Spayn Detailed Product Description
What is Spayn?

- Data Management
- Parameter Analysis
- Core Parameters Identification
- Process Control
- Simulation interface
- Conclusions
What is Spayn? – Application Fields

• Spayn is a statistical analysis software package tailored for the semiconductor industry.

• It is applied for two main fields:
  
  • **Characterization:**
    • Spayn is the ideal statistical modeling tool for analyzing variances from model parameter extraction sequences, electrical test routines, and circuit test measurements
  
  • **Process Control/Analysis:**
    • Spayn performs statistical analyses on parametric data, and helps determine the complex relationships between circuit design and process fabrication parameters
What is Spayn? – Application Fields: Characterization

• Spayn identify the best set of parameters to provide the “golden device” and the nominal SPICE model
• Spayn generates accurate and realistic worst-case Corner models
• Spayn pilots SPICE simulations to evaluate best case and worst case circuit performances
What is Spayn? – Application Fields: Process Control & Analysis

- Spayn helps to identify the critical set of parameters to insure process statistical control
- Spayn defines relationship between process fluctuations and device models or circuit performance variations
- Spayn display parameters distributions on wafer map
What is Spayn? – Users

- Parameter Extraction and Circuit Simulator Support Personnel
- Device Modeling Engineers
- Circuit Designers
- Process Development/Integration Engineers
What is Spayn? – Environment

- Measurement Equipment
- Circuit Test
- Process/Device Simulation
- E-test
- Other sources of process and/or device data
- To Circuit Simulator

Pi = ai1*X1 + ai2*X2 + ... ai6*X6

“Worst-case” Parameters

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• Import UtmostIII automated measurements
  • Automated on wafer measurement including prober control
  • Flexible Die selection
  • Storage in a Spayn compatible Database of:
    • SPICE parameters & model card
    • Electrical tests results
    • Mismatch currents measurement
    • Wafer mapping attributes
• Accept data from the V.W.F including:
  • Athena Process parameters
  • Atlas device parameters
  • Electrical tests and Spice parameters extracted via Utmost from Atlas electrical simulations
• Database conversion utilities from others format:
  • CSV
  • Fixed Length
  • RS/1

• Spayn File manager
  • Automated file type recognition
  • File properties display
Data Management – Database Generation

- Single database source Split/Merge facilities
- Multi database source Append/Merge facilities
- Database generation from fundamental parameters statistics:
  - Means
  - Standard deviations
  - Correlations
- Filtering on:
  - Attributes Criteria's
    - Individual selection
    - Pattern recognition
  - Parameters search based on:
    - User’s defined limits
    - Automatic ‘out of range’ rules

- Search Summary:
  - Easy to identify sources of “out-of-range” data, using different sorting methods
    - Sort by overall frequency
    - Sort by reject frequency
    - Unsorted
Data Management – Visualization Tools

- Spreadsheet:
  - To view combined data from various sources
  - To create new attributes from relations between existing attributes or from external data
  - To create new parameters using elementary mathematical functions

- Statistical summary table:
  - Statistical property summary of each individual parameter
Data Management – Export

- Database export at any format
  - Automated parameters renaming
  - Include generated parameters
- Control file option (saves performed analysis)
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- Parameter Analysis – Distribution -

- Advanced Histograms plots
  - Positively and negatively skewed data
  - Automatic “best fit” option
  - Distributions fit equations:
    - Normal
    - Lognormal
    - Gamma
    - Exponential
    - Weibull
  - Cumulative probability display option
- Print capability (printer/file)
• Correlation table
• Highlighted strong correlations
• Scatter plots
  • Parameters relationships analysis using the least squares method
• Automated Fit
  • Linear, logarithmic, parabolic, reciprocal, hyperbolic, exponential, power, root, or 3rd order polynomial
• Generation of:
  • Resulting error residuals,
  • ANOVA information
• Correlation coefficients
• Any point of the scatter plot can be used to pilot a SPICE simulation
Parameter Analysis – Matching

• Distributions of
  • Parameter differences
  • Parameter ratios

• Matching quantities generation
  • Based on mathematical relation with existing parameter
  • Stored as normal parameters

• Includes user-specified confidence limits
  • Absolute differences
  • Relative differences
Parameter Analysis – Regression

- Regression analysis with:
  - Up to, and including, third order terms
  - Normalized or not predictors
  - Fit Error information
  - ANOVA information
  - Plot estimated
  - (Modeled) parameter values versus measured parameter values using scatterplot
  - TonyPlot can be used to visualize model response surface
Parameter Analysis – Wafer Mapping

- Displays parameters or any others data together with their distributions over die locations
- Wafer geometrical information are either
  - User’s defined
  - Automatically included if Utmost III was used
- Histogram accessible for each parameter/die
- Golden Device feature:
  - Calculate which observation(s) in a particular database most closely match the mean, based on dissimilarity measures
  - Highlight golden device observation in a scattergram
  - => Easy check of a regression model validity
• Data set definition and highlight
  • Histogram/Scattergram allows definition of data sets according to attributes values
  • Set of data are plotted using different color/markers
• Automated generation of Histogram and scattergram files
  • Many format supported, including printer file format or pictures (postscript, gif, pcx ...)
• Correlations between three parameters can be viewed a 3D scattegram
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• Goal of core parameters extraction is to provide the user with a limited set of parameters representative of the complete database fluctuations.

• Spayn provides two methods for core parameters extraction:
  • PCA (Principal Component Analysis)
  • PFA (Principal Factor Analysis)

• Those core parameters have the following properties:
  • Uncorrelated or weakly correlated between each others
  • Representative of process fluctuations

• Those properties made these set of parameters crucial for:
  • Statistical Process control and Yield analysis
  • Worst case model generation.
  • Design of Experimental Plan for simulations
Core Parameters Identification – Overview

Principal Factor Analysis (PFA) or Principal Component Analysis (PCA)

\[ P_i = a_{i1}X_1 + a_{i2}X_2 + \ldots + a_{im}X_m \]

- \( n \) correlated device and/or process monitor and/or circuit parameters
- \( n \times n \) correlations of various magnitudes
- \( m \) (\( m << n \)) uncorrelated process-related factors. Can be used for isolating “core” process variables, relating device and circuit parameters to these “core” process variables, and for statistical circuit design techniques.
Core Parameters Identification – Setup

- Analysis:
  - Principal Factor Analysis (PFA)
  - Principal Component Analysis (PCA)
    - Normal
    - Weighted PCA analysis (Weights users defined or generated from sensitivity analysis)
  - VARIMAX and QUARTIMAX rotations
  - Extensive statistical information of PCA and PFA results
• Identification of dominant parameters and/or factors of variations:
  • Parameters are automatically grouped depending on their dominant factor of variation
  • Analysis of each parameter group then identifies relationships between variations of any kind of parameters
  • Subset of dominant parameter can be users defined or modified
• Model generated are based on:
  • Dominant factors or parameters or user’s defined subset
  • Equations can be fully configured:
    • Linear or not
    • Including interactions terms
    • Up to third degree
  • Parameter variance information’s automatically updated
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• Spayn can be used to determine the underlying statistical nature of IC manufacturing processes and their impact on device performance
• Spayn creates statistical process control (SPC) and process monitor (PM) charts to track the variation of dominant parameters or factors over selected wafers or lots
• SPC charts plot and store Shewhart mean and range/sigma data with the parameters grouped in terms of their attributes
• Spayn helps to identify an efficient process monitoring strategy by identifying the minimum set of dominant factors that must be monitored in production in order to control the yield
• Process monitoring charts are then used to view these parameters
- Monitor core parameters variations
- Custom group based on attributes selection
- Possibility to generate at full parameter set at any point of the PM chart
- Any point of the PM chart can be used to pilot SPICE simulation
Process Control – Statistical Process Control

- Check variations of any Parameters/Factors stay under statistical control
- Provides explicit warning when out of control
- Custom group based on attributes selection
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Simulation Interface – Architecture: External Simulation

• Simulation using External Spice simulator:
  • For any kind of SPICE simulations
  • Model Card defined in Spayn through a specific interface
  • Netlist including analysis
  • Fast SPICE simulator supported through SmartSpice-API
  • Asynchronous simulation interface
Simulation Interface – Model Definition

- Flexible and powerful model definition
  - A Spice label for model card use can be associated to any parameter
  - Constant SPICE parameters automatically added to all model cards
  - A same parameter can be used for several model
  - Clipping mode to check SPICE parameter validity including:
    - Automatic from statistical information
    - Automatic from empirical information
    - Users defined
• Use PCA/PFA models to generate realistic corner models
• Corners models taking parameters correlations into account
• Generation of SPICE model card corresponding to the corners
• Direct link to a spice simulator for automated corner models simulations
• Automated generation of SPICE input deck title for Identification purpose
Simulation Interface – D.O.E.

• Many different Design Of Experiment plan proposed
  • Based on Corners:
    • 2 level full and half factorial,
    • Box-behnken fractional factorial 3-level,
    • Circumscribed Central Composite,
    • Face Centered Cubic.
  • Monte Carlo,
    • Classical, Optimized (using SPICE simulator Monte Carlo features), or For Matching (includes additional Random terms to restore the original variance of the full database)
    • Sample stored in a new database.
    • Performance parameter measured and stored for each sample
  • Gradient Analysis
    • To Evaluate a performance parameter sensitivity to each core parameter
Simulation Interface – D.O.E.

**Spayn**
- Automatic model card generation

**FAST SartSpice API**
- Netlist completion
- Launch simulator
- Run Simulation

**SmartView**
- Simulations result Post-Processing
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• Use Spayn because:
  • Little statistical background required
  • Easy SPICE simulations pilot
  • Up to date statistical methodology applied to semiconductor industry
  • Unique tool to make a vertical analysis of the full manufacturing process

• Use Spayn to:
  • Visualize Data/Correlations
  • Find Groups/Independent Factors/Independent Parameters
  • Perform Worst-Case Design/Monte Carlo Design
  • Investigate Device Current Characteristics
  • Perform Process Monitoring/Control