

# Index

## A

- Agilent Advanced Design System (ADS), 35
- AIDA-C flow, *see* AIDA-C Variation-Aware version tool
- AIDA-C sizing tool, 155
- AIDA-C Variation-Aware version tool
  - analog IC sizing tool, 155
  - architecture, 155, 156
  - “Auto-Setup”, 159
  - circuit analysis, 158
  - corner analysis, 159
  - electrical simulator, 168–170
  - GUI, 164, 169
  - MC
    - iterations, 172, 174
    - simulation, 170
  - monitoring module, 160, 161
  - monitoring windows control, 168, 169
  - multi-objective optimizer block module, 155, 162
  - netlist circuit, 157
  - netlist test-bench, 158
  - new yield estimation methodology, 170, 171
  - new yield optimization technique, 174, 175
  - objective properties window, 167, 169
  - optimization conditions, 170
  - optimization processes, 165
  - optimization processes toolbar, 168, 169
  - optimizer, 165
  - performance measures sections, 158
  - process capability index, 172, 174
  - project form, 158, 159
  - settings window, 166, 167
  - setup module, 155
  - setup process, 159, 169, 170
  - setup summary panel, 165
  - solutions browser panel, 164–166
  - specifications settings screen, 166, 168
  - toolbar, 166
  - variables, 159
  - yield
    - constraint properties screens, 176
    - measure, 172
    - parameter sizing screen, 175
- AIDA framework, 228
- ANACONDA, tool, 38
- Analog IC design
  - AIDA-C, 5
  - CAGR, 4
  - catastrophic yield losses, 2
  - circuit sizing process, 1
  - EDA tool, 2, 5
  - IC market, 4
  - IRDS:2017, 4
  - local variations, 2
  - MC (*see* Monte Carlo (MC))
  - nanometer-scale technology, 225
  - parametric yield losses, 2
  - parametric yield value, 2
  - sized circuit solution, 1
  - SoC, 1
  - technology scale, 2
  - transistor threshold voltage parameter,
    - CMOS technology node, 3
    - VLSI, 1
  - yield estimation methodology, 5, 6
- Analog IC yield estimation, 76, 91
  - accuracy, 180
  - FUZYE (*see* FUZYE methodology)
  - grounded active inductor, 182–184

- Analog IC yield estimation (*cont.*)
    - LNA, 184–186
    - MC analysis, 225
    - MC simulations, 179
    - optimization methodologies, 179
    - single-stage amplifier, 180, 182
    - sub- $\mu$ W Tow-Thomas-based biquad filter, 186–188
  - Analog module generator (AMG), 162
  - Ant colony optimization (ACO), 26, 27, 35, 38, 39
  - ASTRX/OBLX, 34, 38
  - Asymptotic Waveform Evaluation (AWE), 35, 37
  - Automatic analog IC sizing
    - approaches, 57, 59
    - BLADES, 15
    - circuit sizing, 9, 11
    - device structures, 11
    - EDA tools, 11, 14
    - HAD, 11, 12
    - knowledge-based approaches, 14, 15
    - nanometer technology nodes, 11
    - OASYS, 15
    - optimization-based approach (*see* Optimization-based approach)
    - and optimization tools, 225
    - PAD, 15
    - transistors parameters, 9
    - two-stage Miller amplifier
      - design parameters, 9, 10
      - functional specifications, 9, 11
      - performance specifications, 9, 10
    - yield losses, 225
- B**
- Basic variables (BV), 21
  - Bayesian model fusion (BMF), 84, 86
  - Bisecting k-means algorithm, 116
  - BLADES, 15
- C**
- Circuit design and performance parameters
    - definition, 46, 47
    - feasibility regions, 47–50
    - feasibility space, 52
    - features, 51
    - parametric yield, 54–57
    - space, 52, 53
    - values, 51
    - variability, 53
  - Circuit netlist, 157
  - Circuit sizing, 9
  - Circuit sizing process, 1
  - Circuit specifications, 55
  - Cloud width (CW), 76
  - Cluster number reduction technique, 209, 210
  - Cluster representative individual selection, 202, 204
    - design centering technique, 132
    - feasibility region boundary, 134, 136
    - IC sizing and optimization problem, 134
    - KMS-based methodology, 134, 135
    - Min–Max technique, 134
    - optimization objective/values, 134
    - optimization problem objectives, 136
  - Clustering algorithms
    - average runtime, KMS and FUZYE, 194, 195
    - FUZYE, 189–191, 196
    - HAC, 189–191
    - KMS, 189–191
    - MC simulations, 189, 194
    - memory usage, 191–193
    - optimization algorithm, 192
    - optimization methodology, 191
    - parameters, 189
    - population size vs. FUZYE memory , usage, 193, 194
    - population size vs. KMS memory usage, 193
    - simulations runtime, 196
    - yield estimation, 191
    - yield estimation methodology, 226
  - Clustering techniques
    - FCM clustering algorithm, 104
    - goal, 99
    - hierarchical clustering algorithm, 115
    - K-medoids clustering algorithm, 103
    - KMS clustering algorithm, 100
    - NP-hard problem, 99
    - partitions, 100
    - techniques, 99
  - Cognitive component, 25
  - Compound annual growth rate (CAGR), 4
- D**
- Dendrograms, 115, 118
  - Design centering, 89, 91
  - Design-Of-Experiments assisted Monte Carlo (DOE-MC), 91
  - Design parameters, 46
  - Differential evolution (DE), 36, 71

**E**

Electrical simulator, 170  
 Electronic design automation (EDA), 2, 4, 5, 92  
 Environment parameters, 46  
 Equation-based optimization  
   ASTRX/OBLX, 34  
   crossover, 36  
   differential evolution mutation, 36  
   GP, 34  
   LP, 34  
   MODE, 36  
   MOPSO, 35  
   OPASYN, 33  
   posynomial functions, 34  
   PSO, 35  
   SA, 35  
   STAIC, 33  
   Swarm intelligence techniques, 35  
 Evolutionary process, 30  
 Exponential decay method, 207  
 Extensible markup language (XML), 159

**F**

False POF problem  
   cluster objective(s) values, 127  
   cluster representative individual selection, 127, 129  
   EA population, 126  
   FoM, 128  
   KMS algorithm, 128  
   objective(s) functions, 126  
 FCM clustering algorithm  
   between-cluster scatter matrix, 106  
   cluster separation, 106  
   cost function, 105  
   degree of membership, 104–107  
   vs. KMS, 104, 105  
   squared Euclidian distances, 106, 107  
   time complexity, 108  
   within-cluster, 106  
 Feasibility regions  
   design parameter, 47  
   ellipsoids, 48, 51  
   Gaussian distribution, 49, 50  
   Gaussian variables, 48  
   nonlinear parameters, 50, 52  
   polytope, 50, 51  
   range parameter, 47  
   rectangular, 47  
 Feasibility space, 52  
 Figure-of-Merit (FoM), 128, 140

**FUZY methodology**

AIDA-C, 226  
 AIDA-C evaluation process, 206  
 analog IC parametric yield estimation, 226  
 clustering process, 144, 146–148  
 cluster number reduction technique, 209, 210  
 cluster representative individual selection, 148, 149  
 electrical simulators, 226  
 ISE process, 144  
 KMS-based approach, 208  
 LNA, 208, 217, 218  
 MC analysis, 208, 226  
 MC analysis and yield estimation, 149–151  
 MC iterations, 208, 209  
 MC simulations, 226  
 vs. non-yield optimization process, 220, 223  
 optimization results, 210, 211, 214, 216, 217  
 process steps, 144  
 simulation reduction rate, 226  
 single-stage amplifier, 208, 210, 211, 214, 216, 217  
 yield estimation accuracy, 226  
 vs. yield estimation approaches, 227  
 Fuzzy c-means (FCM), 104

**G**

Gain bandwidth (GBW), 82  
 Genetic algorithm (GA), 15, 29, 30, 37–39, 45  
 Geometric programming (GP), 22, 34  
 Geometric yield analysis, 86  
 Gradient descent optimization, 17  
 Graphical user interface (GUI), 155  
 Gravitational search algorithm (GSA), 27, 28  
 Grounded active inductor, 182–184

**H**

Heuristic optimization algorithms, 225  
 Hierarchical agglomerative clustering (HAC), 115, 188  
   AIDA-C sizing and optimization, 140  
   average-linkage, 117  
   complete-linkage, 116  
   Euclidian distance dendrogram, 141  
   Euclidian distance, single-linkage, 141  
   fixed distance measure, 141  
   KMS-based methodology, 143  
   single-linkage, 116, 140  
   task, 139  
   yield estimation methodology, 140

Hierarchical Analog Design (HAD), 12, 46  
 Hierarchical clustering algorithm  
   advantages, 117  
   agglomerative, 115, 116  
   cluster validation indexes, 119  
   dendrograms, 115  
   dimensionality data reduction, 118  
   divisive, 115  
   time complexity, 117  
 Hierarchical divisive clustering, 115  
 High-sigma Monte Carlo (HSMC), 81, 82

## I

Importance boundary sampling (IBS), 80  
 Important sampling (IS), 78, 79  
 Individual-based yield (IBY), 77, 78  
 Infeasible solution elimination (ISE) module,  
   72, 74, 75  
   boundary violation value, 121  
   circuit sizing optimization problem, 120  
   EA, 121  
   elements, 122  
   feasible/infeasible, 120, 121  
   goals, 120  
   negative yield parameter values, 121  
 Integrated circuits (ICs), 1  
 International Roadmap for Devices and  
   Systems 2017 (IRDS:2017), 4  
 Intra-die/local variations, 55

## K

KMD clustering algorithm  
   cluster centroid, 103  
   cost function, 103  
   vs. KMS, 103, 104  
   time complexity, 103  
 K-means++ algorithm, 113–115  
 K-means-based methodology  
   clustering & RI selection module, 122  
   cost function computation, 124  
   drawbacks, 123  
   Elbow method, 123  
   Euclidian distance, 124  
   false POF, 125, 126  
   IC sizing and optimization, 125  
   implementation, 125  
   representation error variation, 124  
   two-phase evaluation process, 122, 123  
 K-means (KMS), 100  
 K-medoids (KMD), 103  
 KMS-based clustering algorithm

  cluster representative individual selection  
     techniques, 201, 204, 206  
   MC simulations, 226  
   OPDK single-stage amplifier, 199–201  
   silicon-based technology single-stage  
     amplifier, 196–198  
   variable number, 202, 204, 206, 226  
 KMS clustering algorithm  
   affecting factors, 102  
   cluster separability, 101  
   computational time complexity, 102  
   cost function, 101  
   implementation, 101  
   indicator function, 101  
   optimization problem, 101, 102  
 KMS variable cluster number selection  
   cluster number decay, 137  
   Elbow method, 136  
   exponential growth function, 137  
   GA-based optimization algorithm, 136  
   MC simulations, 138, 139  
   natural logarithm function, 137  
   natural  $\alpha$  parameter, 137  
   potential solutions, 139  
 Kriging Model, 44  
 Kullback-Leibler divergence, 72, 73, 75

## L

Large distance method, 204, 205  
 Latin Hypercube Sampling (LHS), 42–45, 70  
 Learning/model-based method  
   advantage, 40  
   LDS, 43  
   LHS, 43, 44  
   neural-fuzzy models, 45  
   PCA, 41  
   QMC, 42, 43  
   surrogate models, 40, 42  
   SVM, 44, 45  
 Linear assignment algorithm (LAA), 113–115  
 Linear programming (LP), 20–22  
 Low Discrepancy Sequence (LDS), 42  
 Low-noise amplifier (LNA), 184–186, 208,  
   217–219

## M

MAELSTROM, 37  
 Manufacturing variability, 54  
 MC-based FUZYE methodology  
   (MC-FUZYE), 212, 214, 216  
 MC-based yield estimation

- false POF problem, 126
    - HAC, 139
    - ISE module, 120
    - K-means-based methodology, 122
    - simulation-based optimization, 120
  - MC pseudo-random sampling (MCS), 70
  - MC simulations
    - clustering (*see* Clustering)
    - drawback, 97
    - evolutionary-based optimization
      - algorithm, 97
    - HAC algorithm, 151
    - optimization process, 97
    - population-based optimization algorithm, 98, 99
    - yield estimation technique, 151
  - Memory usage, 192
  - Mesh adaptive direct search (MADS), 90
  - Message Passing Interface (MPI), 37
  - Metaheuristic evolutionary algorithms (EA), 119
  - Metaheuristic optimization strategies, 119
  - Minimization problem, 16
  - Min–Max technique, 134
  - Monitoring module, 160, 161
  - Monte Carlo (MC)
    - circuit parametric yield, 2
    - disadvantages, 2
    - electrical simulations, 225
    - electrical simulators, 2
    - HSMC, 81, 82
    - IBS, 80
    - IS technique, 78, 79, 83
    - linear and quadratic models, 83
    - non-Monte Carlo methods (*see* Non-Monte Carlo methods)
    - OpAmp, 83, 84
    - parametric yield, 67–69
    - PLL, 82 (*see also* Quasi Monte Carlo (QMC))
    - RMS, 83
    - simulations, 5
    - SRAM bit cell, 79, 80
    - SSS, 81, 82
    - two-stage OpAmp, 82
    - two-step optimization process, 80, 81
    - yield-aware sizing tool, 83
    - yield estimation, 5
  - Monte Carlo analysis, *see* MC-based yield estimation
  - Multi-objective Evolutionary Algorithm Based on Decomposition (MOEA/D), 32, 33
  - Multi-objective optimizer block module, 155, 162
  - Multi-objective PSO (MOPSO), 35
  - Multi-objective simulated annealing (MOSA), 162
  - Mutation process, 30
- N**
- Neural-fuzzy models, 45
  - Non-basic variables (NBV), 21
  - Non-dominated Sorting Genetic Algorithm II (NSGA-II), 30–32, 36, 37
  - Non-MC-simulated potential solutions, 143
  - Non-Monte Carlo methods
    - BMF technique, 86
    - design centering, 89
    - DOE-MC, 91
    - geometric yield analysis, 86
    - optimization problems, 87
    - parasitic effects, 91
    - SR technique, 84, 85
    - two-stage OTS, 90, 91
    - WCD, 87, 88, 90
    - worst-case parameter vector, 87, 88
    - yield estimation technique, 84
  - Non-yield optimization process, 220
- O**
- OASYS, 15
  - OPASYN, 30
  - OPDK single-stage amplifier, 199–201
  - Optimal computing budget allocation (OCBA), 71, 72
  - Optimization-based approach
    - ACO, 26–28
    - automatic circuit sizing tools, 15, 16
    - equation-based evaluation techniques, 33–36
    - GA, 29, 30
    - GP, 22
    - LP, 20–22
    - minimization problem, 16
    - model-based method, 40–45
    - MOEA/D, 32, 33
    - multi-objective optimization problem, 17
    - NSGA-II, 30–32
    - POF, 17
    - PSO, 25, 26
    - SA algorithm, 23, 24
    - simulation-based methods, 36–39
    - SPS, 24, 25

- Optimization-based approach (*cont.*)  
 steepest descent optimization, 17, 18
- Optimization-based random-scale differential evolution (ORDE), 70
- Optimization problem, 16, 17
- Ordinal optimization (OO), 70
- Organic Process Design Kit (OPDK), 199, 201
- Organic top-gated carbon nanotube (OTFT), 180, 196
- Orthogonal Array Design (OAD), 42
- P**
- Parallel re-combinative simulated annealing (PRSA), 37
- Parameter space, 52
- Parameters variability, 54
- Parametric yield  
 analog ICs, 55  
 circuit specifications, 55  
 definition, 65–67  
 environmental operating conditions, 55  
 Gaussian distribution, 56  
 intra-die/local variations, 55  
 losses, 2  
 manufacturing variability, 54  
 MC, 2, 67–69  
 non-symmetrical double-sided constraint, 59  
 one-sided and double-sided constraint, 56–58  
 parameters variability, 54  
 value, 2  
 variations, 54
- Parasitic effects, 91
- Pareto optimal front (POF), 17
- Particle swarm optimization (PSO), 25, 26, 35, 39
- Partition entropy index, 112
- Partitional clustering parameters  
 cluster number, 108, 109  
 cluster partition, 112  
 cluster validity indexes, 111, 113  
 elbow method, 108  
 Euclidian distance, 109, 112  
 k-means++, 113  
 KMS clustering algorithm, 109  
 LAA, 113–115  
 partition entropy index, 112  
 random initial center data points, 111  
 silhouette index, 109  
 silhouette method, 108
- Pattern Search algorithm (PSA), 24, 25
- Phase-locked loop (PLL), 82, 83
- Principal component analysis (PCA), 41
- Procedural Analog Design (PAD), 15
- Process capability index, 172–174
- Process design kits (PDKs), 5, 6
- Proximity, 99
- Q**
- QMC-FUZY, 216, 218
- Quadratic model, 88
- Quasi Monte Carlo (QMC), 42–44, 214  
 analog circuit sizing, 74  
 analog optimization tool, 72  
 circuit synthesis tool, 75  
 commercial electrical simulators, 70  
 CW, 76, 77  
 evolutionary-based optimization algorithms, 72  
 fitness value, 75  
 folded cascade operational transconductance amplifier, 71  
 folded cascode amplifier, 74  
 IBY, 77  
 initial fitness/cost function, 75  
 ISE, 74  
 Kullback-Leibler divergence, 72, 73, 75  
 LHS, 70  
 MCS, 70  
 OCBA, 71  
 OO, 70  
 optimization problem constraints, 71  
 ORDE, 70  
 sample size, 76  
 sampling approach, 76  
 two-stage operational transconductance amplifier, 73  
 WCPF, 77  
 yield-aware sizing process, 77  
 yield-aware sizing tool, 76
- R**
- Recombination/crossover, 29
- Response surface methodology (RSM), 83
- S**
- Scaled-sigma sampling (SSS), 81
- Selection techniques, 29
- Sequential quadratic programming (SQP), 80, 90
- Shrinking circles technique, 39
- Sigma Amplification, 92

Silhouette index, 109  
 Silicon-based technology single-stage amplifier, 196–198  
 Simulated annealing (SA), 23, 35, 37, 45  
 Simulated binary crossover (SBX), 71, 72  
 Simulation-based optimization  
   ACO, 38, 39  
   AIDA-C, 37  
   ANACONDA, 38  
   electrical simulator, 37  
   GA, 37  
   GSA, 39  
   MAELSTROM, 37  
   PRSA, 37  
   shrinking circles technique, 39  
 Single-stage amplifier  
   BSIM3V3 MOSFET model, 182, 183  
   design variables and ranges, 182  
   enhanced DC gain, 181, 210  
   *m* fuzziness parameter values, 212  
   MC simulations reduction rate, 211, 212  
   MC-FUZY, 212, 214  
   non-yield optimization process results vs. FUZY methodology, 214  
   optimization problem objectives, 180  
   OTFT, 180  
   performance specifications, 180, 181  
   POF, 211, 212  
   QMC, 214  
   QMC-FUZY, 216  
   silicon-based technology, 180, 182  
   yield estimation error measure, 211  
 Social component, 25  
 Sparse regression (SR), 84  
 SRAM bit cell, 79  
 Statistical parameters, 46  
 Steepest descent optimization, 17, 18  
 Stochastic pattern search (SPS), 24, 25, 38  
 Sub- $\mu$ W Tow-Thomas-based biquad filter, 186–188  
 Support Vector Machine (SVM), 44, 45  
 Surrogate models, 40  
 Swarm intelligence techniques, 35  
 System-on-a-chip (SoC), 1

**T**

TAGUS, 15  
 Two-phase evaluation process, 122

**U**

Uniform Design (UD), 42

**V**

Very large scale integration (VLSI), 1  
 Virtuoso Analog Design Environment (ADE)  
   XL, 92

**W**

Worst-case distance (WCD), 77, 87–89  
 Worst-case Pareto front (WCPF), 77, 78  
 Worst-case performance (WCP), 76, 77, 90

**Y**

Yield-aware circuit sizing optimization, 228  
 Yield-aware optimization  
   cluster representative individual selection, 129, 132  
   FCM applications, 143  
   KMS algorithm, 129  
   KMS variable cluster number selection, 136  
   MC simulations, 129  
   multi-objective optimization algorithm, 132  
   POF, 131  
 Yield-aware sizing tool, 76, 83  
 Yield estimation techniques, 5–7  
   EDA tools, 92, 93  
   MC (*see* Monte Carlo (MC))  
   MC analysis, 67–69  
   parametric yield, 65–67  
 Yield optimization  
   KMS (*see* KMS-based clustering algorithm)