

## Index

- Admittance parameters. *See* Y-parameters
- Analytic function, 10, 28, 38, 133–134
- Artificial neural network. *See* Neural network
- Autonomous system, 10, 48, 74, 76–77, 103,  
*See also* Autonomous response
- Behavioral model, 53, 88–89, 93–97, 104, 109–111,  
115–116, 119, 122–125, 149, 151, 170, 181,  
218, 220, 222–224, 228, 233, 235, 248,  
262–277, 293
- Boundary conditions, 62–63, 109
- Boundary-value problem, 62–63
- Broadband spice model, 329
- Capacitance matrix, 238, 241–246, 251, 254–255,  
293
- Cardiff model, 119, 125, 150–151
- Characterization, 273, 277
- I/V characterization, 223, 226, 228–230, 241, 259,  
276, 284, 294, 323
- Isodynamic, 284, 306–307, 309
- Large-signal, 111, 115, 119, 149, 233, 237, 252,  
273, 275–286, 324, 329
- Large-signal network analyzers. *See* Nonlinear  
vector network analyzer
- Load-pull, 144, 147–148, 151, 303
- LSNA. *See* Nonlinear vector network analyzer
- Nonlinear vector network analyzer, 116, 169, 172,  
175, 218, 275–287, 293, 299, 306
- NVNA. *See* Nonlinear vector network analyzer
- Pulsed Bias, 275, 282–283, 306–307, 323
- Pulsed S-parameters, 275, 306, 309
- Small-signal, 14, 70, 203, 233, 237, 242, 245, 248,  
251–252, 257, 304, 319
- Source-pull, 325
- Vector network analyzer, 93, 187, 189, 212
- VNA. *See* Vector network analyzer
- X-parameters. *See* X-parameters
- Commensurate frequencies, 77, 117, 151, 153–154,  
160, 276
- Compact model, 115, 125, 235, 276–277, 282–283
- Complex envelope, 15, 19–22, 83–85, 88–89, 160,  
169
- Constitutive relation, 123–125, 218–231, 235–241,  
245–248, 255–269, 274–275, 283–287,  
291–292, 294, 302, 306, 315
- Conversion matrix, 70, 151
- Convolution, 5, 35–37, 53, 68, 74, 90
- Correlation
- Auto-correlation, 34
  - Cross-correlation, 33–34
- Co-simulation, 88–89
- dc
- Analysis, 62–63, 76, 237, 322
  - bias. *See* dc operating point
  - Block, 12, 60
  - Feed, 13
  - Operating point, 14, 18, 62, 106, 108–109, 111,  
122, 125–127, 129, 131, 134–135, 139,  
144–146, 150–151, 168, 182, 184, 195,  
203–205, 208–210, 212–215, 238–239, 269,  
272, 276, 280, 284, 291, 324
  - Power, 9, 214, 273, 329
  - Power supply, 8, 10, 118, 167, 273, 329
  - Quiescent point, 10, 23, 62, 70, 319, 329
  - Source, 12, 123, 128, 144, 213
- Diode, 103, 106, 115, 167, 195, 294
- Equation, 267, 275
- Discrete Fourier series, 35, 54, 77, *See* Fourier series
- Dispersive
- Effects, 224
  - Elements, 54
- Distortion mechanisms
- Miller effect, 16, 310–321
  - Nonlinear charges, 310–315
  - Nonlinear current, 307–309
  - Phase-lagging, 314
  - Phase-shift, 311–314
  - Thermal effects, 307
  - Time-varying capacitances, 310
  - Trapping effects, 307
- Distributed
- Effects, 204, 214
  - Elements, 49, 51–53, 66, 109, 125
  - Model, 109, 197, 219, 269

- Empirical model. *See* Behavioral model
- Energy conservation, 8–9, 245–252, 293–294
- Envelope following analysis
- Envelope-transient harmonic-balance, 84–86, *See* Harmonic-balance
  - Envelope-transient over shooting, 86–87, *See* Shooting method
- Envelope-following analysis, 82–88
- Equivalent circuit model, 13, 22, 50, 52, 94, 106, 182, 200, 205–206, 215–216, 219–220, 222, 302
- Distributed elements, 51
  - Frequency dispersion, 274
  - Lumped elements, 49, 108, 199–201, 206, 214–215
  - Physical structure, 182, 303
  - Quasi-static approximation, 223, 259
  - Scaling rules, 193, 197, 214
  - Symmetry, 262
  - Topology, 190, 195, 199, 203, 212, 215, 220, 222, 239, 241, 302
- Euler method, 55, 63, 66, 85–86
- Final condition. *See* Final state
- Final state, 63, 65, 171
- Finite-differences in time-domain, 63
- Forced system, 10, 49, *See also* Forced response
- Fourier coefficients, 6, 35, 43, 66–69, 83, 85, 120, 135–136
- Fourier series, 34, 43, 66–68, 78, 80, 120, 150
- Fourier transform, 6, 36, 43–44, 54, 81, 104
- Harmonic superposition, 144–146
- Harmonic-balance, 67–82
- Almost-periodic Fourier transform, 79–81
  - Artificial frequency mapping, 81–82
  - Conversion matrix. *See* Conversion matrix
  - Jacobian matrix, 69, 71, *See* Jacobian Matrix
  - Multidimensional Fourier transform, 80–81
  - Multitone harmonic-balance, 77–79
  - Nodal-based harmonic-balance, 70–71
  - Oscillator analysis, 74–77
  - Piece-wise harmonic-balance, 71–74
  - Toeplitz matrix, 68
- Impedance matrix. *See* Z-parameters
- Incommensurate frequencies, 77–78, 80–81, 83, 127, 151–154, 156–157
- Initial condition. *See* Initial state
- Initial state, 55, 61–66, 70, 171
- Initial-value problem, 62
- Jacobian matrix, 56–57
- Kirchhoff's laws, 13, 49–50, 104, 124, 240
- Large-signal operating point, 70, 125–130, 135, 139, 144–146, 149–150, 154–156, 165, 319, 324
- Least-squares, 29, 32, 80, 100, 130, 224, 227
- Linear circuit model elements
- Bond-wires, 305
  - Extrinsic elements, 183, 190–191, 302
  - Intrinsic elements, 183, 190–191, 199, 202, 214, 302, 306
  - Linearized circuit elements, 107
  - Manifolds, 189
  - Package, 302, 304
  - Parasitic elements. *See* Extrinsic elements
  - Pre-matching, 302, 304–305
- Linear model, 181–182, 184–185, 195, 199, 203–205, 207, 209–210
- Additivity, 3, 5, 8
  - Convolution, 5–6
  - Homogeneity, 3–4, 8
  - Memory span, 37, 40
  - Superposition, 3–8, 37, 44, 96, 101–102, 111–112, 115, 126, 139, 144–147, 149, 181
  - Transfer-Function, 7, 18, 20, 43–44, 70, 224
- Linear system. *See* Linear model
- Load-line, 276, 282, 286
- Dynamic, 147, 278, 286, 323
- Load-line method, 322–323
- Look-Up-Table, 40, 42, 214, 218, 228–237, 248–251, 293
- LSOP. *See* Large-signal operating point
- Lumped
- Elements, 48–49, 51, 125, 181, 199, 239, 255, 305
  - Model, 49, 52–54, 61, 89, 109, 198, 219, 238, 269, 274, 329
- LUT. *See* Look-Up-Table
- Memory effects, 20–21, 166–169
- Baseband. *See* Long-term
  - Carrier memory effects. *See* Long-term
  - Long-term, 167–169, 326, 329
  - Short-term, 168–169
- Model definition, 2
- Model extraction, 31, 181, 306, 309
- Calibration, 93, 187–189
  - Cold FET, 190–191
  - De-embedding, 190, 199, 302
  - Dummy device, 304
  - Forward bias, 195–196, 199, 304
  - Methodology, 203, 223, 226
  - Optimization, 227–228
  - Parameter extraction, 182–184, 187–188, 190–197, 201, 205, 218, 224–225, 227, 229, 235, 241, 268, 276–279, 304
  - Polynomial, 30
  - Reference plane, 188–190, 199
  - Strategy. *See* Methodology
- Model extrapolation, 233, 235–237
- Model formulation. *See* Constitutive relation
- Model implementation, 225, 315
- Advanced Design System, 315

- Model implementation (cont.)
  - APLAC netlists, 316
  - AWR. *See* Microwave Office
  - Microwave Office, 316
  - Schematic, 316
  - Symbolic Defined Device, 315
- Neural network, 40, 218, 234–237, 249–250, 261, 268, 283–287, 291–293
  - Adjoint network. *See* Neural network training
  - Extrapolation, 235–237. *See* Model extrapolation
  - Neuron, 234
  - Time delay, 41–42
  - Training, 235, 248, 257, 261, 286
- Newton-Raphson Method, 55–59, 63–66, 69–74, 76
- NMSE. *See* Normalized mean square error
- Nonlinear circuit model elements
  - Charge source, 309
  - Current source, 316
- Nonlinear distortion
  - ACPR, 163–166, 168, 239–240
  - adjacent channel power ratio. *See* ACPR
  - AM to AM conversion, 9–10, 15–16, 20, 301–302, 306–310, 312–315, 321–329
  - AM to PM conversion, 9, 15–16, 20, 301–302, 310–314, 329, 331–333
  - Cross-talk, 11
  - Desensitization, 11
  - Gain compression, 9, 14–15, 285, 287, 310, 329
  - Harmonic distortion, 9, 11, 18, 117, 130, 231, 279, 319
  - IMR. *See* Intermodulation distortion
  - Intermodulation distortion, 9, 11, 111, 137, 152, 163, 165, 167, 173, 227, 239, 289, 320
  - IP3, 165–166
  - Phase shift. *See* Nonlinear distortion AM to PM conversion
  - Spectral leakage, 59
  - Third-order intercept. *See* IP3
- Nonlinear model
  - Artificial neural network. *See* Neural network
  - Compact model. *See* Compact model
  - Look-Up-Table. *See* Look-Up-Table
  - Poly-harmonic distortion. *See* Poly-harmonic distortion
- Normalized mean square error, 31
- ODE. *See* Ordinary differential equation
- Ordinary differential equation, 49, 51–52, 84–85, 270
- Output conductance, 59, 71, 220, 258, 261, 269, 272, 306
- Output-equation, 49–50, 52, 54
- Periodic-steady-state. *See* Shooting method
- Phase-state. *See* State-space
- Physical charge conservation, 48, 240, 246
- Physically based model, 218–223, 231, 258, 292
- Poly-harmonic distortion, 70. *See* X-parameters
- Polynomial approximation. *See* Polynomial model
- Polynomial coefficients, 29
- Polynomial model, 27–31
  - Polynomial coefficients, 29
  - Taylor series, 29–31, 39, 56, 63, 128
  - Volterra series, 39, 143, 151
  - Wiener series, 41–42
- Power amplifier characterization, 328
  - Continuous-wave testing, 16, 319, 323, 328–329
  - CW. *See* Continuous-wave testing
  - Drain efficiency, 301, 323–325
  - Gain, 17, 308, 319–320, 329–332
  - Modulated signal testing, 329, 332
  - Multitone testing, 328–333
  - PAE. *See* Power-added efficiency
  - Power dissipation, 168, 233, 273, 277
  - Power-added efficiency, 9, 147, 261, 274, 287–288, 302, 319–320, 329
  - Two-tone testing, 156, 162, 166, 173–174, 289, 319–321, 329–331
  - Video-bandwidth, 326
- Power amplifier design
  - Bias, 319–321, 325
  - Electromagnetic simulation, 325–329
  - EM. *See* Electromagnetic simulation
  - Layout, 326
  - Load-line, 324. *See* Load-line; Load-line method
  - Load-pull, 302–306, 309, 321, 323–324
  - Matching, 302–321, 325, 329
  - Quiescent point, 319, 329. *See* Bias
  - Schematic, 328
  - Source-pull, 325
  - Using X-Parameters, 148
- Power Amplifier Operation Modes
  - Class A, 62, 273–274
  - Class AB, 273–274, 308, 314, 320, 330
  - Class B, 308, 319–320, 323, 330
  - Class C, 62, 149, 273, 308, 319–321, 330
  - Class F, 323–325
  - Doherty, 148–149, 310
- Power amplifier stability, 324–325
- Predistortion, 168
- Quasi-static approximation, 49, 161–166, 168, 176, 258–259. *See* Quasi-static model
- Quasi-static Elements, 74
- Quasi-static model, 161–166, 173, 176, 218, 223–224, 228, 258–261, 293
- Regression matrix, 34
- Response
  - Autonomous response, 12, 22–26, 42
  - Chaotic response, 22, 25, 28, 42, 67, 77, 117
  - Finite impulse response, 40
  - Forced response, 12, 22, 24, 61

- Impulse response, 4–7, 36–40, 43, 53, 101, 171
- Infinite impulse response, 42
- Large-signal, 111. *See* Characterization: large-signal
- Periodic response, 6, 11, 19, 22–23, 42, 48, 54, 61–63, 65–67, 74–76, 78, 85–87, 89, 120, 122–123, 277, 283, 329
- Quasi-static response, 170
- Sinusoidal response. *See* Response: Periodic response
- Small-signal. *See* Characterization: small-signal
- Steady-state regime. *See* Periodic response
- Step response, 171, 175
- Transient response, 60–62, 171, 274
- Unstable regime, 10. *See* Autonomous response
- Runge-Kutta method, 58
  
- Sampling frequency, 4–5, 54
- Sampling interval. *See* Sampling frequency
- Scattering matrix. *See* S-parameters
- Schottky contact, 182, 195, 294. *See also* Diode
- Shooting method, 63–66
- S-parameters, 66, 93–112, 115–116, 118–119, 124–127, 129, 131–133, 136, 140, 143–144, 146, 148, 169, 181, 184–191, 199–205, 208, 215, 233, 238–242, 245, 256, 258, 276–278, 282, 286–287, 306, 309, 319, 325
  - Hot S-parameters, 111, 133, 151
  - large-signal S-parameters, 111
  - Large-signal S-parameters, 70
- Spectral map, 36, 68, 81, 93, 101–111, 115, 117, 119–122, 125–129, 132–133, 152–156, 262
- SPICE, 48, 54–55, 61, 90
- State-equation, 49–52, 54–55, 57, 63, 67, 71, 84, 89–90, 275
- State-space, 52, 56
- State-variables, 23, 49–51, 54, 56, 61, 63, 68–69, 71, 73, 75, 77, 83–85, 280–281, 284
- State-vector. *See* State-variables
- Superposition. *See* Linear model
- system
  - Definition, 2
  - System state. *See* State-variables
  
- Table-based model. *See* Look-Up-Table
- Terminal charge conservation, 218, 240, 245–247, 251–255, 292–293
- Thermal effects, 307
  - Circuit model, 269, 275
  - Frequency dispersion, 259, 284
  - Self-heating, 167, 269
  - Time constants, 319
- Time invariance, 3, 102–104, 119–122, 153–154
- Time samples, 4, 31, 35, 55, 63, 66, 80, 83, 88, 162–164
  
- Time-delayed look-up-table. *See* Look-Up-Table
- Time-step integration, 55–61, 64, 83
- T-parameters, 70
- Training
  - Model. *See* Model extraction
- Transcapacitance, 205–209, 242, 252–255, 294
- Transconductance, 15, 29, 50, 59, 70, 191, 206, 258, 261, 306, 319
  - Bias-dependent, 184
  - Time-delay, 199, 209–210
  - Time-varying, 70–71
- Transistor, 103, 106, 115, 167, 181, 219, 222
  - Field-effect, 22, 106, 182, 215, 219, 221, 230
  - GaAs pHEMT, 182, 197–198, 200, 212, 221, 230–233, 244, 246, 250, 256–259, 269, 285
  - GaN HEMT, 147, 149, 201, 218, 287, 310–315
  - Heterojunction bipolar, 239, 247, 256
  - III-V semiconductors, 218, 222, 273–275, 293
  - Si LDMOS, 231, 302, 304, 310–315
  - Si MOSFET, 221, 232
- Transistor characteristics
  - Breakdown voltage, 319
  - I/V curves, 306
  - Knee voltage, 319
  - Soft turn-on, 309
  - Thermal resistance, 214, 270, 323
  - Triode region, 309
  - Triode region, 309
- Transmission matrix. *See* T-parameters
- Trapezoidal integration rule, 58–59, 65
- Trapping effects, 273, 307
  - Circuit model, 275
  - Current collapse, 329
  - Drain-lag, 167, 274, 319
  - Frequency dispersion, 259, 284, 329
  - Gate-lag, 274
  - Self-biasing, 323, 329
  - Soft-compression, 329
  - Time constants, 319
  
- Window function, 60
  
- X-parameters, 70, 115–177, 262, 277, 289, 293
  - Dynamic X-parameters, 116, 160, 169–176
  - Identification - offset frequency method, 137–140
  - Identification - offset phase method, 129–132
  - Load dependent, 129, 146–150
  
- Y-parameters, 108, 185–186, 191, 194, 200, 203, 209–211, 216, 241, 243–245, 339
  
- Z-parameters, 194, 196–197