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DEVICES, INC.

## MACROMODELS THAT SPEED SOFTWARE SIMULATION BECOME A USEFUL PRE-BREADBOARDING TOOL

### INTRODUCTION

As today's analog systems become more sophisticated, complex and precise, and as industrial, instrumentation, telecom and automotive electronic control systems need to perform more functions, it becomes increasingly cost effective to integrate components such as op amps, comparators, digital logic, etc. into a single Application Specific IC. While microelectronics technology have increased in capability, it is also increasingly complex, and expensive. It has become necessary to have better and faster engineering tools to tackle these higher level design challenges, while decreasing the time to market.

In examining a typical design process, the design task usually starts conceptually with an outline of desired capabilities, specifications and features of the system. After design concept has been established, One of the critical steps in the design process, namely the prototype functional implementation and evaluation requires that individual functional blocks be specified, and that individual components specifications be evaluated as to their effect upon overall system performance.

It is at this level of design that the designer needs to know quickly what functions, components, and particular specifications are suitable and how they effect the system performance, and be able to determine whether or not these components will perform the function within required system specifications. Once these selections are made, the circuit design can be synthesized and developed further.

Finally, a prototype breadboard can be constructed to test the design concept, and gather data that are unattainable otherwise and facilitate further circuit evaluation. Changes, corrections, and improvements can clearly be evaluated. In order to reconcile any differences between the design goal and the breadboard implementation, not only the functionality of the breadboard has to be adequate, but any incompatibilities or inconsistencies between the various components must be resolved.

The design task takes on an additional dimension when analog components are used and especially when such parameters as tempo, offset voltages, and offset currents, noise, gain, device matching, tracking of voltages and currents, power supply rejection ratio, and common mode rejection ratio become important to the proper operation of the system.

Integration of these analog components into a single custom monolithic IC while addressing these issues can become a daunt-

ing task. And yet to reduce space, simplify manufacturing, reduce parts count, and to reduce time to market, the designer often must look towards an ASIC implementation. The pressure to integrate mounts especially when production volumes are seen to increase. At that point, if the original prototype design was done without due consideration for integration, a complete redesign is usually necessary.

### ALD ASIC PROGRAM

To address the situation mentioned above, Advanced Linear Devices (ALD) of Sunnyvale, California has embarked on a two prong approach to provide the designer with inexpensive, common sense tool that provides a powerful mixed signal ASIC design environment while still providing the component level design and prototype parts for an off the shelf low to medium volume design. Essentially a prototype and low volume solution with the ease of integration without a redesign.

First, ALD provides a design kit consisting of predesigned and pre-fabricated analog functional blocks that have been completely tested and characterized, these parts are standard parts, complete with characterization curves and specifications. These analog functions are not only useful in breadboarding for functionality but also useful in determining any potential second order effects that may affect performance of the final system.

The question arises: If these analog cell are so well designed and engineered to be adequate for this purpose, then why not sell these blocks as a standard product? Indeed that's exactly what ALD has done. They have made their standard packaged parts available as standard cell integrated components. These products are available as packaged parts or as ASIC functional blocks. ALD guarantees that all of their products are fully compatible with each other on the same chip. These products, therefore are available for prototyping, volume manufacturing or as ASIC components.

Second, ALD has also developed a unique family of macromodels, subcircuits, and components that are fitted to their processing parameters. They are designed to be compatible with PSPICE and most other SPICE based circuit simulators. These macromodels have been developed specifically to ease the burden of the system designer when utilizing the ALD products for board level design or for designing breadboard/prototype for ASI implementation.

With these models, it now has become practical to simulate an analog board level system on a personal computer. In addition a breadboard using the actual IC components can be constructed. Due to the complexity of most applications, utilizing hundreds of transistors, the macro-model approach allows a designer to simulate develop a

system-on-a-chip using both software and hardware tools, thus performing trial and error experimentation on the personal workstation as well as on the lab bench. Of course, the final design will only be as good as what the designer can measure or predict using simulation and breadboard measurements. With simulation added to the design verification process, convergence upon a design solution is rapid. In addition, this approach allows the manufacturer the possibility to verify his system through actual field tests, limited production, and beta test sites, before committing to the expensive of custom IC production.

Actual chip level experimentation and mask iteration are not only costly, but as systems get increasingly complex, the probability of a designer actually developing a working ASIC system under the time and budget constraints diminishes. For complex analog or mixed analog digital system development intended for ASIC implementation, the ability to inexpensively and quickly do design iterations and measurements, whether on a computer station, or on a breadboard, is vital to the ultimate success of the project.

Of course, the ability to do both software and hardware iteration produces a desirable combination for engineering analysis. For certain situations, a quick run on a computer simulator can verify a circuit configuration that performs an intended function. Unfortunately, nice, idealized graphs presented on a computer terminal do not always represent actual circuit behavior and in many analog systems full simulation with regard to all parametric behavior is impractical if not impossible.

For other situations, such as to verify signal levels and timing of interface between the ASIC and other board components such as transducers, and to "feel" the adequacy of an analog signal, a breadboard as an actual hardware simulator can prove superior as an engineering tool. When all the pieces of individual subcircuits are simulated or designed, the time comes to put them together and verify that they perform as a system. This is a time when a designer needs all the engineering tools at his disposal. As software simulators and models may assist in spotting problems early on, hardware simulators and real hardware help other problems to show up. This two prong approach to circuit development eliminates redundant engineering effort when an ASIC needs to be implemented later in a production cycle.

A design initially developed with this approach would not need additional engineering effort when its time to integrate. More importantly, this approach cut out most of the technical risks of ASIC implementation because the designer has close feedback and ability to observe and measure the actual as well as the simulated system. Thus the often stated goal of a quick implementation onto an ASIC chip can be easily handled as the need and justification develops.

#### EASY ASIC BREADBOARDING FOR AN ASIC

Available from ALD is a design kit that contains a box full of analog IC parts such as operational amplifiers, comparators, oscillators and transistors that allow a designer to develop custom cir-

cuitry. Also available from ALD is a proprietary library of macromodels of these specific analog IC parts developed for a standard SPICE circuit simulator such as PSPICE, in addition a design manual that contains complete information and useful hints is provided.

When working with the kit, one can design and simulate using the ASIC library components or breadboard these circuits with Advanced Linear Devices' standard parts. The designer can use any number of analog cells from the design kit and in any configuration desired, and later decide on the package or pinout for an ASIC part. Since ALD's ASIC program is semicustom standard cell approach, there is no rigid limitation on how many instances of any of function block, pins, components or even the values used.

Furthermore, digital logic such as HC, 74C and CD4000 family parts can also be used in the software simulator as well as the hardware prototype. Many software circuit simulator suppliers already supply digital parts by individual part numbers in their digital library. These digital parts simulate the logic and performance of, say, a CD4027 Dual JK Flip-Flop. ALD has developed functional equivalent digital cells in its computer library that will perform the identical logical functions.

A custom prototype system designed around using these generic digital part types along with analog parts supplied by ALD can be readily implemented into an ASIC with virtually no performance differences. With this complete library of digital MSI functions such as counters, encoders and decoders, no logic conversion is necessary from standard part type to implementation of the ASIC. All digital circuit blocks in ALD's digital library perform identical functions to the generic part types in the simulation library.

#### Background on macromodels

An operational amplifier modeled with detailed transistor level parameters and circuitry may run for five or six hours equivalent CPU time based on a Pentium class personal computer for each parametric iteration. With several amplifiers and tens or hundreds of simulations with perhaps dozens of parameters each requiring multiple passes to run in order to completely analyze or optimize an analog system design, analysis of these systems can readily overwhelm available computer resources.

In addition, many simulation induced problems tend to creep up using detailed transistor operational models. These problems include setting the correct internal node conditions, non-convergence of the circuit and simulation induced oscillation. In analog simulation, where signal amplification, precision voltages and feedback are common circuit parameters, circuit behavior of a specific circuit block may depend not only on the transistor models and the simulators used, but also on user specified iteration limits and tolerances. If these limits are set improperly, circuit may take hours to converge, generate useless data, or terminate abruptly in the middle of the simulation.

In the integration of a complex ASIC where several complex functional blocks are used, a detailed transistor level simulation is sim-

ply impractical. A macromodel that emulates the behavior of the operational amplifier, on the other hand, can be simulated in a few seconds. Macromodels have been developed for the purpose of simulation of a function block while using minimum computer memory and CPU time and still provide adequate functional emulation.

These are generally compositions of simple idealized elements, as opposed to individual transistor level models, this reduces the matrix of variables that needs to be iterated on a computer station. These macromodels have been developed to perform the simulate the function of individual functional blocks. Ideal circuit elements like ideal voltage controlled current sources are used to emulate these amplifiers Also a set of equations in the simulator can emulate the behavior of an operational amplifier.

In many cases, the real difficulty in using this approach stems from the fact that a real life operational amplifier may not be so "ideal" in behavior. As any design engineer would attest, a real life circuit can have idiosyncrasies, behaviors and capabilities that can be different from the ideal, resulting in unintended behavior. The most noteworthy of these differences can be incorporated into the macromodel in order to better model the actual behavior of a circuit. However, in the case of second order effects like nonlinear parametric changes, where a matrix of equations or even the best macromodel may not accurately describe actual circuit behavior, the user would be well advised to check out his circuit with a breadboard after simulation is completed.

Notwithstanding these limitations, in many applications a first order macromodel can prove adequate as a circuit analysis tool. These macromodels, when carefully engineered and constructed, provide the user with a convenient intermediate step where analysis complexity goes beyond paper and pencil, and the circuit function may not yet be ready for breadboard construction in the laboratory. Macromodels used in a simulators can and do give quick first order trial analysis of the ability of a circuit configuration to perform a given task. If a user also has working experience with an actual part, and has developed intuition and feel to use it properly, then a combination of the capabilities of computer simulation and breadboarding can be indeed a powerful engineering tool set indeed.

#### ALD-simulation model libraries

ALD models are designed to support board level macro simulation such as PSPICE simulation where packaged circuit elements such as transistors, operational amplifiers, MSI and SSI logic functions, counters, latches, and gates are used. These are components that one would normally put on a circuit board to prototype a system.

For ALD ASIC implementation, all chip macromodels and circuit elements should be partitioned from other circuit elements. Partitioning of the system involves no more than determining connection points between circuit elements that are intended on-chip and those that are off-chip. ALD supplies a SPICE library designed for ASIC integration that contains detailed SPICE circuit models of analog integrated components like resistors, capacitors, diodes, transistors and of course all the major macro-models of functional

blocks of the standard integratable parts. Once a partition of the system is made, into on ASIC components, and off chip components, then a simulation of the proposed ASIC can be done- including the designers off chip components.

The circuit elements used in a simulator can be divided into four major categories: ALD analog standard part macromodels, ALD ASIC element macromodels, digital function models and standard vendor supplied PSPICE models.

ALD analog cell macromodels consists of a library of macromodels of ALD standard parts including operational amplifiers, voltage comparators, timers, oscillators, voltage references and transistors. These macromodels can also be used in applications where ASIC implementation is not planned. ALD ASIC element macromodels include diodes, transistors, zener diodes, input protection circuits, and on-chip integrated resistors and capacitors. These element models are only needed where an on-chip ASIC implementation of these elements are planned.

Digital function models are specifically standard CMOS logic family functions including, at present, HC logic family (5V only), 74C logic family, and CD4000 logic family (5V to 12V). These components and their models are widely available from a variety of sources. Users can incorporate these functions into the their simulator. ALD has these digital functions in its ASIC library ready for ASIC implementation.

Standard vendor supplied models are models of other circuit elements, such as a relay, microphone, piezoelectric crystal, or an I.C. that is out of the scope of the ALD ASIC integratable library. PSPICE provides a large selection of generic parts composed by various vendors. These circuit elements can be used with the circuit simulator and the circuit breadboard but would not be included in the ASIC chip.