RF System Design and Analysis Software Enhances RF Architectural Planning

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This new software enables convenient simulation of system-level performance, from cascaded gain and noise figure to detailed analysis of spurious signals and harmonics.

Historically, commercial software for designing RF and microwave products at the circuit level matured before equivalent full-featured system level software became widely available. The gap between CAE (Computer Aided Engineering) tools at the circuit level and what was needed for designing at the system level was often filled by designers creating their own system analysis tools in spreadsheets, using common office software such as Excel. There were many drawbacks to the spreadsheet as system analysis tool. Their one-of-a-kind nature, narrow focus on the analysis of one type of problem, and the inability to track the creation and propagation of spurious signals and intermodulation products top the list of drawbacks.

Even when excellent system analysis spreadsheets were developed in-house they were often difficult to maintain, especially if the author(s) were no longer available. They were often hard to adapt to system architectures that were significantly different than the original product or system they were created to analyze.

Eventually, competition in the electronic design automation (EDA) industry lead to easy-to-use GUIs and a more or less standard approach to the operational behavior of most circuit level RF simulation software. Unfortunately, commercial RF system simulation software took a more divergent path. Some software simply commercialized the spreadsheet approach while other software mimicked the spreadsheet with stand-alone cascade budget calculators. Larger, full-featured software applications offered spectral analysis in addition to budget analysis. However, implementa-
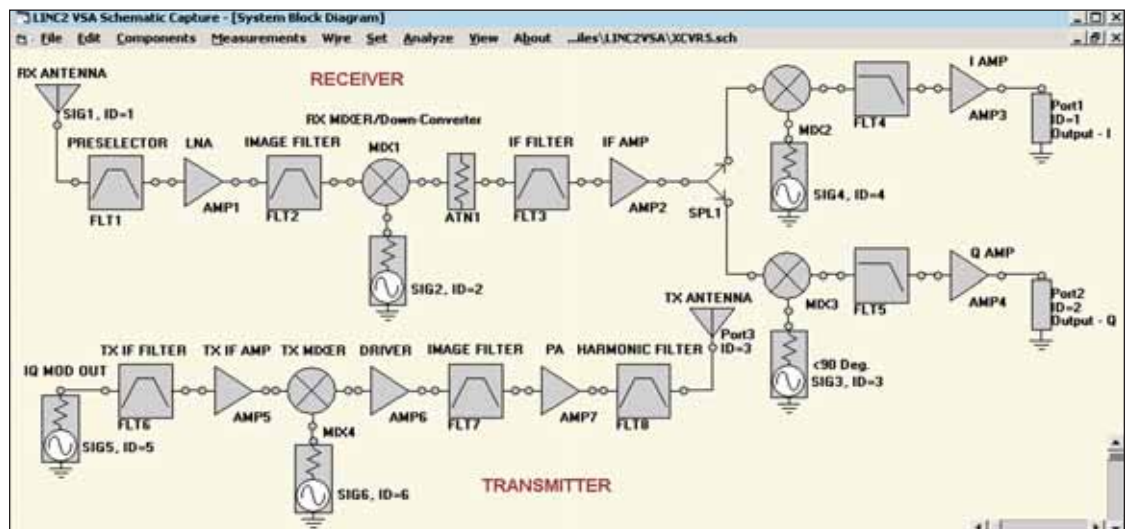

Figure 1 · A typical ACS Visual System Architect system schematic.

tion varied among vendors, making it difficult for the user to migrate from one package to another.

Worse than the lack of standardization among products is the fact that within a given product, the user is often required to engage a different "simulation engine" in order to perform different analyses or produce different types of simulation results. For example, some software can do both an RF cascade budget analysis and perform a spectral domain analysis, but not simultaneously. The requirement to remove the budget analysis simulation definition in order to place a Harmonic Balance simulation setup on the schematic, just to produce a spectrum analyzer type display, seems artificial to the user. Then, when it is discovered that another type of simulator is required to complete the desired simulation tasks, the user may have the unpleasant task of configuring the simulator properly in order to get meaningful results. Setup defaults (if provided) rarely apply to the problem at hand and other setup parameters may be confusing or cryptic, even after consulting the manual or Help.

LINC2 Visual System Architect

The new LINC2 Visual System Architect (VSA) software from Applied Computational Sciences (ACS) was designed to eliminate most of these issues. One of the goals of the LINC2 VSA program was to make the software not only easy to use but so completely intuitive that users can be productive with it right out of the box. The program met these objectives through the following enhancements:

- Schematic based system simulation capable of analyzing arbitrary system topologies

    With schematic based simulation, any system that can be drawn on the schematic page can be analyzed, including branches that diverge from the main signal path (using splitters) and multiple independent parallel signal paths.
- One simulation engine (single pass simulation) produces all available analysis results
- Little or no simulation setup required (simply click Analyze and View Results)
- System budget analysis and spectral domain analysis results are available immediately for simultaneous display
- A signal and spur viewer identifies and traces all signals and otherwise unknown spurs through the system all the way back to their origins
- Non-linear power sweep curves display output versus input power, including sweeps through gain compression and saturation
- All analysis results can be exported to spreadsheets (such as Excel) or other programs via standard CSV output files

- Library of built-in component models including non-linear amplifiers and mixers
- Behavior models include frequency translation (mixers) and frequency selective components (filters)
- Splitter model allows analysis of multiple parallel paths (branches) driven by one or more signal sources
- Simultaneous analysis of multiple independent system cascades (parallel paths driven by independent signal sources)
- User-defined equations

    The user can compose equations that relate system component parameters to variables in new ways, creating new relationships between variables and component values that are defined and controlled by the user.
- Variables—The numerical parameter value(s) of any system component can be selected for real-time interactive tuning. Thus, displayed analysis results (such as plots and numerical tables of system response data) are updated as the component's parameter is adjusted, giving visual and numerical feedback on how the system is affected by each selected parameter for any component in the system. Variables can enhance the tuning method in the following two ways: A named variable can be assigned to any number of system component parameters so that tuning results in all these component parameters being assigned the current numerical value of the variable (ganged tuning). As mentioned above, the variable can be mapped through an equation to produce a new value for the component parameter. The variable can also be used with other variables in an equation to produce a more complex relationship between the variables and the assigned component parameter.

The LINC2 VSA System schematic works exactly like the familiar circuit level schematic. System components can be placed anywhere on the schematic page and wired to other components in any configuration desired, so practically any kind of system can be constructed and analyzed. Figure 1 shows a typical system schematic representing a radio transceiver. As indicated, the schematic captures the entire RF system from antenna to the individual I and Q channels.

Several important system analysis capabilities are evident from the schematic in Figure 1. The ability to analyze multiple independent subsystems means that the LINC2 VSA program can produce complete analysis results for both the transmitter and receiver simultaneously. The VSA splitter model enables the analysis of architectures involving parallel branches that depart from the main signal path. In the example in Figure 1, the RX IF signal is split and distributed evenly to the I and Q
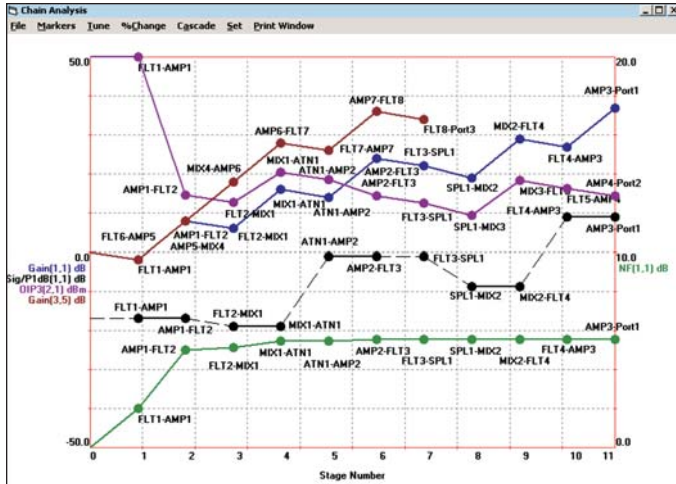
Figure 2 · The VSA's cascade budget plots.

Figure 3 · The VSA reports table.

down-converters for which the signal path is identical in these two parallel hardware channels (except for the 90 degree phase shift). This example also demonstrates the ability to include frequency translation (mixer models) and frequency selectivity (filter models) in the analysis.

The VSA is part of an integrated EDA software suite from ACS. While providing many new design and analysis capabilities for designing at the system level, the VSA program maintains a common user interface with the ACS LINC2 circuit simulator. With the VSA addition to the LINC2 Pro circuit design and simulation software suite, system level designs created with the Visual System Architect can proceed to the circuit design level, all within a common integrated user interface. Thus, RF and microwave circuit design can be appropriately driven by high level system design that links product specifications to circuit level specifications and subsequently to detailed circuit designs.

Because the program is not limited to a single chain of cascaded components, the user can quickly and easily construct systems of arbitrary topology using a comprehensive menu of system component behavioral models such as amplifiers, mixers, filters, splitters, and attenuators, etc. The VSA renders obsolete the traditional spreadsheets and system cascade calculators. It does this in part by providing the flexibility of schematic entry, the ability to model the spurious products created in non-linear stages, the ability to identify and track spurs back through the system to their origin and by displaying spectrum analyzer type views of all signals and spurs at the output or at selected nodes throughout the system.

VSA Cascade Budget Analysis

Plots of power budget, efficiency, gain, IP3 (intercept point), NF (noise figure) and signal/P_{1dB} (signal level relative to the component's P_{1dB}) are provided on a cumula-
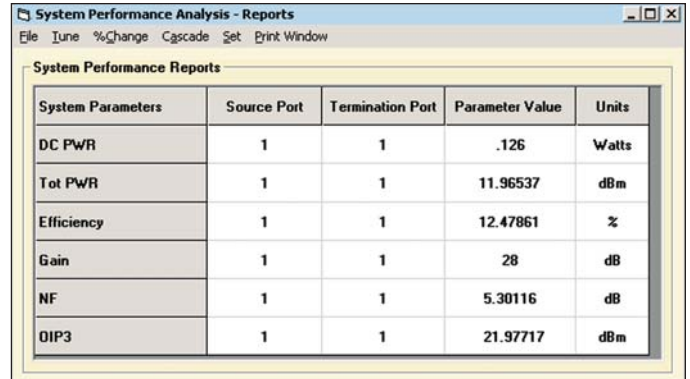
tive or stage-by-stage basis as well as a tabular summary of total system performance. Figure 2 shows a typical system cascade budget plot where each data point represents a particular system performance parameter at each consecutive circuit node or stage. Figure 3 displays the numerical summary of end-to-end system performance.

Non-Linear Power Sweep Analysis

While the traditional budget plots are essential to RF system analysis, the VSA program offers a much wider array of performance measurement methods and analysis tools. For example, the VSA provides input-output power sweeps that are useful in determining the useable dynamic range of a device (such as an amplifier) or an entire system. As shown in Figure 4, the power sweep curves include additional useful information such as P_{1dB}, the power saturation region, and the point at which the fundamental power begins to decrease as more power is shifted into harmonics.

Any component parameter in the system can be selected from the power sweep's tune menu, and its value can be adjusted incrementally up or down using the arrow keys to see the effect the selected parameter has on system linearity and compression curve characteristics. The light curve in Figure 4 shows the (real-time interactive tuning) effect of reducing the gain parameter of a system component while the heavy curve indicates the original (un-tuned) response. Power sweep curves can be plotted for any system output port. Internal nodes (at any stage in the system) can also be accessed to produce power sweeps from any input source up to and including the selected component node.

System Signal and Spur Viewer—The VSA Signal Tree

The file and folder navigation tree found in the Windows Explorer/File Browser has been an integral part of that operating system for as long as most of us can remember. The familiar tree structure is also seen in many other applications as the most efficient way to dis-

play and navigate through a complex structure of items (files and folders) and related items (subfolders) that are distributed throughout any number of levels and sublevels. Since the navigation tree is such a powerful and familiar tool, it was the natural choice for the LINC2 VSA signal and spur viewer. The VSA signal tree is a unique tool in the VSA system signal and spur viewer window (Fig. 5) that displays and navigates through all the signals and spurs for the entire system simulation.

As shown in Figure 5, each signal in the VSA signal tree is identified by a text description and a numerical signal identifier. The text describes the most current transformation that the signal has gone through, such as an increase in gain through an amplifier, or how the signal was created if it is new—for example, the second harmonic of an existing signal created by the non-linear function of the current system component. Preceding every signal in the list is a numerical tag that uniquely identifies the signal. The signal identifier tag is comprised of three numbers of the form: Source, Node, Index, uniquely identifying each signal according to the Source that was the ultimate origin, the Node at which the signal exists, and the Index that identifies this signal among the array of signals that may be present at this node.

The highest level in the VSA signal tree lists all the signals present at a user selected node (the output node, for example). Clicking on any signal at this level opens the next level in the tree for that signal. At this next lower level is the list of all the signals involved in the creation of the selected signal. A "+" symbol in front of a signal indicates that it has an additional history. Repeatedly clicking the "+" at each level expands the signal path to the next lower level until it is traced back to its source. Any signal at any node along the path can be right-clicked to reveal its amplitude, frequency and phase.

VSA Spectral Domain Analysis

Figure 6 shows the LINC2 VSA's Spectrum Analyzer view for an amplifier with multi-tone inputs. The number of input signals is limited by the (RAM) memory available for the computer used. However, there are no restrictions on the relative amplitudes of the tones or their spacing. (Note the different amplitudes and spacing for the ten fundamental signals in Figure 6). Thus, one or multiple signals can be input to the system with complete freedom to independently specify the amplitude, frequency and phase of each input signal.

The spectrum analyzer is an invaluable tool for a number of important tasks involving RF and microwave circuits and systems. It can be used in the design verification process to ensure that desired signals exist where they should, and at the required levels, while unwanted or spurious signals are not present or are below required limits. Ensuring that spurious signals are not generated and propagated through the system to places where they may degrade circuit or system performance is one of the most challenging tasks for an RF designer. The sensitivity of a receiver can be degraded by undesired spurious signals at the antenna port, or by spurious products generated in the receiver itself or in its supporting circuitry. Interfering signals as well as internally generated spurs can put a stage into compression and prevent the modulation on a desired signal from passing through to the next stage in the system properly.

The ability to bring a wireless product to market depends not only on the product meeting certain performance specifications, but also various regulatory requirements that put limits on both in-band and out of band emissions. Designing a product that meets these requirements is a daunting task without the proper tools because thousands of spurs can be generated in the product, including spurs mixing with other spurs, or desired signals mixing with spurs to create even more spurs that could be harmful to system performance. However, the intermodulation of signals as a result of the non-linearity of a device or stage in the system is not the only mechanism for the creation of undesired signals. Leakage paths due to insufficient isolation can cause desired signals to

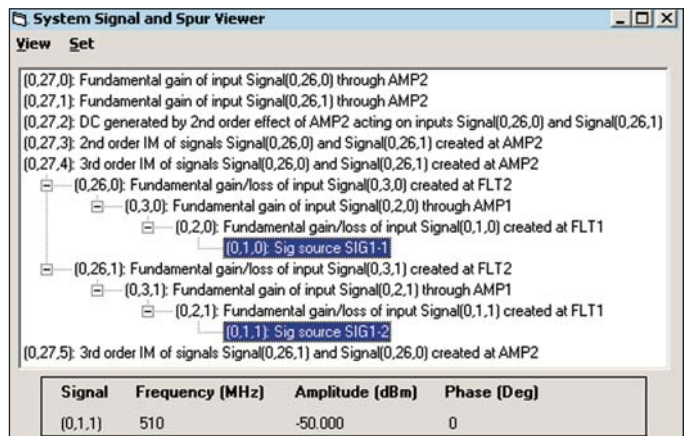Figure 4 · The VSA's power sweep plots.

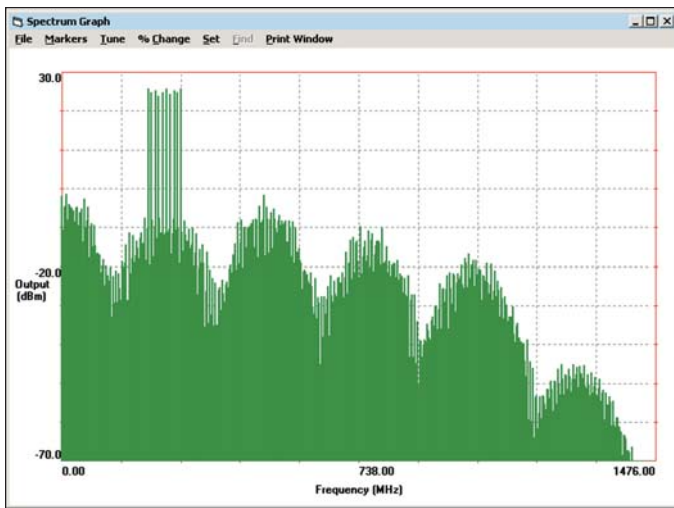Figure 5 · The VSA system signal and spur viewer.

Figure 6 · The VSA's power output spectrum plot.

end up as undesired signals in other places in the system. An example is in the case of a local oscillator signal leaking over to the mixer's RF port and propagating back through the receiver or transmitter chain to the antenna port where it can fail the regulatory requirements for conducted emissions.

Fortunately, the LINC2 VSA software includes spectral domain analysis in the form of spectrum analyzer type graphs that can plot all the signals and spurs in the system. To help isolate the cause and path of any unknown spurs, the VSA spectrum analyzer graph can turn any signal source on or off to see which signals or spurs are related to a given source. Looking at these things early in the system design with the aid of the LINC2 VSA's spectrum analyzer or system signal and spur viewer can help ensure that the product will meet the spectral requirements before valuable time is spent on detailed circuit design and prototyping. At the same time, other product specifications can be verified by employing the VSA's Cascade Budget Analysis tool and the Power Sweep tool.

Summary and Conclusions

The VSA's schematic-based system simulation enhances design productivity by providing the flexibility to quickly and easily construct systems of arbitrary topology. "What if" scenarios can quickly be investigated by simply dragging components to new locations on the schematic page or by selecting and dragging system component models from the Components menu into new line-up configurations.

The VSA maintains a common user interface between system level and circuit level schematics making it easy to transition from system design to detailed circuit design and back without having to learn or become reacquainted

with a different operational behavior. LINC2 system simulation and circuit simulation is also operationally similar and both have the same easy to use operator interface-simply enter schematic, set output options, click "analyze" and "view results/reports."

The program includes all the system budget analyses that are essential for the successful design and analysis of RF and microwave systems. System design productivity is further enhanced by the ability to perform output versus input power sweeps that reveal the linear and compression curve characteristics of the system (including P_{1dB} and saturation/PSat region). VSA spectral domain analysis provides an invaluable combination of spectrum plots and the VSA Signal Tree for viewing signals and spurs at any system node or tracing their paths back through the system to their sources.

Documenting system performance and report generation is easy since the VSA software can export the tabular data from the reports page, as well as all data from cascade budget analysis, power sweeps, and spectrum analysis graphs, into standard CSV files that can be imported into spreadsheets such as Excel. The data is also compatible with a wide variety of other programs through the common CSV format.

ACS has offered design automation with the LINC2 circuit simulation software for nearly 15 years. Over the last decade the LINC2 Pro software suite has included circuit design, synthesis, simulation, optimization and statistical yield analysis. Now with the addition of the Visual System Architect, RF and microwave circuit design can be appropriately driven by system design in a process that more accurately flows product specifications down to the circuit design level. This linkage between product specifications (properly distributed over components at the system level) and circuit specifications is essential to minimize or eliminate expensive and time consuming rework or redesign after prototyping when the product enters the design verification stage.

Author Information

Dale D. Henkes is the owner of Applied Computational Sciences (ACS), LLC, and has more than 25 years of professional experience in RF design/electrical engineering. He earned his B.S. degree in engineering at Walla Walla University, College Place, Washington. He is a member of the IEEE Microwave Theory and Techniques Society and the author of more than a dozen articles in prominent trade publications. He may be contacted via email at: henkes@appliedmicrowave.com.

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