Index

absorption/gain spectra, 245 absorption processes, 21-24 acceptor, 19 ACPR, see adjacent channel power ratio (ACPR) active baluns and unbals, 414-416 active forward operation, 116 adjacent channel power ratio (ACPR), 375-376 amplifier configurations common drain/common collector, 321-323 common gate/common base, 319-321 common source/common emitter, 316-318 Miller effect, 318 with two transistors, 329-336 Battjes $f_{\rm T}$ doubler, 333 cascode amplifier, 333-336 common-drain/common-source, 329-332 Darlington amplifier, 332-333 y matrix representation, 315-318 amplifier linearity, 370-376 adjacent channel power ratio, 375-376 single-tone excitation, 370-372 two-tone excitation, 372-375 ANN, see artificial neural networks (ANN) anti-guiding parameter, 244 APD, see avalanche photodiodes (APDs) arbitrary terminations, 299-300 Armstrong oscillator, 388 artificial neural networks (ANN), 168-169 associated gain, 312 atomic bonding, 8 covalent bonding, 8-9 atomic physics, 9 Bohr model, 10-11 photoelectric effects, 9-10 avalanche photodiodes (APDs), 275, 276 input signal photocurrent for, 276 ionisation coefficient, 272-273 multiplication factors, 273-274 optical generation rate, 273 (SAM) separate absorption and multiplication, 275 avalanching, 120 bandgap energy, 222, 262 band line-up, 38-39 bandwidth enhancement, 328

base design dilemma, 136-137 base push out, 125 base resistance, 128 base transit time, 126 base transport factor, 121 Battjes $f_{\rm T}$ doubler, 333 bipolar and hetero-bipolar transistors, 115 heterojunction base design dilemma, 136-137 drift base, 139-140 HBT implementations, 140-143 III-V versus Si/SiGe HBTs, 146-147 Si/SiGe HBTs, 143-146 wide-gap emitter, 137-139 homojunction, 115-116 collector current equation, 117-118 diffusion triangle, 116-117 Early effect, 122-124 ideal base current, 118-119 ideal current gain, 119 Kirk effect, 124-125 non-ideal current contributions, 119-120 non-ideal current gain, 120-121 saturation, 121-122 large-signal modelling, 147 BJTs and HBTs, 155-156 Ebers-Moll model, 147 Gummel-Poon model, 147-150 MEXTRAM model, 152-153 VBIC95 model, 150 microwave noise performance of bipolar transistors, 131-134 small-signal dynamic behaviour, 125-129 maximum frequency of oscillation, 130-131 transit frequency, 129-130 transit time optimisation collector transit time optimisation, 135-136 drift field in base, 134-135 bipolar junction transistors (BJT), 46 BJT, see bipolar junction transistors (BJT) BJTs and HBTs, 155-156 Bloch theorem, 16 body-centred cubic lattice (BCC), 6 Bohr formulation, 11 Bohr model, 10-11 Boltzmann's constant, 222 Bragg frequency, 356

improvement, 326-329

wore information

424	Index
-----	-------

broadband amplifier techniques, 350-354 feedback techniques, 353-354 shunt peaking, 351-353 building blocks for high-speed analogue circuits, 291 baluns, unbals and hybrids active baluns and unbals, 414-416 passive baluns and unbals, 412-414 quadrature generation, 417-419 mixers, 396 diode-based, 406-407 double-balanced, 402-404 image-rejection mixer topologies, 407-410 micromixer, 404-405 noise figure, 411-412 resistive, 398-400 single-balanced, 401-402 transconductance multiplier, 397 oscillators, 383 noise, 393-396 non-linearity in oscillators, 387-388 oscillator topologies, 388-392 resonators, 383-385 self-excitation criteria, 385-387 transistor amplifiers, 313-314 broadband amplifier techniques, 350-354 configurations, 314-323 configurations with two transistors, 329-336 differential, 336-341 distributed amplification, 354-365 feedback, 323-329 linearity, 370-376 low-noise, 365-370 power, 376-383 source-coupled, 341-342 tuned, 342-350 two-port networks, basic relations for impedance matching, 297-298 Mason's unilateral gain, 305-306 maximum available gain and maximum stable gain, 305 maximum frequency of oscillation, 306 power gains for amplifier design, 298-302 scattering parameter theory, 291-295 Smith chart, 295-297 stability, 302-305 built-in potential, 32 bulk semiconductor, 257 Burrus diode, 229

CAD modelling of HEMTs, 88 MESFET *versus* HEMT, 91–92 non-linear capacitance equations, 90–91 static current equations, 88–90 carrier confinement, 36 carrier lifetime, 226, 240–241, 248 carrier transport in semiconductors, 29

diffusion current, 29 drift current, 29 cascode amplifier, 333-336 topology, 368 cavity photons, 252-253 channel, 46 channel length modulation, 103 channel noise, 63 COBRA current equation, 89 collector current equation, 117-118 resistance, 128 transit time optimisation, 134-136 common-collector configuration, 321 common-drain configuration, 321 common-source configuration, 329-332 common-emitter configuration, 316 common source configuration, 316 confinement configuration, 230, 232, 236, 238, 239, 248, 257 conformal mapping, 296 constant-velocity approximation, 51-55 constant-velocity model, 52-53 cost function, 163-164 Coulomb scattering, 67-69 covalent bonding, 3, 8-9 critical thickness, 39 crystal directions, 7 and planes, 6-8 crystal structure, 5-6 current continuity, 50 current-voltage characteristics, 33-34 dark current flowing in slab, 263 Darlington amplifier, 332-333 de Broglie relation, 11-12 density of states, 3, 19, 20, 35, 36 depletion, 30 approximation, 30 capacitance, 33 layer width, 32-33 device model optimisation, 163-164 diamond, 8 differential amplifiers, 336-341 common mode, 338-339 differential mode, 336-338 neutralisation of, 339 diffusion components, 254 diffusion current, 29 diffusion triangle, 116-117 diode-based mixers, 406-407 diode responsivity, 270 direct and indirect semiconductors, 20

absorption processes, 21-24

direct bandgap semiconductors, 20

exciton absorption, 24-25

Index

425

distributed amplification, 354-365 amplifiers with cascode cell, 360-361 amplifier variations, 359-360 gain and loss in amplifiers, 358-359 general design procedure, 356-358 using Si/SiGe HBTs, 363-365 distributed Bragg reflector (DBR) lasers, 253 distributed feedback (DFB) laser, 253 donor, 19 double-balanced mixer, 402-404 drain current, 50-51, 100-101 backgating, 102 constant-mobility model, 101-102 non-ideal effects in short-channel MOSFETs, 102 - 105velocity saturation, 105-106 drift base, 139-140 drift current, 29 density, 268 drift field in base, 134-135 drift saturation velocity, 52 Ebers-Moll model, 147 edge-emitting LED, 228 electrical pumping, 222 electrons and hole distribution, 19-20 in semiconductor, 16 electrostatic theory, 67 emission coefficient, 120 emitter efficiency, 121 emitter follower, see source follower epoch, 173 exciton absorption, 24-25 external power efficiency, 226 extrinsic semiconductors, 18-19 Fabry-Perot lasers, 248 face-centred cubic lattice (FCC), 6 facet mirror reflectivity, 230 Fermi-Dirac distribution, 16 fitness index, 180-181 flat-band, 99 FM signal, 372 forward-biased emitter-base junction, 125 free electron, 16

 $f_{\rm T}$ doubler, 332 GaAs MESFET, 48 gain coefficient, 239–240 gain-guided lasers, 231–233 gain saturation sets, 371 gate length, 49 gate width, 49

generation-recombination noise, 265

gradual channel approximation, 49 Gummel–Poon model, 147–150

Hawkins' theory, 133 HBT, see heterojunction bipolar transistors (HBT) Heisenberg uncertainty principle, 12 heterojunction bipolar transistors (HBT) base design dilemma, 46, 136-137 drift base, 139-140 III-V versus Si/SiGe HBTs, 146-147 implementations, 140-143 Si/SiGe HBTs, 143-146 wide-gap emitter, 137-139 heterojunction LED, 228 heterostructures, 35-37 band diagrams, 37-38 band line-up, 38-39 constructing heterostructure band diagrams, 37 - 38lattice mismatch, 39-40 heterostructure bipolar transistor photodetector, 284 HICUM model, 153-155 high electron mobility, 80 high electron mobility transistor (HEMT), 67 CAD modelling, 88 MESFET versus HEMT, 91-92 non-linear capacitance equations, 90-91 static current equations, 88-90 charge control, 69-74, 69-75 channel current - constant mobility, 75-77 channel current - constant velocity, 77-78 Coulomb scattering, 67-69 high electron mobility, 80 non-ideal behaviour, 80-83 trapping effects, 83-85 small-signal parameters, 78-79 structural variations, 85 metamorphic, 87-88 pseudomorphic structure, 86-87 pulse-doped structure, 85-86 high-speed lasers, 259-261 separate confinement (SC) region, 261 tunnelling injection laser, 261 hill-climbing capability of SA, 166 homojunction bipolar transistors, 115-116 collector current equation, 117-118 diffusion triangle, 116-117 Early effect, 122-124 ideal base current, 118-119 ideal current gain, 119 Kirk effect, 124-125 non-ideal current contributions, 119-120 non-ideal current gain, 120-121 saturation, 121-122 Hopfield recurrent neural networks energy function, 174 HBTs modelling of, 174-177

426 Index

image frequency, 407 image-rejection mixer topologies, 407-410 impedance inverters, 349 impedance matching, 297-298 index-guided lasers, 231-233 indirect gap semiconductors, 223 inductive source degeneration, 326 input signal photocurrent, 270 internal quantum efficiency, 225-226 intrinsic and extrinsic base resistances, 193-195 intrinsic semiconductors, 18 ionic bonding, 8 ion-implanted MESFET, 53 JFET, see junction field effect transistor (JFET) Johnson noise, 265, 306 junction field effect transistor (JFET), 47 Kirchhoff's law, 50 Kirk effect, 124-125 knee voltage, 51 Kronig-Penney model, 16-17 carriers in semiconductors, 18 effective mass, 17-18 Langevin components, 254 large-signal CAD model, 55-56 capacitance model, 56-57 parasitic circuit elements, 57-58 laser noise, 253-255 lattice. 5 lattice constant, 5 lattice mismatch, 39-40 LED, see light-emitting diodes (LED) L-I curve, 242-244, 249 light-emitting diodes (LED) carrier dynamics for, 226 mechanisms for, 222 modulation response, 226-227 n⁺-p junction, 223–224, 226–227 optical power and, 225 recombination rate, 222-223 reflection coefficient, 225 responsivity of, 226 structure of, 227-229 usage of, 229 light inversion, 98 Lilienfeld's FET concept, 47 linear regime, 51 linewidth broadening factor, 252-253 linewidth enhancement factor, see anti-guiding parameter local minimum trapping, 164 lossless networks, 294 lossy networks, 294 low-frequency noise, 64 low-noise amplifier, 365-370

mapping, 296 Mason's unilateral gain, 305-306 massively distributed computing networks, 170 - 171maximum available gain, 344 and maximum stable gain, 305 maximum frequency of oscillation, 112, 130-131, 306 Meissner oscillator, see Armstrong oscillator MESFET, 46-50 constant-velocity approximation, 51-55 drain current, 50-51 large-signal CAD model, 55-56 capacitance model, 56-57 parasitic circuit elements, 57-58 noise performance, 62 low-frequency noise, 64 microwave noise, 62-64 small-signal equivalent circuit, 58-61 versus large-signal model, 58 maximum frequency of oscillation, 61 transit frequency, 60-61 in third millennium, 64-66 Metal-oxide-semiconductor field effect transistors (MOSFET), see MOSFET metal-semiconductor field effect transistor (MESFET), see MESFET metal-semiconductor-metal detectors, 277 capacitance of, 278 quantum efficiency, 279 metamorphic HEMT, 87 metastable region, 42 MEXTRAM model, 152-153 micromixer, 404-405 microwave noise, 62-64, 112-114 performance of bipolar transistors, 131 - 134Miller capacitance, 58 Miller effect. 318 Miller indices, 7 mirror reflectivity, 230 mixer noise figure, 411-412 mixers 396 diode-based, 406-407 double-balanced, 402-404 image-rejection mixer topologies, 407-410 micromixer, 404-405 noise figure, 411-412 resistive, 398-400 single-balanced, 401-402 transconductance multiplier, 397 mode suppression ratio (MSR), 242 modulated cavity photons, 252 modulated optical power, 227 modulation response, 226-227 MOS diode operation, 97-100

Index

427

MOSFET, 46 MOS (metal oxide-semiconductor) diode, 96 multiacronym device (MAD), 80 multi-layer perceptron (MLP) neural networks, 171 backpropagation, 171-173 circuit design process, flow chart for, 173 epoch, 173 neural networks and modelling, 168-179 ANN, 168-169 classes of, 169 Hopfield recurrent neural networks, 174-179 massively distributed computing networks, 170 - 171multi-layer perceptron neural networks, 171-174 neuron, 169 physical implementation of, 171 structure of, 170 neural networks by genetic algorithm, optimisation of, 180 chromosomes and genes, 180 crossover, 180-181 fitness index, 180 flow chart for application of, 181 HBT I-V characteristics of, 177-178 large-signal neural network model of, 177 mutation, 180 over-fitting, 181 neurons, 169-171 Neuron Transfer Function, 171 noise, 393-396 noise in two-ports figure, 307-309 figure with arbitrary generator admittance, 310-313 phenomena, 306-307 noise equivalent power (NEP), 265 noise figure, 307-313 with arbitrary generator admittance, 310 - 312of cascaded two-ports, 309-310 noise in two-ports noise figure, 307-309 noise figure with arbitrary generator admittance, 310-312 noise phenomena, 306-307 noise performance, 62 low-frequency noise, 64 microwave noise, 62-64 noise phenomena, 306-307 non-linearity in oscillators, 387-388 non-radiative recombination coefficient, 240 normalised detectivity, 265 n⁺-p junction, 223-224, 226-227

optical generation rate, 273 optical sources, 221 light-emitting diodes, 222-229 preliminaries, 222 semiconductor lasers optical waveguides, 231 - 239Optimisation and parameter extraction of circuit models device models, 163-164 neural networks applied to modelling, 168-170 Hopfield recurrent neural networks, 174-179 massively distributed computing networks, 170-171 multi-layer perceptron neural networks, 171 - 174neural networks by genetic algorithm, 180-184 semi-analytical device parameter extraction analysis, 184-198 parameter extraction results, 198-203 simulated annealing, 164-168 small-signal model of the collector-up (inverted) HBT, 212-214 small-signal parameter extraction, 209-211 Z-parameters at zero bias, 208-209 Z-parameters for HBT, theoretical approximations, 203-208 structured genetic algorithm, 181-184 oscillation frequency, 392 oscillators, 383 noise, 393-396 non-linearity in oscillators, 387-388 oscillator topologies, 388-393 resonators, 383-385 self-excitation criteria, 385-388 oscillator topologies, 388-393 over-fitting, 181 parasitic elements extraction of, 186-189 passive baluns and unbals, 412-414 photoconductor detector, 263, 266 generation-recombination noise, 265 with interdigitated fingers, 266 noise equivalent power (NEP), 265 normalised detectivity, 265 photoconductor slab, 263 signal-to-noise ratio, 265 photodetectors, 261-262 avalanche photodiodes, 271-277 heterostructure bipolar transistor photodetector, 2.84metal-semiconductor-metal detectors, 277-279 photoconductor detector, 263-265 P-I-N diodes, 265-271 responsivity of, 262 travelling wave p-i-n photodiodes, 279-283 photoelectric effects, 9-10

428

Index

photon density, 240 photon flux density, 267 photon lifetime, 240-241 photons, 9 pinch-off voltage, 50-51 P-I-N diodes, 265-271 conduction current density, 268-269 diffusion current density, 268 drift current density, 267-268 p-i-n junction photodiode, 267 equivalent circuit of, 270 Planck's constant, 9, 10 p-n junction(s), 30-31, 222 under bias, 33 built-in potential, 32 current-voltage characteristics, 33-34 depletion capacitance, 33 depletion layer width, 32-33 photodiode, 267 Poisson's equation, 54 polycrystalline solids, 5 poly-Si plug, 128 port isolation, 400 port matching, 325-326 power amplifiers, 376-383 class D amplifier, 379-381 class E and F amplifiers, 381-383 classes of operation, 376-377 switched amplifiers, 377-379 power gains for amplifier design, 298-301 definitions, 301-302 power output against current, 249 powers at input and load, 300-301 probability and uncertainty principle, 12-13 propagation constant, 230 pseudomorphic HEMT structure, 86-87 pseudo-temperature, 165 pulse-doped HEMT, 85-86 pulse-doped MESFET, 53 quadrature generation, 417-418 quanta, 9 quantum dot lasers, 255-261 quantum mechanics, 12 probability and uncertainty principle, 12-13

wave equation, 13–15 quantum well lasers, 229, 255–259, 261 and quantum dot lasers, 258–261

radial relaxation oscillation frequency, 250 radiative recombination, 20 coefficient, 223, 240 rate, 222 radio frequency MOSFETs, 95–96 drain current, 100–101

backgating, 102 constant-mobility model, 101-102 non-ideal effects in short-channel MOSFETs, 102 - 104velocity saturation, 105-106 large-signal modelling, 106-109 MOS diode operation, 97-100 small-signal model and RF performance, 109-110 maximum frequency of oscillation, 112 microwave noise, 112-114 transit frequency, 110-112 structure, 96 reciprocal mixing, 393 reciprocity, 294 recombination rate, 222-223, 241 reference planes, 294-295 relative intensity noise (RIN), 253 relaxation frequency, 251 relaxation oscillation frequency, 221, 249-251, 254, 260-261 resistive mixer, 398-404 resonators, 383-385 quality factor, 384-385 ridge laser, 232-233, 237 Rollet factor, 304, 305 SA, see simulated annealing (SA) SAM, see separate absorption and multiplication (SAM) saturated regime, 51 saturation, 122 scattering parameter theory, 291-295 Schottky diode, 34-35, 49 Schrödinger wave equation, 14 second medium index, 231 second-order intermodulation, 396 self-excitation criteria, 385-386 semi-analytical device parameter extraction equivalent circuit elements, extraction of base-collector capacitance, 189-190 base-collector resistance, 190-192 base contact lead inductor, 193 collector contact lead inductor, 190 collector extrinsic resistance, 192-193 emitter lead inductor and base-emitter capacitance, 195-196 emitter resistance and base-emitter resistance. 195 intrinsic and extrinsic base resistances, 193-195 parasitic elements extraction of, 186-189 transport factor, 196-198 parameter extraction results, 198, 201-202 bias-dependent parameters, 200-201 bias-independent parameters, 199 optimisation error, 199-200

Index

semiconductors band diagrams, 22 carriers in, 18 elemental and binary compound, 4 in equilibrium electron and hole distribution, 19-20 extrinsic, 18-19 intrinsic, 18 materials, 4 in periodic table, 4 recombination and radiation in. 25-26 spontaneous and stimulated emission, 26-28 ternary and quaternary, 4 semiconductor heterostructures, central design principle of, 40 semiconductor lasers, 229 absorption, emission and gain, calculation of, 244 classification, 231-232 concepts of, 229-231 confinement factor, 230-231 emission characteristics of, 238 carrier lifetime, 240 gain coefficient, 239-240 L-I curves, 242 photon lifetime, 240-241 high-speed lasers, 259-261 laser noise, 253-255 mirror reflectivity, 230 optical waveguides in, 231-238 quantum well and quantum dot lasers, 255-259 rate equations, 244-248 steady-state and dynamic characteristics, 248-253 cavity photons, 252-253 linewidth broadening factor, 252-253 power output against current, 249 radial relaxation oscillation frequency, 250, 251 separate absorption and multiplication (SAM), 275 separate confinement (SC) region, 261 series-series feedback, 324 Shockley-Read-Hall recombination, 26 short-base diode condition, 117 shunt-shunt feedback, 324 signal-to-noise ratio, 265, 271 silicon-germanium heterostructures, 40-43 simulated annealing (SA), 164 hill-climbing capability of, 166 modelling of HEMT, application of, 166-168 pseudo-temperature, 165 single-balanced mixer, 401-402 single quantum well vertical cavity laser, 259 single-sideband noise figure, 411 single-tone excitation, 370-371 Si/SiGe HBTs, 143-146 III-V versus Si/SiGe HBTs, 146-147 slab waveguide, 232

small-signal amplifiers, 324-325 small-signal dynamic behaviour, 125-129 maximum frequency of oscillation, 130-131 transit frequency, 129-130 small-signal equivalent circuit, 58-61 versus large-signal model, 58 maximum frequency of oscillation, 61 transit frequency, 60-61 small-signal model and RF performance, 109-110 small-signal model of the collector-up (inverted) HBT, 212-214 small-signal parameter extraction, expressions approximation at $R_{bi} = 0, 212$ parameter extraction, 209-211 Z-parameters for HBT, theoretical approximations, 203-208 at zero bias, 208-209 small-signal photons in cavity, 252-253 Smith chart, 295-297 solids, types of, 5 source-coupled amplifier, 341-342 source follower, 322 space charge region, 30 spontaneous emission, 26-28 factor, 247 spreading resistance, 113 stability, 308-305 circles, 303-305 Rollet's stability factor, 304-305 unconditional, 303 statistical mechanics Fermi-Dirac distribution, 16 free electron, 16 stimulated emission 26-28 stimulated transition, 27 strong inversion, 98 structured genetic algorithm (SGA) modelling of HEMT amplifier, application of, 182 parameters for, 184 for neural networks, 183 simplified power amplifier schematic, 183 supply layer, 75 surface-emitting LED, 229 surface recombination, 223 thermal noise, see Johnson noise three-layer slab symmetric guide, 232, 237 threshold current density, 240 total cavity photons, 252 transconductance multiplier, 397 transistor amplifiers, 313-314 broadband amplifier techniques, 350-354 configurations, 314-323 configurations with two transistors, 329-336 differential amplifiers, 336-341

distributed amplification, 354-365

feedback, 323-326

Index

430

transistor amplifiers (cont.) linearity, 370-376 low-noise amplifier, 365-370 power amplifiers, 376-383 source-coupled amplifier, 341-342 tuned amplifiers, 342-350 transit frequency, 60-61, 110-112, 129-130 transit time optimisation collector, 135-136 drift field in base, 134-135 transmission line, 382-383 transport factor α, 196–198 transverse electric field, 24 trapezoidal Germanium profile, 145 trapping effects, 83-85 travelling wave p-i-n photodiodes with coplanar electrodes, 280 equivalent circuit of, 282 and p-i-n structure, 281-282 velocity mismatch, 282-283 waveguide photodetector (WPD), 280 tuned amplifiers, 342-350 input and output matching networks, 344-350 resonant loads, 342-344 tunnelling injection laser, 261 two-dimensional electron gas (2DEG), 70 two-port networks, basic relations for impedance matching, 297-298 Mason's unilateral gain, 305-306 maximum available gain and maximum stable gain, 305 maximum frequency of oscillation, 306

power gains for amplifier design, 298-299 scattering parameter theory, 291-295 Smith chart, 295-303 stability, 302-305 two-tone excitation, 372-375 two-tone second-order intermodulation products, 373 two-tone third-order intermodulation products, 373 ultrafast lasers, 229 under bias, 33 unilateral gain, 305 unilateralisation, 325 unloaded Q, 385 VBIC95 model, 150 Vertical cavity surface emitting lasers (VCSELs), 258, 259, 270 virtual ground, 337 wall plug efficiency, see external power efficiency wave equation, 13-15 waveguide mode refractive index, 238 waveguide photodetector (WPD), 280 wide-gap emitter, 137-139 WPD, see waveguide photodetector (WPD) zero-gap configuration, 39 Z-parameters for HBT, theoretical approximations, 203-208

at zero bias, 208-209