



Index

- A/D interface 565
 - ABCD state model
 - block diagram 629
 - state variable notation summary 628
 - accelerometer 123, **128**
 - actuator 108
 - actuator saturation 538
 - nonlinear model 662
 - actuator-process-transducer structure 106, 109
 - aliasing 566
 - amplification 398
 - anti wind-up circuit 539, 541
 - anti-alias filters 566
 - attenuation 398
 - autopilot 8, 10
 - control specification 317
 - autotune 578
 - process reaction curve method 578
 - technology 578
 - auxiliary equation 184

 - bandwidth 406
 - open and closed loop 408
 - signal 407
 - block diagram **103**
 - block
 - absolute value 542
 - multiplier 541
 - feedback path 208
 - forward path 208
 - manipulation 204
 - open loop 208
 - push-through rule 207
 - shorthand formula 208
 - signal equations 205
 - system block 103
 - Bode plot 393, 426, 428
 - adding a pole at the origin 457
 - adding a real pole 458
 - adding a real zero 460
 - effect of damping ratio 454
 - finding the transfer function 446
 - gain and first order lag 445
 - identification of second order transfer function 455
 - s-term and first order lag 448
 - two first order lags 449
 - boiler system 556
 - bounded signals 264, 268
 - table 266

 - cascaded system 105, 117, 456, 484
 - causality 43
 - characteristic equation
 - complex roots 185
 - real roots 184
 - characteristic polynomial 281
 - chemical system, state variables 622
 - closed loop 197
 - control signals 203
 - control system 202
 - closed loop bandwidth **509**
 - closed loop control, block diagram analysis 280
 - closed loop frequency response **461**
 - Nichols 513
 - closed loop peak magnitude, M_p 509
 - closed loop polynomial 354
 - closed loop stability 281, 292
 - closed loop system, PD control analysis 301
 - commercial controller units 578
 - comparator 201
 - compensator, effect of 485
 - complementary sensitivity function 461
 - complex numbers 17
 - addition and subtraction 20
 - cartesian form 17
 - complex exponential form 17, 18
 - division 21
 - magnitude, gain and phase 22
 - modulus 18
 - multiplication 20
 - parameter (frequency) dependence 24
 - polar angle 18, 22
 - polar form 17
 - rectangular form 17
- contours
 - constant damping 250, 363
 - natural frequency 250, 363
 - control improvements
 - natural resource usage 2
 - quality control 1
 - quality of life 2
 - control matrix, **B** 712
 - controller structure 473
 - selection of PID terms 313
 - conveying system
 - actuator 139
 - complete block diagram 142
 - process 137
 - Simulink model 142
 - state variable model 640
 - transducer 138
 - co-ordinate measuring machines, description 8–10
 - corner frequency 441, 454
 - critically damped 178, 252
 - cut-off rate 400

 - d.c. gain 399, 582
 - d.c. motor **139**
 - D/A interface 565
 - damped oscillation method 601
 - advantages/disadvantages, table 606
 - procedure 600
 - rule-base 600
 - damped oscillation, ω_d 134
 - damper element 124, 174
 - damping 126
 - damping factor 127
 - damping ratio, ζ 127, **176**, **178**, 419, 456,
 - effect on Bode plot 454
 - data outliers 585
 - DCS system 530

- deadtime 165
 - Padé approximation 168
 - temperature model 165
- decibel 387
- delay time 582
- denominator, closed loop 281
- denominator polynomial 28, 243
- derivative, bandwidth limited 539
- derivative control 278, **299**
 - disturbance rejection 305
 - Laplace domain formula 299
 - noise amplification 545
 - reference tracking 302
 - relationship to damping ratio 302
 - time domain formula 299
- derivative kick 335, 539, 550
- derivative term
 - Bode plot 545
 - digital form 569
 - filter 539
 - incremental form 572
 - modified Bode plot 547
- derivative time constant 531, 579
- design pole polynomial 716
- design specifications 410, **470**, 220
- diagonalisation of a matrix 689
- differentiation, numerical approximation, backward form 567
- differentiator 278
- digital control 734
 - algorithm 565
 - PID control 565
 - recurrent relationship 565
- digital filters 566
- digital PID control
 - incremental form 572
 - positional algorithms 572
 - summary table 570
 - velocity form 572
 - summary table 573
- direct feedthrough matrix 628
- disturbance 198, 203, 279
 - input and output 204
- disturbance rejection 233, 279, 281
 - Laplace analysis 288
- disturbance rejection performance 296
 - derivative control 305
- driving matrix, **B** 712
- dynamics 148
- eigenvalue 688
 - determinant formula 689
- eigenvalue–eigenvector formula 689
- eigenvector 688
- electrical circuit, state variable model 632
- electrical system, state variables 622
- electromagnetic coil 122, 129
- electro-mechanical system model, state variable model 717
- error transfer function 221
- exothermic reactor system 556
- feedback 413
- feedback control system 200
- Final value theorem 221, 223
 - application 315
 - definition 45
- first order differential equation **150, 156**
- first order lag plus deadtime response 582, 584
- first order terms, magnitude and phase 440
- flight control systems description 6–8
- fluid flow system 110
- forced response 157
 - state-space 635, 639
- Fourier analysis 384
- free response 157
 - state-space 635, 638
- frequency, damped oscillation, ω_d 134
- frequency axis 390, 428
- frequency content of a signal 47
- frequency ranges 433
- frequency response **386, 397**, 426, 430
 - amplification 398
 - attenuation 398
 - MATLAB plot 430
 - roll-off rate 400
- frequency response plot, interpretation 409
- frequency scales 390
- functional specification 116
- gain, constant 104
- gain calculation 428
- gain crossover frequency 405
- gain margin **414**
 - Bode 415
 - Nichols 416
 - Nyquist 417
- gain terms, magnitude and phase 437
- gas turbine system control specification 318
- general polynomial form 181
- hertz 390
- high-frequency asymptote 400, 440
- hot strip rolling mills, description 11–13
- ideal gas law, nonlinear equation 662
- industrial heaters, description 14–15
- infinite zeros 354
- initial value theorem, definition 46
- input disturbances 203
- input matrix, **B** 628, 712
- integral control 278, **290**
 - closed loop system analysis 291
 - first order system analysis 291
 - Laplace domain formula 290
 - summary table 299
 - time domain formula 290
- integral controller, phase lag 486
- integral term
 - digital form 569
 - incremental form 572
- integral time constant 531, 579
- integral wind-up 539
- integrating factor 156
- integrating process 40
- integration, numerical approximation 568
- integrator, $1/s$ 278
- inverse response system 368, 557
- inverted pendulum system, state variable model 695
- Kalman filters 732
- lag term 444
- Laplace transform models 110
- Laplace transforms 16, **25**
 - $1/s$, integrator 37
 - decaying exponential cosine signal 33
 - decaying exponential signal 26, 31
 - decaying exponential trigonometric signal 33
 - definition 25
 - derivations, first principles 30
 - derivative of a signal 37

- differential equation 38
- Final value theorem, example 45
- first derivative of a signal 37
- growing exponential trigonometric signal 33
- initial value theorem, definition 46
- integration of a signal 37
- inverse Laplace transform 28
- Laplace transform tables 29
- Laplace variable, s 26
- left half plane (LHP) 26
- partial fractions 44
- properties, linear combination 34
- properties, signal by a constant 34
- properties, table of 35
- ramp signal 31
- right half plane(RHP) 26
- s , differentiator 37
- second derivative of a signal 37
- sine signal 32
- s -plane 26, 27
- step signal 30
- superposition theorem 42
- lead term 444
- left half plane (LHP) 244
- limit cycle 607
- linear relationship 660
- linear system 41, 660
- linearisation 668
 - actual process values 671
 - general nonlinear state variable model 675
 - output equations 669
 - procedure 668
 - system dynamics 668
- liquid level model
 - actuator 117
 - complete block diagram 120
 - performance specification 116
 - process 112
 - Simulink model 121
 - transducer 114
- liquid level system
 - nonlinear model 662
 - state variable model 636
- load disturbance 279, 581
- logarithmic frequency 390
- low frequency asymptote 440
- low pass filter 546

- magnetic suspension model 666
- magnitude of sinusoidal signal 386
- magnitude axis 428
- magnitude plot 48, 393
- manipulated variable 104
- manufacturing systems 135
- mass and spring system model, state variable model 699
- matrices
 - determinant 687
 - diagonal eigenvalue matrix 688
 - inverse 686
 - inverse (2×2), formula 687
 - inverse ($n \times n$) formula 687
 - MATLAB eig command 689
 - MATLAB inv command 687
 - multiplication 684
 - compatibility 685
 - postmultiplication 687
 - premultiplication 686
 - unity matrix 686
- maximum peak value, y_{\max} 228
- M-contours 508
- mechanical system, state variables 622
- MIMO 104
- model
 - conveying system 137
 - earthquake disturbance on building 190
 - fan pressure system 601, 610
 - feeder tank simulation 254
 - first order with time delay 341
 - industrial furnace 279
 - liquid level 112
 - motor 332
 - RC circuit 159
 - shaker table 124
 - trailer suspension 174
- model parameters K and τ 158
- modelling 103, 109
- modified derivative term 546
- multivariable system 624
- natural frequency, ω_n 176, 179, 232
- N-contours 509
- negative feedback 200
- negative gain 557
- negative step 154
- Nichols chart 395, 505
- Nichols chart design
 - bandwidth specification 523
 - gain margin specification 517, 520
 - M_p specification 522
 - phase margin specification 518, 521
- Nichols plot 394, 507
- nominal linear model 664
- non-interacting form, PID 554
- nonlinear model, magnetic suspension 666
- nonlinear system 41, 154, 538, 660, 662
- non-minimum phase 369
- numerator polynomial 27, 243
- numerical approximations 567
- Nyquist plot 395

- observers 732
- on-off control 578
- on-off relay 605, 607
- open loop system 197
- operating points 664
- optical encoder 136
- optimal control 732
- oscillation 174
- oscillatory system 251
- output disturbances 203
- output feedback control 713
 - closed loop analysis 714
 - closed loop pole polynomial 716
 - closed loop system matrix 715
 - reference gain matrix 715
 - two-degrees-of-freedom output control law 713, 722
- output matrix, C 628, 712
- overdamped 178, 253

- Padé approximation 168
- parallel form, PID control 531
- parameter (frequency) dependent
 - complex numbers 24
- parameter Root Locus 370
- partial fractions 44
- PD control
 - P on error, D on measured variable 335
 - procedure for type 1 model 336
 - textbook form 333
- peak disturbance, D_{peak} 234
- percent overshoot, OS(%) 228, 232
- phase axis 428
- phase calculation 386, 428, 437
- phase crossover frequency 405, 607
- phase graphs 401
- phase lag lead, summary 500
- phase margin
 - advantages/disadvantages, table 614
 - Bode 415

- example 610
- Nichols 416
- Nyquist 417
- PID tuning 609
- phase plot 48, 393
- phase shift 389
- phase-lag controller 482, 486
 - as integral controller 486
 - design example 489
 - design procedure 488
 - properties 482
- phase-lead controller 482
 - as derivative controller 493
 - controller 491
 - design example 496
 - design procedure 494
 - properties 483
- physical realisability 43
- PI control, design example 477
- PI control of first order model 327
 - general analysis 327
 - procedure (design) 329
 - steady state offset, specification 327
 - transient specification 328
- PID control 11
 - damped oscillation method 600
 - decoupled form 315
 - digital formula, summary table 570
 - Laplace domain formula 314, 531
 - manual tuning 318
 - manual tuning procedure 318
 - non-interacting form 554
 - parallel form 315, 531
 - pole-placement 340
 - pole-placement procedure 343
 - relay experiment 605
 - sustained oscillation method 592
 - term selection chart 483
 - textbook and industrial forms, summary 532
 - textbook form 314, 531
 - textbook form 531
 - time domain formula 531
 - time-constant form 531
 - Ziegler and Nichols rule base 586
- PID control terms, effects of, summary table 314
- PID controller family
 - Laplace domain formula 314
 - summary table 314
 - time domain formula 314
- PID industrial forms, summary table 555
- PID tuning
 - diagram 537
 - rule-based 579
 - SCADA interface 537
- pole-placement 340
 - design specification 343
- pole-placement design, state variable model 717
- poles 27, **243**
 - finding 245
 - link to system eigenvalues 691
 - on $j\omega$ axis 268
 - open loop and closed loop 259
 - pole-zero conservation 354
 - pole-zero map 245
 - second order poles 249
- process 106
- process controller unit
 - description 535
 - diagram 536
- process reaction curve
 - advantages/disadvantages, table 592
 - procedure 584
- proportional and derivative control 300
 - Laplace domain formula 300
 - time domain formula 300
- proportional band 533
 - formula 534
 - relationship with proportional gain 534
 - table of values 534
- proportional control 278, **282**
 - closed loop analysis 282
 - closed loop stability 283
 - design example, with lag term 471
 - disturbance rejection 286
 - disturbance time response 287
 - final value theorem 285
 - first order system analysis 283
 - Laplace domain formula 282
 - reference tracking 285
 - summary table 290
 - time domain formula 282
- proportional control of first order model 321
 - disturbance rejection 323
 - reference tracking 323
 - steady state offset, disturbance rejection 324
 - steady state offset, reference tracking 324
- proportional control of type 1 model 332
 - disturbance rejection 333
 - reference tracking 333
- proportional gain 531, 579
- proportional kick 338, 476, 547
- proportional term
 - digital form 568
 - incremental form 572
- quadratic equations 23
- quarter amplitude display 600
- rate of change equation 39, 559
- rate of change variables, for state variables 622
- RC circuit, model 159
- reference signal 200, 279
- reference tracking performance 279, 280, 293
 - derivative control 302
- regulator design 280
- relay experiment 605
 - PID rule-base 609
 - procedure 608
- reverse-acting controllers 556
 - PI control 562
- right half plane (RHP) 244
- rise-time, t_r 230
- robust control 733
- roll-off rate 400, 472
- root locus
 - adding a pole 366
 - adding a zero 365
 - asymptotes 359, 360
 - branch 359, 360
 - breakaway points 360
 - closed loop poles 356
 - MATLAB investigations 357
 - poles and dynamic response 352
 - rules 360
- rotational system 137
- sampled data values 565
- sampling 565
- sampling, notation 567
- saturation characteristic 538, 539
- SCADA system 530
- scaling, input scaling 472
- second order differential equations 183
- sensitivity, magnitude plot 464
- sensitivity transfer function **461, 210**
- servo-control design 280
- setpoint 200
- settling time, t_s 229

- disturbance input 235
- shaft encoder 138
- Shaker table model
 - actuator 129
 - complete block diagram 131
 - process 124
 - Simulink model 131
 - transducer 127
- ship autopilot design, control
 - problems 10–11
- ship steering system, state variable model 693
- signal 103
- signal equations 222
- signal take-off 201
- single degree of freedom
 - controller 713
- sinusoidal signal 386
- SISO 103, 112
- sketching table, Bode plot 439
- small change model 668
- span, transducer 108
- specification 414
- speed of response 163
- spring element 124, 175
- square systems 712
- stability, eigenvalue condition 692
- stable system 268
- start-up procedure 560
- state 621
- state space to transfer function, Laplace analysis 691
- state variable 621
 - inputs 712
 - outputs 712
- state variable block diagram 629
- state variable feedback 722
 - closed loop analysis 723
 - closed loop system matrix 724
 - reference controller 724
- two-degrees-of-freedom state control law 722
- state variable model, procedure for defining 624
- state variable notation 623
- state variable system model
 - eigenvalue and system dynamics 697
 - non-uniqueness 696
- state vector 622
- state-feedback design freedom 723
- state-space icon, MATLAB 630
- state-space to transfer function 643
 - example 644
 - general analysis 643
 - ss2tf, MATLAB command 645
- steady state 148, 151, 158, 220
- steady state
 - design specification 223
 - performance 221
 - specification 473
- steady state conditions 666
- steady state error, e_{ss} 221
- steady state output, y_{ss} 151
- steam boiler example 621
- stem position 118
- step response 151
 - second order examples 187
- step response tests, example 315
- s-terms, magnitude and phase 437
- stiffness constant 126
- summation symbol 105
- supply disturbance 581
- sustained oscillation
 - advantages/disadvantages, table 599
 - basic principles 593
 - Bode plots 593
 - gain margin 594
 - Nyquist plot 593
 - procedure 594
 - time response plot 593
 - tuning rules, PID 595
 - ultimate gain 594
- system gain, K 151, 152, 176, 177, 387, 456
 - dimensional units 115
 - units 104
- system identification 582, 733
- system matrix, \mathbf{A} 628, 712
- system matrices 624
- system overshoot 227
- system stability 243, 267, 412
 - Nichols 518
- system type 332
- tank level system, control specification 317
- tank system
 - model 39
 - transfer function 40
- Taylor series 667
- temperature model, with deadtime 165
- thermistor, nonlinear equation 662
- time constant, τ 151, 152, 158, 582
 - relation to system pole 248
- time delay 165, 368
- time domain specifications 317
- time-constant form, PID control 531
- torque 137
- trailer suspension model 174
- trailer suspension system
 - state variable model 624
- transducer 107
 - level 114
 - pressure measurement 111
- transfer function 22
- transfer function components 434
 - magnitude and phase 436
- transfer function representation
 - gain-time constant form 162
 - general polynomial form 181
 - pole-zero form 162
 - unity constant coefficient form 181
 - unity s^2 coefficient form 181
- transfer function to state space 647
 - companion form 648
 - general analysis 650
 - phase variable 648
 - tf2ss, MATLAB command 653
- transient 148, 220
- transient performance 226
- transport delay 165
- two degrees of freedom controller 713
- unbounded signal 412, 265
 - table of 266
- underdamped 178, 251
- underdamped system, frequency response 451
- unity constant coefficient form 181
- unity feedback system 207
- unity s^2 coefficient form 181
- unstable closed loop 7
- unstable system, test by eigenvalues 696
- valve 112, 118
- viscous friction constant 125
- wastewater treatment plant, description 4–6
- wind turbine systems, description 3–4
- working regions 664
- zeros 27, 243
 - at infinity 354
 - blocking zeros 259
 - finding 245
 - how do they arise? 253

750 Index

- in RHP 256, 368
- open loop and closed loop 260
- origin of zeros 253
- Ziegler and Nichols rule base
586



MATLAB and Simulink index

- command history 53, 69
- command window 53, 54
- constants 59
- current directory 53, 69
- functions 59
 - as M-files 72
- graph, co-ordinate finding 62
- help command 60
- help window 60, 70
- house heating system
 - comparator 84
 - setpoint 85
 - thermostat block 90
- house model **86**
 - disturbances 88
 - first order differential equation 87
 - first order dynamics 88
 - rate of change equation 87
 - system gain 88
 - time constant 88
- labels on plots, axes 62
- launch pad 53, 68
- MATLAB commands, table 78
- matrices
 - data entry 58
 - inverse 59
 - power 59
 - product 59
 - sum 59
 - transpose 59
- M-files 70
 - types 71
- multiple plots 62
- operations 55
- plotting, MATLAB 61
- polynomials
 - convolution 58
 - data entry 57
 - deconvolution 58
 - divide 58
 - manipulations 58
 - multiply 58
- running MATLAB 53
- Simulink
 - connecting blocks 95
 - continuous library 92
 - data input 95
- icon
 - constant 94
 - gain 94
 - relay 96
 - scope 94
 - sum 94
 - transfer function 94
- library browser 84
- model construction procedure 91
- parameters command 96
- scope 91
 - simulation command 96
- SISO design tool 75
- state-space icon 630
- time responses, commands 66
- transfer function input 64
- transfer function manipulation 65
- vectors 55
 - column 55
 - manipulations 56
 - row 55
 - size of 55
- workspace 53, 68

MATLAB command index

There is a table of MATLAB commands on p. 78

- bode 431
- clear 61
- eig 689
- feedback 67, 212
- figure 62
- freqresp 430
- ginput 62
- hold on 62
- inv 687
- ngrid 511
- nichols 511
 - ngrid 511
- pade 168
- plot 61
- pole 66
- pzmap 66
- rlocus 375
- rltool 75, 363, 375, 432
- semilogx 63
- ss2tf 645
- step 66
- tf2ss 653
- variable, ans 61
- who 61
- zero 66

