Verilog-A Device Models for Cryogenic Temperature Operation of Bulk Silicon CMOS Devices

These models can be used in cryogenic electronics applications such as cooled imagers and sensors, medical electronics, and remote sensing satellites.

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Verilog-A based cryogenic bulk CMOS (complementary metal oxide semiconductor) compact models are built for state-of-the-art silicon CMOS processes. These models accurately predict device operation at cryogenic temperatures down to 4 K. The models are compatible with commercial circuit simulators. The models extend the standard BSIM4 [Berkeley Short-channel IGFET (insulated-gate field-effect transistor) Model] type compact models by re-parameterizing existing equations, as well as adding new equations that capture the physics of device operation at cryogenic temperatures. These models will allow circuit designers to create optimized, reliable, and robust circuits operating at cryogenic temperatures.

Circuits that operate reliably at cryogenic temperatures are very difficult to design, because reliable semiconductor device and circuit models are not available for these temperatures. The unique aspect of this problem is the unknown physical characteristics of devices operating at cryogenic temperatures. Standard circuit models such as BSIM4 contain equations that can only predict device operation near room temperature. Therefore, new equations and re-parameterization of existing equations need to be done in order to functionalize the operation of state-of-the-art silicon CMOS devices at cryogenic temperatures.

These models will extend the room-temperature BSIM4 type compact models to temperatures as low as 4 K. The models are developed using the behavioral description language Verilog-A. Verilog-A allows for change in standard BSIM equations, re-parameterization of existing equations, and addition of new equations that capture the physics of semiconductor device operation at cryogenic temperatures.

Creation of these Verilog-A based cryogenic models requires the following:

a. Test chip with an array of devices fabricated in the process of interest or test data for the process;
b. Room and cryogenic temperature measurement of test chip;
c. First parameterization of BSIM4 model using room temperature data;
d. Verilog-A model parameterization using the developed equations and using the cryogenic temperature data;
e. Optimization of new model; and
f. Testing the new model by simulating test circuits and comparing them with measurements of circuits on the test chip.

Next, Verilog-A cryogenic CMOS device models are inserted into a simulator. Circuit simulations are run using the new models at temperatures as low as 4 K. These models work in conjunction with other standard compact models without causing any convergence or other errors in the circuit simulator.

The models can be further modified to include effects of radiation such as total ionizing dose at cold temperatures. These models will be able to predict long-term reliability of CMOS-based electronics operating under cryogenic temperatures in radiation-rich environments. The new models include the effect of threshold voltage variation at extreme cold temperatures and variation in mobility at cryogenic temperatures.

This work was done by Akin Akturk, Siddharth Potbhare, Neil Goldsman, and Michael Holloway of CoolCAD Electronics for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16112-1

Rapid Process to Generate Beam Envelopes for Optical System Analysis

Two models take less time to complete beam envelope analysis.

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The task of evaluating obstructions in the optical throughput of an optical system requires the use of two disciplines, and hence, two models: optical models for the details of optical propagation, and mechanical models for determining the actual structure that exists in the optical system. Previous analysis methods for creating beam envelopes (or cones of light) for use in this obstruction analysis were found to be cumbersome to calculate and take significant time and resources to complete. A new process was developed that takes less time to complete beam envelope analysis, is more accurate and less dependent upon manual node tracking to create the beam envelopes, and eases the burden on the mechanical CAD (computer-aided design) designers to form the beam solids.

This algorithm allows rapid generation of beam envelopes for optical system obstruction analysis. Ray trace information is taken from optical design software and used to generate CAD objects that represent the boundary of the beam envelopes for detailed analysis in mechanical CAD software.

Matlab is used to call ray trace data from the optical model for all fields and entrance pupil points of interest. These are chosen to be the edge of each space, so that these rays produce the bounding volume for the beam. The x and y global coordinate data is collected on the surface planes of interest, typically an image of the field and entrance pupil internal of the optical system. This x and y coordinate data is then evaluated using a convex hull algorithm, which removes any internal points, which are unnecessary to produce the bounding volume of interest. At this point, tolerances can be applied to expand the size of either the field or aperture, depending on the allocations. Once this minimum set of coordinates on the pupil and field is obtained, a new set of rays is generated between the field plane and aperture plane (or vice-versa).

These rays are then evaluated at planes between the aperture and field, at a desired number of steps perceived necessary to build up the bounding volume or cone shape. At each plane, the ray coordinates are again evaluated using the convex hull algorithm to reduce the data to a minimal set. When all of the coordinates of interest are obtained for every plane of the propagation, the data is formatted into an *xyz* file suitable for FRED optical analysis software to import and create a STEP file of the data. This results in a spiral-like structure that is easily imported by mechanical CAD users who can then use an automated algorithm to wrap a skin around it and create a solid that represents the beam.

This work was done by Joseph Howard and Lenward Seals of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16176-1

High-Performance, Multi-Node File Copies and Checksums for Clustered File Systems

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Modern parallel file systems achieve high performance using a variety of techniques, such as striping files across multiple disks to increase aggregate I/O bandwidth and spreading disks across multiple servers to increase aggregate interconnect bandwidth. To achieve peak performance from such systems, it is typically necessary to utilize multiple concurrent readers/writers from multiple systems to overcome various single-system limitations, such as number of processors and network bandwidth. The standard cp and md5sum tools of GNU coreutils found on every modern Unix/Linux system, however, utilize a single execution thread on a single CPU core of a single system, and hence cannot take full advantage of the increased performance of clustered file systems.

Mcp and msum are drop-in replacements for the standard cp and md5sum programs that utilize multiple types of parallelism and other optimizations to achieve maximum copy and checksum performance on clustered file systems. Multi-threading is used to ensure that nodes are kept as busy as possible. Read/write parallelism allows individual operations of a single copy to be overlapped using asynchronous I/O. Multi-node cooperation allows different nodes to take part in the same copy/checksum. Split-file processing allows multiple threads to operate concurrently on the same file. Finally, hash trees allow inherently serial checksums to be performed in parallel.

Mcp and msum provide significant performance improvements over standard cp and md5sum using multiple types of parallelism and other optimizations. The total speed-ups from all improvements are significant. Mcp improves cp performance over 27×, msum improves md5sum performance almost 19×, and the combination of mcp and msum improves verified copies via cp and md5sum by almost 22×. These improvements come in the form of drop-in replacements for cp and md5sum, so are easily used and are available for download as open source software at http://mutil.sourceforge.net.

This work was done by Paul Z. Kolano and Robert B. Ciotti of Ames Research Center. Further information is contained in a TSP (see page 1). ARC-16494-1

Stiffness and Damping Coefficient Estimation of Compliant Surface Gas Bearings for Oil-Free Turbomachinery

Initial applications include design of turbochargers, blowers, compressors, pumps, and turbine engines.

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Foil gas bearings are a key technology in many commercial and emerging oil-free turbomachinery systems. These bearings are nonlinear and have been difficult to analytically model in terms of performance characteristics such as load capacity, power loss, stiffness, and damping. Previous investigations led to an empirically derived method to estimate load capacity. This method has been a valuable tool in system development. The current work extends this tool concept to include rules for stiffness and damping coefficient estimation. It is expected that these rules will further accelerate the development and deployment of advanced oil-free machines operating on foil gas bearings.

Foil gas bearings are self-acting hydrodynamic bearings comprised of a series of sheet-metal foil layers from which they derive their name. They are compliant bearings that offer high-speed rotor support while accommodating shaft misalignment and distortion often encountered in turbomachinery. Lightly loaded, low-temperature foil gas bearings are commodities that predominate in the rotor support for aircraft air cycle machines (ACMs). More highly loaded foil