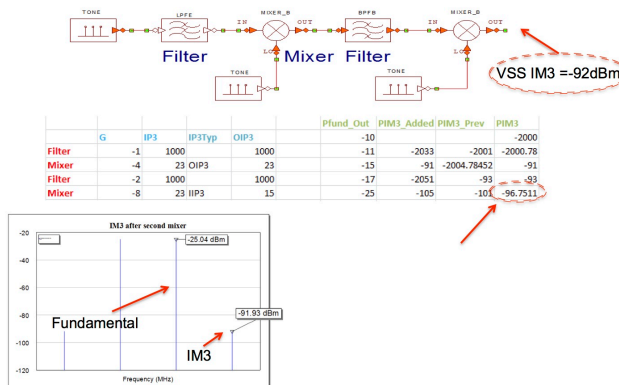


Figure 20: The IM3 product is measured at the output of the second mixer and compared to the spreadsheet

AWR VSS software enables users to understand the contributions to a particular spur and what causes the spur to be at that particular value—indicating there is something contributing to that product to make it higher than expected, something that is folding into the frequency (Figure 21).

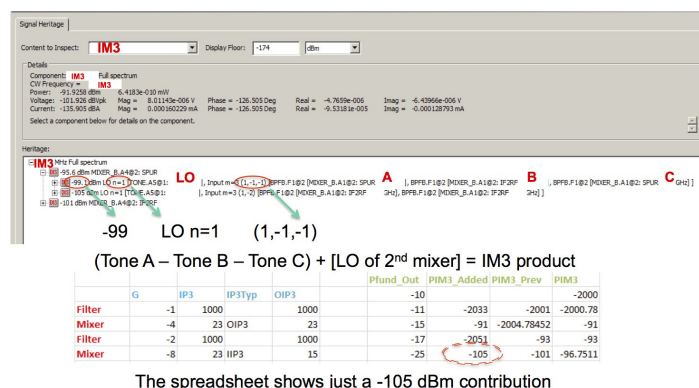


Figure 21: The RFI signal heritage window reveals a spur that falls on the IM3 product of -99dBm in addition to the expected -105dBm

Note there are no frequencies labeled, but there is a combination of Tones A, B, C in the index of one on the first LO, the combination of Tone A minus B minus C plus the LO is causing that value of -105dBm to be -99dBm. That is what the software calculated. Something folded over into that product.

So, the voltage combined -95.5dBm + -101dBm equals -92dBm. What is coming into that mixer? At this point, RFI reveals that Tones C, A, and B are combined with the LO (Figure 22), and that value fell onto the IM3 product. So how can the combination of Tones C, A and B in the LO be removed?

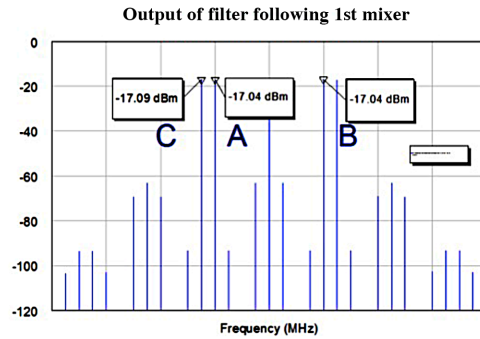


Figure 22: RFI reveals the output of the filter following the first mixer, Tones C, A, and B

The mathematics in the spreadsheet can't indicate the solution, but the AWR VSS software's spur analysis tool does. It suggests that a filter be placed to eliminate unwanted tones (Figure 23). A filter can be placed at that point to eliminate any of the Tones—A, B, or C. The LO can't be eliminated, but once one of the tones is suppressed, the software gives exactly what the spreadsheet said: -101dBm from the previous and -106dBm from AWR VSS software. (Note: if designers are worried, they can dive into -106dBm to see what contributed to that to make a difference from the -105dBm.)

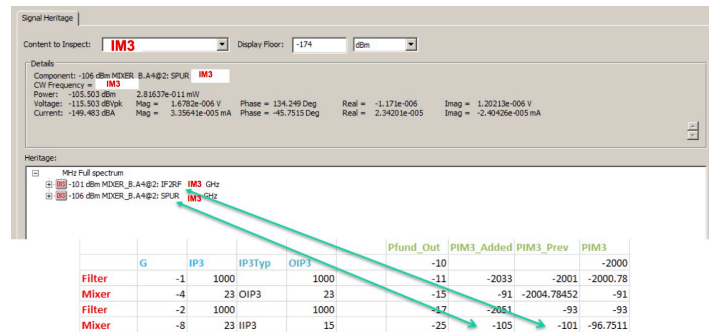


Figure 23: RFI suggests placing a filter to eliminate unwanted Tones A and C

Once again the software was able to find the problem and offer a solution. A filter is added, two of the tones are reduced, the measurement is made, and the results are now reconciled (Figure 24).

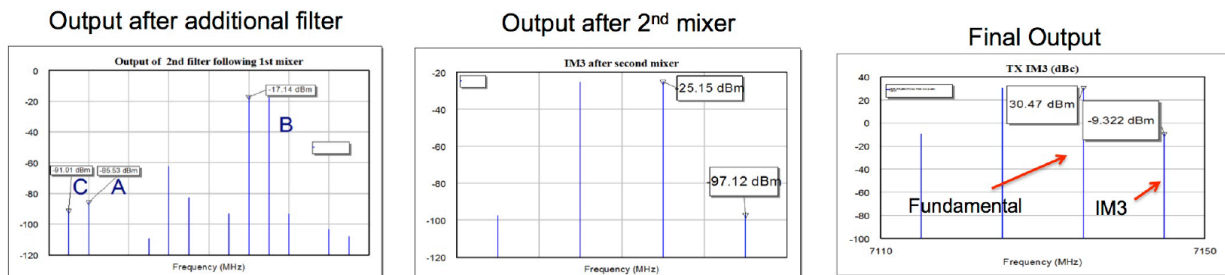


Figure 24: Spectrum plots showing the output after the additional filter is added, the output after the second mixer, and the final output of 30.47dBm minus -9.32dBm, equaling 39.79dBm

Using modern software tools to determine system specifications provides much more value than using a spreadsheet as the only method. The software provides for a richer set of models, real word effects accounted for in the calculations, optimization and yield analysis, as well as in-depth spur analysis. Tools such as AWR VSS software give designers much more accuracy and automation in determining system requirements than working exclusively with and maintaining legacy spreadsheets.

## RF Planning Speeds System-Level Analysis

AWR VSS software provides insight early in the design process about how a circuit, subsystem, or system will perform, enabling designers to make changes up front in component values and circuit configurations with far less effort. It doesn't matter whether the ultimate application is a wireless base station or mobile device, radar system, or surveillance receiver, the software can iron out potential difficulties—before they become show stoppers.

### System-Level Analysis

AWR VSS software is a natural evolution of the way most designers accomplish system-level analysis: by using office productivity software such as Microsoft Excel (Figure 25). AWR VSS software accounts for the most important factors—component mismatches and phase noise—that affect system performance. It also allows circuit designs or S-parameter files to be imported, offers a library of components from which to choose, can pinpoint the source of a spurious response or intermodulation product, and much more.

Input Power = -15								
RF Link								
	Attenuator	Filter	Filter	Switch	Amp	Mixer	RoC	
Gain (dB)=>	-2	-1	-3	-1	15	-6.5		40
NF (dB)=>	2	1	3	1	2	6.5		6
OIP3 (dBm)=>	100	50	50	50	22	13		20
P1dB=>	100	100	100	100	6	1		
Cum Gain (dB)	-2	-3	-6	-7	8	1.5		41.5
Cum NF (dB)	2.00	3.00	6.00	7.00	9.00	9.29		10.25
Cum OIP3 (dBm)	100.00	50.00	45.24	43.21	22.00	11.06		20.00
Cum IIP3 (dBm)	102.00	53.00	51.24	50.21	14.00	9.56		-21.50
Stage Output Pwr (dBm)	-17	-18	-21	-22	-7	-13.5		26.5

Figure 25. Traditional spreadsheet approach to system-level analysis

While spreadsheets can be powerful and account for numerous system-level effects, they do not fully explore nor correctly calculate all the effects of a system (such as noise) that determine a receiver's RF link quality, inclusive of cascaded NF and image noise. This source of noise is typically incurred in the down-conversion process, which produces a desired (center) signal from the difference between a mixer's LO and input frequencies. The center frequency also incurs a noise penalty from a higher image frequency that places a signal at the center frequency after down-conversion. The amount of added image noise depends on how much of the image frequency band is present at the input of the mixer, and failure to account for it can result in significantly degraded receiver performance.

Image noise can be reduced through filtering, but if the system-level analysis is performed solely with a spreadsheet, the effect of image noise can only be assumed, since it cannot be accurately calculated. As a result, a designer can either ignore it and hope for the best or overcompensate for its effect based on an assumed noise value. Either solution is imprecise at best. That's simply not acceptable in today's design environment, where systems use complex protocols such as orthogonal frequency division multiplexing (OFDM), and the time-to-market window continues to shrink. In short, performance-killing system-level effects must be dealt with early in the design, as quickly and painlessly as possible. This is precisely what AWR VSS software is designed to achieve.

## Using AWR VSS Software

AWR VSS software enables advanced system-level planning and empowers designers to account for variables that are not feasible within a spreadsheet-based approach. The “heavy-lifting” is done by the tool, so designers can devote their efforts to creating microwave products rather than writing software to evaluate them. Both the baseband and microwave portions of a design can be evaluated together, enabling the consideration of all possible component interactions. AWR VSS software works seamlessly with AWR Microwave Office software providing a complete solution, from concept through verification (Figure 26).

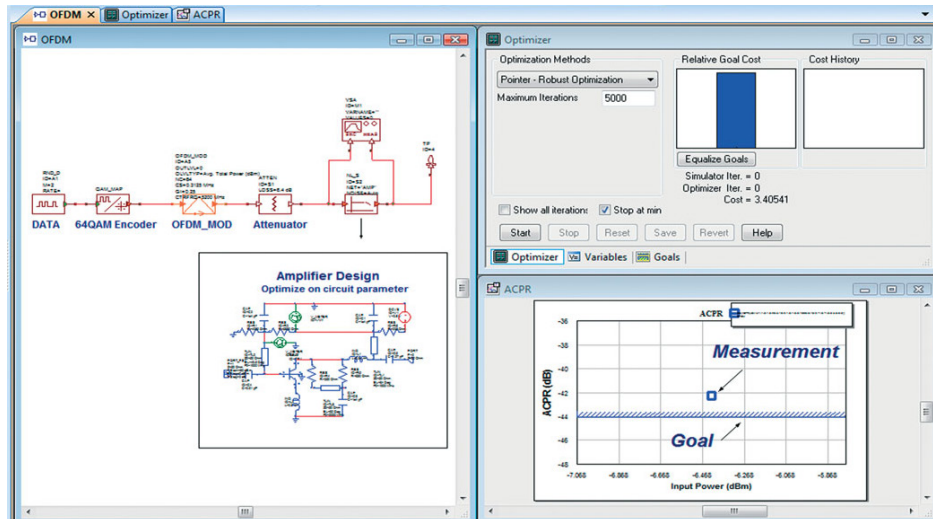


Figure 26: AWR VSS software co-simulates with the Microwave Office software's design environment

Virtual testbenches (Figure 27) are integrated into AWR VSS software for a dedicated simulation set-up to measure key performance metrics for specific wireless standards such as the emerging 5G waveforms, as well as global system for mobile communications (GSM), enhanced data GSM environment (EDGE), high-speed packet access (HSPA), digital video broadcasting handheld (DVB-H), digital video broadcasting terrestrial (DVB-T), wideband code-division multiple access (WCDMA), Institute of Electrical and Electronic Engineers (IEEE) 802.11 a/b/g, and worldwide interoperability for microwave access (WiMAX). They include standard-specific measurement criteria that must be applied in order to ensure compliance with an applicable standard.

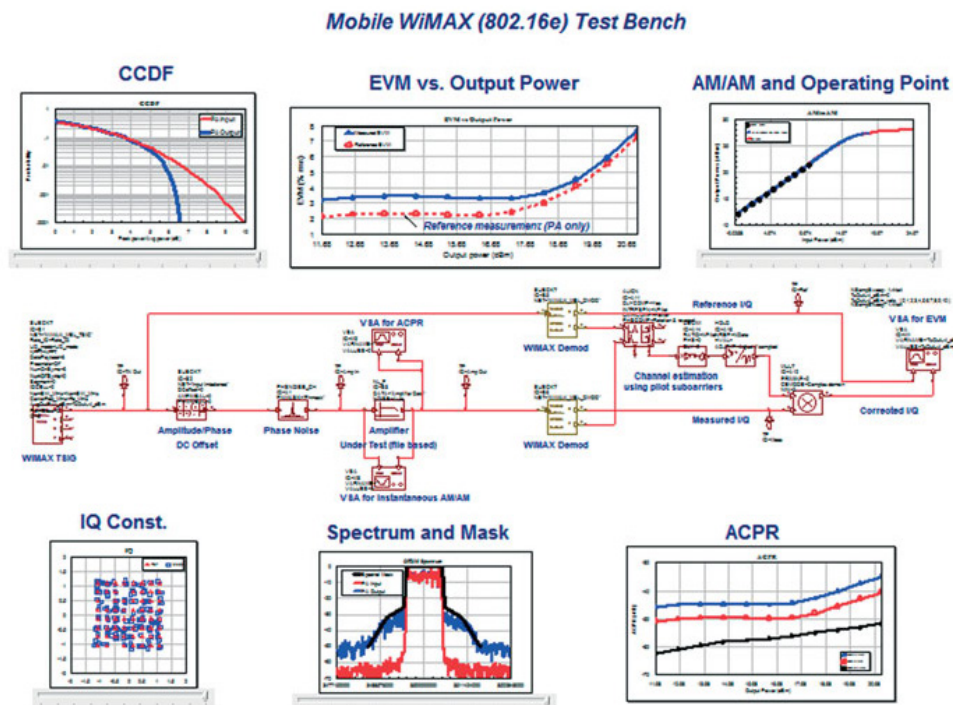


Figure 27: A WiMAX test bench in AWR VSS software: all of the required tools in one place

The RFB tool, a main component of AWR VSS software, enables standard cascaded RF measurements such as gain, NF, and OI3 (including image noise) to be performed throughout the project, which helps ensure proper component selection.

The RF link with automatic gain loop (AGC) shown in Figure 28 illustrates the benefits of the RFB tool. The link consists of two amplifiers, a filter, and a variable gain amplifier (VGA). The amplifier model in AWR VSS software is dependent on a data file that accounts for the frequency dependency of common amplifier parameters, including input and output reflection coefficients.

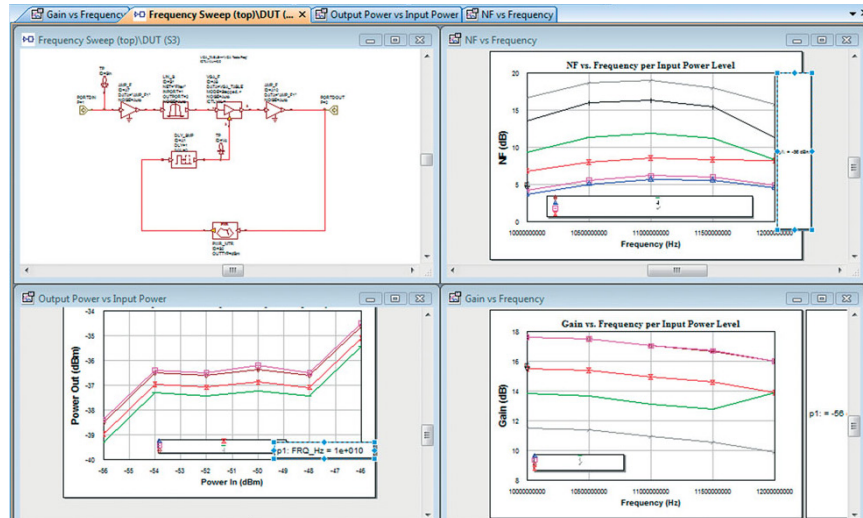


Figure 28: RFB screen for an RF gain control circuit

The VGA accounts for frequency dependency, hysteresis, and S-parameters. In both cases, the frequency-dependent settings are interpolated for frequencies between the smallest and largest frequencies. The models also include saturation shaping of the input signal, and, if desired, designers can work at the highest level of abstraction using RF models with parameter windows for P1dB, IP3, NF gain conversion, and other parameters.

The AWR VSS software's simulation is set to sweep through several frequency points and power levels. For each frequency, the cascaded NF, gain, and output power versus input power are monitored. In the case of NF versus frequency, each input power level is represented by a different color trace and the X-axis is defined as frequency. The power input versus power output graph in the figure shows the region of operation in which relatively stable gain can be achieved. In short, AWR VSS software lets the subsystem designer evaluate the AGC loop under realistic conditions, and can do so with eight mouse clicks in less than five minutes. This is obviously a dramatic improvement over what even the best spreadsheet can do.

In the upper left area of Figure 29, a AWR VSS software project is shown that consists of two RF links, each composed of a bandpass filter, low-noise amplifier (LNA), image-noise rejection filter, quadrature mixer, low-pass filter, and 50 Ohm terminating load. The mismatch between components is simulated in both links.

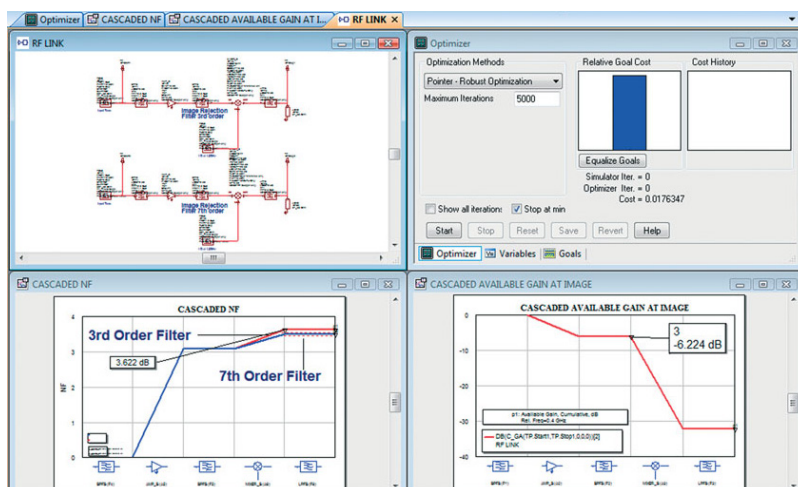


Figure 29: RFB screen showing an RF link, cascaded NF measurements, and cascaded available gain at the image frequency



The difference between the two links is the order of the image noise rejection filter, in one case employing a third-order filter and in the other a seventh-order filter. The seventh-order filter has a sharper cutoff in the stop band than the third-order filter. The cascaded NF graph of the RF link (lower left) shows that a lower NF can be achieved using a seventh-order filter than a third-order filter. The available cascaded gain at the image frequency is shown at the lower right. The reduction in cascaded gain after the mixer is caused by the frequency conversion.

To maintain the overall cascaded NF, the designer can either keep the third-order filter (which is less expensive to implement) and optimize the noise figure of the LNA to provide the same effect as using a seventh-order filter. The available cascaded gain at the image frequency can be monitored as well. The graphical interface of AWR VSS software simultaneously shows both optimization and yield analysis, one of the unique advantages of using a software simulation tool for visualizing the effects of circuit interactions. Setting up the simulation takes only a few minutes and can be enabled instantly for the next design or variation.

The RFI component of AWR VSS software helps users identify the cause of impairments such as intermodulation products or spurious signals anywhere in the signal chain, which designers can then isolate and/or eliminate. This system-level, frequency-domain simulator solves for voltages and currents at each RF node for each generated spectral component and includes the effects of conversions, harmonics, intermodulation, and mixer leakage (LO-to-IF, IF-to-RF, and RF-to-IF). The RF link can be simulated with CW or modulated signals. For each of these contributors to overall performance, the RFI tool can determine their frequency content, identify their path, examine their voltage, current, and power, and classify them as signals of interest, distortion, or interference.

Designers can monitor the full spectrum, only the spectrum of the signal, the spectrum of the distortion products, and the spectral content of any node after simulation. To determine the individual contributions to a particular tone, designers can simply double click on a tone to open up the RFI dialog box that contains detailed information about the content of the selected spectrum component.

Flags of different colors are used to identify the desired signal, intermodulation products, and distortion products. Figure 30 shows RFI applied to a converter circuit that has test points (TP), combiners (COMB), and Butterworth bandpass filters (BPFB). In this circuit, the signal is down converted at 2.14GHz and has undesired signals at 1.4 and 2.4GHz.

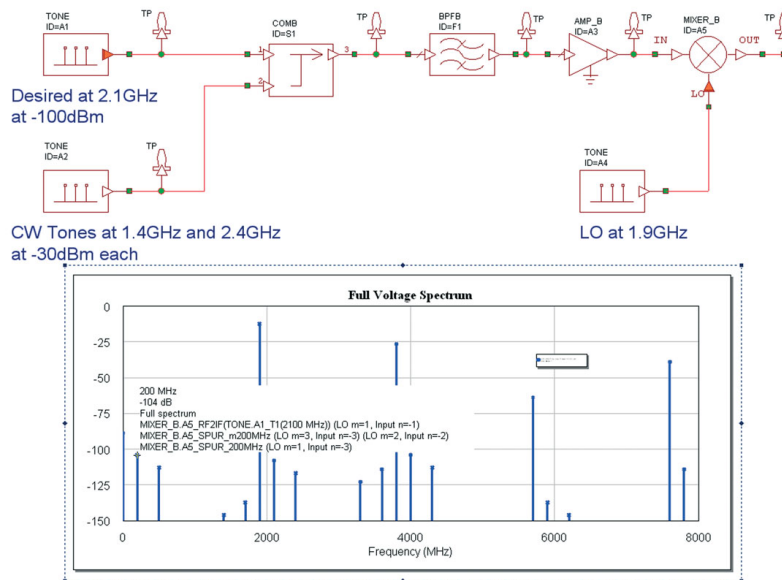


Figure 30: RFI applied to a converter circuit that has test points (TP), combiners (COMB), and Butterworth bandpass filters (BPFB)

Designers have long needed the AWR VSS software's system-level simulation tool, which is a natural upgrade from spreadsheets. It can do far more than even the most elaborate spreadsheet in enabling the creator of a circuit to optimize its performance. It helps designers fully understand the profound damage that impairments can wreak on RF links, especially those in the latest generation of wireless systems and in those to come. It can dramatically reduce design time, rework, and cost, and ensure that the design performs well in service.

## Conclusion

This white paper has presented some examples highlighting the use of the AWR VSS software's system simulation tool within AWR Design Environment software, to perform more rigorous link budget analysis than can be done with spreadsheets. Capabilities in AWR VSS software enable the system designer to monitor signal strength as well as spurious signals arising from device nonlinearity throughout the RF front end and determine the appropriate architecture and component specifications to ensure successful data transmission. As communication systems grow increasingly complex in order to support higher data rates and capacity, optimum system architectures leveraging multipath propagation for greater over-the-air efficiency via technologies such as multiple-in-multiple-out (MIMO) antennas, along with component specification that provides the necessary link margin, will all be required. Dedicated RF communication system simulation software will ensure the engineering team is able to address all of these challenges in a productive and cost-effective manner.



Cadence is a pivotal leader in electronic design and computational expertise, using its Intelligent System Design strategy to turn design concepts into reality. Cadence customers are the world's most creative and innovative companies, delivering extraordinary electronic products from chips to boards to systems for the most dynamic market applications. [www.cadence.com](http://www.cadence.com)

© 2020 Cadence Design Systems, Inc. All rights reserved worldwide. Cadence, the Cadence logo, and the other Cadence marks found at [www.cadence.com/go/trademarks](http://www.cadence.com/go/trademarks) are trademarks or registered trademarks of Cadence Design Systems, Inc. All other trademarks are the property of their respective owners. 15429 11/20 DB/SA/WP-V-RF-LNK/PDF

