

OVERVIEW

High-frequency technology didn't earn its reputation as black magic for no reason. Unlike low-frequency circuits, microwave circuits don't behave in a totally predictable way, so "tweaking" has been an accepted mainstay of the microwave design approach/flow. Fortunately, high-frequency design tools have dramatically improved so that tweaking of prototype circuits is much less common, and today's engineer has powerful tools that can make sense of the black magic.

As this white paper will demonstrate, AWR's Visual System Simulator (VSS) design environment, a comprehensive software suite for design and optimization of communications systems, 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, VSS can iron out potential difficulties—before they become show stoppers.

SYSTEM-LEVEL ANALYSIS

VSS is a natural evolution of the way most designers accomplish system-level analysis: by using office productivity software such as Microsoft Excel (Figure 1). VSS 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 into them, 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 1. Traditional Excel spreadsheet approach to system-level analysis.

While spreadsheets can be powerful and account for numerous system-level effects, they do not fully exploit nor correctly calculate all the effects of a system, for example, noise, that determine a receiver's RF link quality inclusive of cascaded noise figure and image noise. This source of noise is typically incurred in the downconversion process, which produces a desired (center) signal from the difference between a mixer's local oscillator 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 downconversion. 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.



Upfront RF Planning
Speeds System-Level
Analysis

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 VSS is designed to achieve.

THE BENEFITS OF VSS

The benefits of using VSS above and beyond a spreadsheet are compelling:

- ◀ VSS was created for the express purpose of advanced system-level planning and enables designers to account for variables that are not feasible within a spreadsheet-based approach.
- ◀ VSS is a part of AWR's Design Environment™ and works seamlessly with the Microwave Office® high-frequency design suite, which provides a complete solution, from concept through verification (Figure 2).

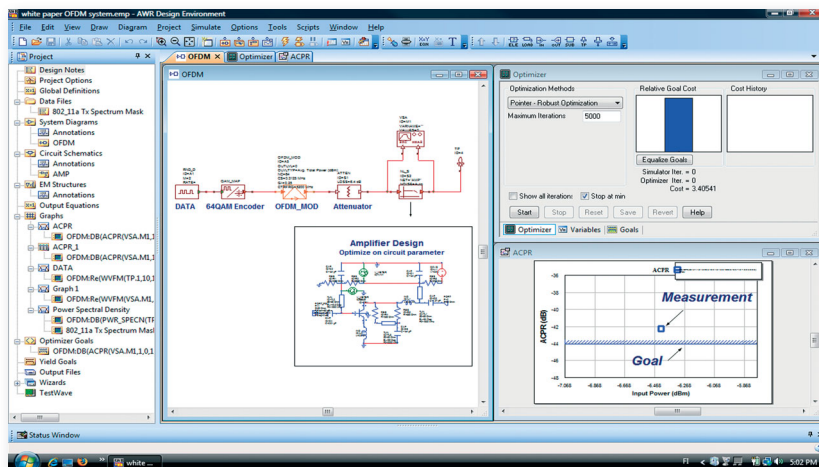


Figure 2. VSS co-simulated with the Microwave Office design environment.

- ◀ The "heavy-lifting" is done by VSS, 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.

- ◀ "Test benches" (Figure 3) are integrated into VSS that are dedicated to specific wireless standards, such as GSM, EDGE, HSPA, DVB-H, DVB-T, W-CDMA, IEEE-802.11a/b/g, and WiMAX, and include standard-specific measurement criteria that must be applied in order to ensure compliance with an applicable standard.

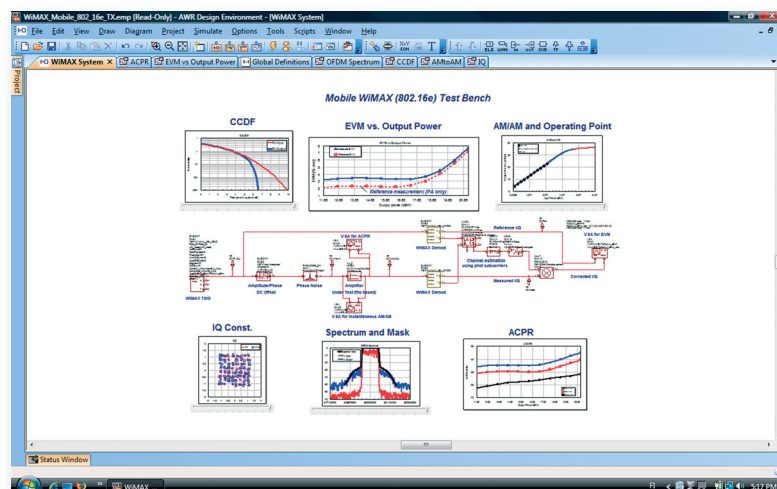


Figure 3. A WiMAX test bench in VSS: all of the required tools in one place.

- System-level variables are dealt with early in the design, so the need for circuit rework is dramatically reduced and often eliminated.
- When used in conjunction with AWR's TestWave™ software, circuits, subsystems, and even complete systems can be evaluated using actual standards-based waveforms generated by signal generators, and evaluated by vector signal analyzers, spectrum analyzers, vector network analyzers, and other external instruments. Complex test routines can be created, configured, and controlled by the TestWave software and the results compared with a simulation performed in VSS (Figure 4).

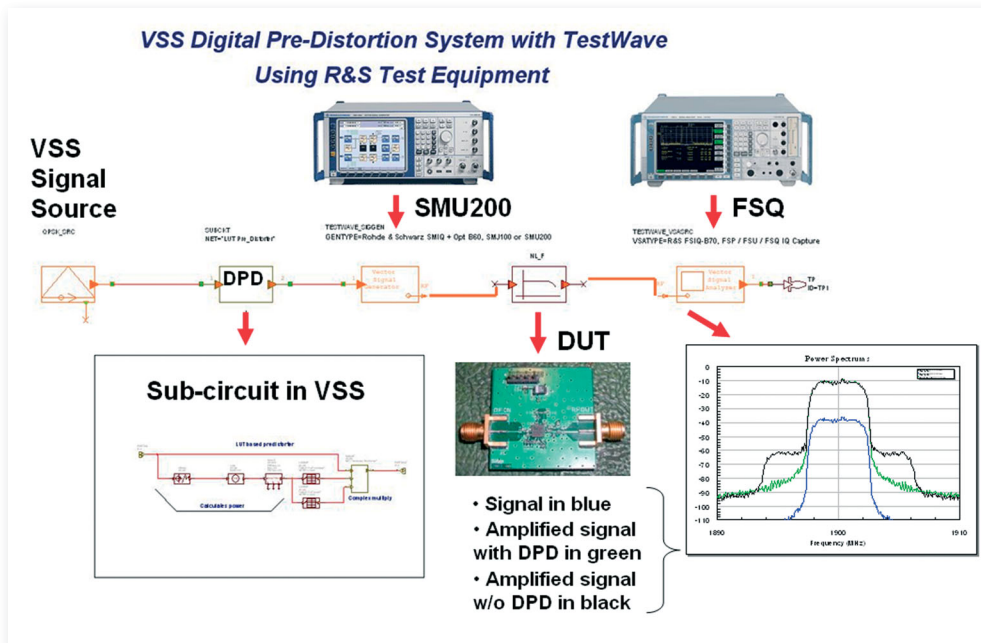


Figure 4. VSS digital pre-distortion using TestWave software and Rohde & Schwarz instruments.

VSS IN A NUTSHELL

VSS is an “end-to-end” solution for system design, an all-encompassing tool that helps designers create the best possible system architecture, optimize each of its components, and reduce cost by eliminating rework and ensuring components are not overspecified. Designers can begin at the behavioral level, progress to the component level using Microwave Office or Analog Office® software, and then verify system performance using actual measurements.

RF Budget Analysis™ A main component of VSS, enables standard cascaded RF measurements such as gain, noise figure, and third-order intercept (including image noise) to be performed throughout the project, which helps ensure proper component selection.

RF Inspector™ Another important component of VSS, helps users identify the cause of impairments such as intermodulation products or spurious signals anywhere in the signal chain, and then isolate and eliminate them.

TestWave As mentioned earlier, this optional tool provides the ability to verify the performance of the system by stimulating and evaluating the performance of devices using external test equipment to reveal weaknesses, which can then be remedied by VSS.

RF Budget Analysis in Action The RF link with automatic gain loop (AGC) shown in Figure 5 illustrates the benefits of the RF Budget Analysis tool. The link consists of two amplifiers, a filter, and a variable gain amplifier (VGA). The amplifier model in VSS is dependent on a data file that accounts for the frequency-dependency of common amplifier parameters, including input and output reflection coefficients. 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, noise figure, gain conversion, and other parameters.

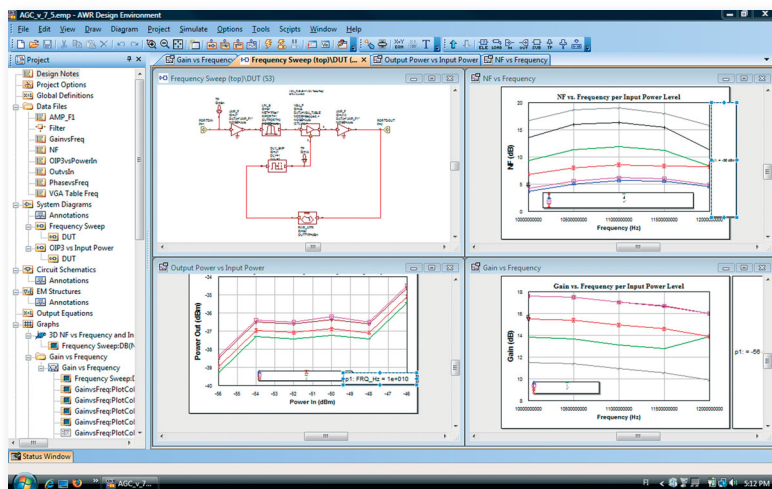


Figure 5. RF Budget Analysis screen for an RF gain control circuit.

The VSS simulation is set to sweep through several frequency points and power levels. For each frequency, the cascaded noise figure, gain, and output power versus input power are monitored. In the case of noise figure 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, VSS 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.

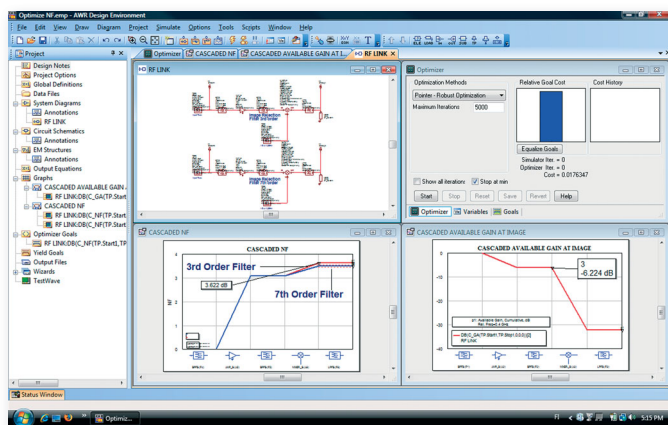


Figure 6. RF Budget Analysis screen showing an RF link, cascaded noise figure measurements, and cascaded available gain at the image frequency.

The upper left area of Figure 6, a VSS project is shown that consists of two RF links, each composed of a bandpass filter, low-noise amplifier, image-noise rejection filter, quadrature mixer, low-pass filter, and 50-ohm terminating load. The mismatch between components is simulated in both links. 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 noise figure graph of the RF link (lower left) shows that a lower noise figure 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.

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To maintain the overall cascaded noise figure, the designer can either keep the third-order filter (which is less expensive to implement) and optimize the noise figure of the low-noise amplifier 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 VSS 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.

RF Inspector Finds the Offenders RF Inspector is a system-level, frequency-domain circuit simulator. It 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 continuous wave (CW) or modulated signals. For each of these contributors to overall performance, RF Inspector 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 RF Inspector 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 7 shows RF Inspector applied to a converter circuit that has test points (TP), combiners (COMB), and Butterworth bandpass filters (BPFB). In this circuit, the signal is downconverted at 2.14 GHz and has undesired signals at 1.4 and 2.4 GHz. RF Inspector can identify the components that are producing the largest contributions to these unwanted signals and calculate the outcome when adjustments are made.

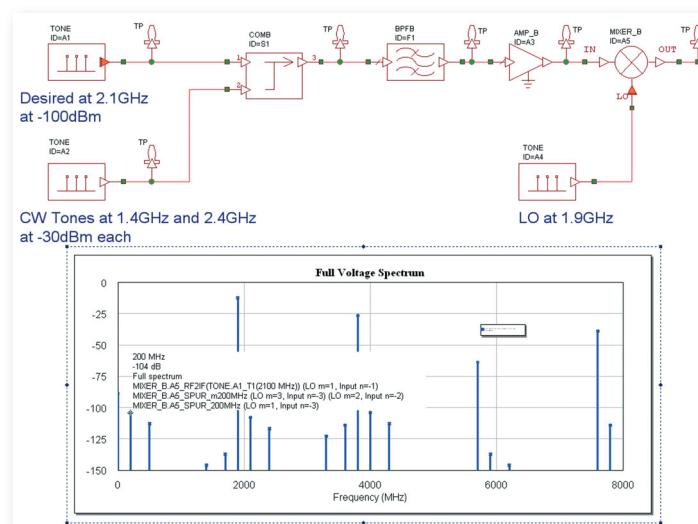


Figure 7. RF Inspector applied to a converter circuit that has test points (TP), combiners (COMB) and Butterworth bandpass filters (BPFB).

SUMMARY

VSS is the system-level simulation tool that designers have long needed and a natural upgrade from Excel. 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.



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