Index

Note: Page numbers followed by *f* indicate figures and *t* indicate tables.

A

absolute encoders, 31, 32, 33*f*
absolute pressure, 40
accumulated value. *See* counters
accuracy, sensor, 23, 81–82
  thermocouples, 82
AC input units, 80, 80*f*
ACK signals, 97
AC motors, 49
actions, in SFC, 165–167, 166*f*, 166*t*
actuators, 43. *See also* output devices
ADCs (analog-to-digital converters), 81, 81*f*
addition
  of binary numbers, 68, 70
    floating point numbers, 71
  of data in data registers, 284–285
  in structured text (ST), 168*t*
ALARM, 103
alarm system example, 199*f*
Allen-Bradley
  ControlNet network, 105
  Data Highway network (Allen-Bradley), 100, 106
  PLC-5 system, 13–15, 20, 104–105, 108
    example (bundle cutting saw), 314–335
Allen-Bradley ladder diagrams
  addition operation, 285*f*
  battery-backed relay circuits, 192
  conditional jumps, 216*f*
  counters, 248*f*, 250*f*
    timers with, 252–254, 254*f*
    up-down counters, 253*f*
  data movement, 281*f*
  greater-than comparison, 282*f*
  latch and unlock functions, 196*f*
  master control relays, 201, 201*f*
  notation for, 119, 120*f*
  off-delay timers (TOF), 231, 231*f*, 232*f*
  on-delay timers (TON), 226–228, 227*f*
  one-shot operation, 193*f*
  retentive timers (RTO), 234, 234*f*
  sequencers, 256–258, 257*t*, 258*f*
  shift registers, 272*f*
  subroutines, 218, 218*f*
alphanumeric characters, codes for. *See* ASCII codes
amplifying voltage levels, 86–87, 87*f*, 344*f*
  op-amp comparators, 88–89
analog devices, defined, 8
analog I/O modules, 14
analog signals, 79, 81
  as output, 84, 85
  signal conditioning, 85–89
    changing voltage levels, 86–88, 88*f*
    op-amp comparators, 88–89
    output protection, 89
  standard, 86, 86*f*
analog-to-digital converters (ADCs), 81, 81*f*, 82
AND logic gates, 120–121, 121*f*, 132*f*
  functional blocks, 133*f*
  instruction lists, 157*f*
  instruction lists for, 153*f*
AND operation
  algebra with, 135
  in structured text (ST), 168*t*
angular position sensors. *See* resistive linear and angular position sensors
Apple Firewire bus, 94
application development. *See* program development
application layer (ISO/OSI model), 102
applications of control systems, 53–56. *See also* programs, specific
application storage, 313
architecture of PLCs, 9–11, 10*f*
  central processing unit (CPU), 7, 9, 12, 79
arithmetic functions, 284–285
  operations, 284–285
arithmetic with binary numbers, 68–71
  floating point numbers, 70–71
  one's and two's complements, 69–70
armature (DC motors), 46–48
ASCII codes, 98
  examples of, 98*t*
assembler, 115
assembly language, 115
assignment statements (ST), 167–168
ATN line (IEEE-488), 95, 96*t*

authoring documentation for PLC systems, 313–335
automation tasks, 7
auxiliary relays. *See* internal relays

B

barrier for car park (example), 352–356
base (floating point numbers), 71
baseband, 104
basic relay, 1–3, 2*f*
battery-backed relays, 192, 193*f*
battery failure, 313
baud rates, 92–93
BCD format, 66–67, 280
  examples of numbers in, 67*t*
bellows-type pressure sensors, 40
bimetal element, 33–34, 34*f*
bimetallic thermostat, 341, 342*f*
binary coded decimal (BCD) format, 66–67, 280
  examples of numbers in, 67*t*
binary systems, 63, 64, 69, 279
  arithmetic of, 68–71
    floating point numbers, 70–71
    one's and two's complements, 69–70
    signed and unsigned numbers, 69
  conversion to/from denary system, 64
  conversion to/from hexadecimal system, 66
  conversion to/from octal system, 65
  examples of numbers in, 67*t*
binary words, 9. *See also* bits (data)
bipolar motors, 52–53
bistables, 73
8-bit registers, 267
bits (data), 9, 64, 108, 267, 279–280
  parity checks, 97
  shift registers. *See* shift registers
  sign bit, 69
  tokens, 99
  words, 9, 71–72, 81, 279
bit storage. *See* internal relays; memory; shift registers
Boolean algebra, 135–138
Boolean logic, 120–126
  AND logic, 120–121
  NAND logic, 124–125
  NOR logic, 125
  NOT logic, 123–124
  OR logic, 121–123
  in structured text (ST), 168*t*, 380
  truth tables. *See* truth tables
  XOR (exclusive OR) logic, 126
Boolean type data, 72
BOOLs (Boolean type data), 72
Bosch CAN bus, 94
bottle packing program (example), 358–364
bounce, with mechanical switches, 26–27
box systems. *See* brick (single-box) systems
branching
  IL (instruction lists), 155–158
  SFCs (sequential function charts), 163–165
brick (single-box) systems, 12
  I/O addresses, 108
broadband, 104
brushless DC motors, 48–49
built-in switch, 27, 28*f*
Bundle Cutting Saw documentation (example), 314–335
buses
  for parallel communications, 94–95
  for serial communications, 91, 93
bus networks, 99, 99*f*, 100
bytes, 108

C

CAN bus, 94
  DeviceNet network, 105–106
capacitive displacement sensors, 38
capacitive proximity sensors, 43
capacitive proximity switches, 29*f*, 38*f*
car park barrier operation (example), 352–356
carrier sense multiple access (CSMA), 100
carrier sense multiple access with collision detection (CSMA/CD), 100, 102
cascaded timers, 229*f*
cascaded TON timers, 228–229
CASE statement, in ST, 170–171
center roller lever, 28
central heating system (example), 344
central processing unit (CPU), 7, 9, 12, 79
chassis, for mounting modules, 13–15
checking PLC software, 306
circuit diagrams versus ladder diagrams, 116
CJP (conditional jumps). *See* jump instruction
clocked D latch, 73–74, 74*f*, 74*t*
clocked JK flip-flops, 75, 75*f*
clocked SR latches, 74–75, 74*f*, 75*t*
closed loop control, 285–289, 286*f*
  modes of control, 286–288
coaxial cables, 90
coils. *See* internal relays
collision, data, 100
combinational logic systems, 63, 72–73
combined modes (closed loop control), 287*f*, 288
commercial I/O systems, examples of, 103–106
commissioning of PLC systems, 304–308
  simulation, 307–308
  software-checking, 306
  testing inputs and outputs, 305–306
common voltage supply, 85, 85*f*
communication modules, 15
communications interface of PLCs, 8
  model for, 8*f*
communications paths. *See* buses
communications systems. *See* I/O processing
comparing data, 282–283
computers versus PLCs, 6–7
computer touch pads, 30

conditional jumps. *See* jump instruction
conditional statements
in pseudocode, 296, 297*f*
in ST, 169–171, 380
condition sensors, 43
CONNECT, 103
constants, defining in ST, 173
contactors, 44
continuous updating, 106
control circuit, 2*f*
control drawing, relay-controlled systems, 3–4, 3*f*
Controller Area Network (CAN) bus, 94
DeviceNet network, 105–106
controller module, 13
controllers
in distributed networking systems, 100
for parallel communications, 94
ControlNet network, 105
control system applications, 53–56. *See also* programs, specific
control systems design. *See* designing PLC systems
control task and input sensors, 1, 2*f*
convergence, with SFC, 163–165, 164*f*
conveyor belts, 53, 53*f*
counters with, 249
full example program, 357–364
bottle packing, 358–364
OR gates with, 123
packages on, detection of, 55–56
tracking items with shift registers, 270–272, 274*f*
count-down underflow (UN) bit, 249
counters, 245–266
forms of, 245
sequencers, 254–258
timers with, 252–254, 254*f*
up-down counters, 251, 253*f*, 376–377
count-up overflow (OV) bit, 249
CPU (central processing unit), 7, 9, 12, 79
cross roller plunger, 28
CSMA (carrier sense multiple access), 100
CSMA/CD (carrier sense multiple access with collision detection), 100, 102
CTD. *See* down-counters
CTS (clear-to-send) signal, 97
CTU. *See* up-counters
current sinking. *See* sinking
current sourcing. *See* sourcing
cycles, PLC, 106
in ladder diagrams, 117
one-shot operation, 193–194
cycle times, PLCs, 107, 108
cyclic movement, piston in cylinder (example), 347–348
cyclic redundancy check (CRC) codes, 98
cylinders, 46, 46*f*, 47*f*

D

DACs (digital-to-analog converters), 84*f*
Darlington pairs, 31
data, 71–72
collisions of (in networking), 100
parallel communications, 90–91, 94–95, 109
parity checks, 97
serial communications, 90–94, 109
data communications. *See* I/O processing
data handling, 279–294
arithmetic functions, 284–285
operations, 284–285
closed loop control, 285–289, 286*f*
data comparisons, 282–283
data movement, 280–281
data selection, 283
Data Highway network (Allen-Bradley), 100, 106
data link layer (ISO/OSI model), 101
data types, defining in ST, 172
DAV line (IEEE-488), 95, 95*f*, 96*t*
D4CC miniature limit switches, 28
DC input units, 80, 80*f*
DC motors, 46–48, 48*f*
dead band, 346
debug mode (Telemecanique), 307
decimal system. *See* denary system
delay-on timers. *See* on-delay timers (TON)
denary system, 63, 280
binary coded decimal (BCD) format, 66–67, 280
examples of numbers in, 67*t*
conversion to/from BCD system, 67
conversion to/from binary system, 64
conversion to/from hexadecimal system, 66
conversion to/from octal system, 65
examples of numbers in, 67*t*
fixed point numbers, 70–71
floating point numbers, 70–71
two's complements, 70*t*
derivative action time, 288
derivative mode (closed loop control), 287*f*, 288
designing PLC systems, 295–340. *See also* program development
desktop consoles, 19
detecting faults. *See* fault finding
DeviceNet network, 105–106
D flip-flop, 26–27, 27*f*
diagnostics. *See* fault finding
diaphragm-type pressure sensors, 40
differential amplifiers, 87, 87*f*
digital devices, defined, 8
digital I/O modules, 14
digital signals, 9
converting to/from analog, 81, 81*f*, 82, 84*f*
defined, 8, 79
levels of, 10–11, 79
paths for. *See* buses
sensors for, 23
digital systems, 63–78
binary system. *See* binary systems
combinational logic systems, 63, 72–73
data. *See* data
sequential logic systems, 63, 73–75

www.newnespress.com

digital-to-analog converters (DACs), 84*f*
DINTs (double-integer numbers), 71–72
directional control
  motors, 48, 48*f*
  valves, 44–46, 45*f*, 46*f*
discrete signals, defined, 79. *See also* digital signals, defined
displacement sensors, 37–38
distributed networking systems, 100
division, in structured text (ST), 168*t*, 169
division operation, 284–285
D latch, 73–74, 74*f*, 74*t*
documentation of PLC systems, 313–335
door monitoring, 303
double-acting cylinders, 46, 46*f*, 47*f*
double-integer numbers (DINTs), 71–72
down-counters, 245, 246*f*, 376–377
  up-down counters, 251, 253*f*, 376–377
drift, 25
drinks machine, 367
  FBD program, 367, 367*f*
  ladder program, 367, 368*f*
drum sequencers, 254–258
D101 to D108 lines (IEEE-488), 96*t*
D-type connectors, 91, 92*f*
dual-channel emergency stop relays, 302–303

E

eddy current proximity switches, 29, 29*f*
electrical conductor, 30
emergency stop relays, 302–303, 304
emergency stop switches, 141, 141*f*, 302–303
EMF protection, 89
encoders, 31–33
ENQ/ACK protocol, 97
ENQ signals, 97
entering programs, 129–130
  ladder symbols, 130
EOI line (IEEE-488), 96*t*
EPROM (erasable and programming read-only memory), 13, 14*t*, 15*t*, 313
  with smart sensors, 42
equal-to comparison, 282
erasable and programming read-only memory (EPROM), 13, 14*t*, 15*t*, 313
  with smart sensors, 42
error-checking in communications, 97, 98
  serial communications, 91
error, sensor, 23, 24*f*
error signal, reacting to. *See* closed loop control
Ethernet, 104–105
exclusive OR. *See* XOR logic gates
expected value checks, 311
exponent (floating point numbers), 71
external relays, 187–188

F

factory-floor networks, 106
fail-safe systems, 300
fan heater, 367–369, 369*f*, 370*f*
fault finding, 308–313
  detection techniques, 308–312
  program storage, 313
FBDs. *See* function block diagrams (FBDs)
fiber-optic cabling, 90
fibre optic sensors, 43
field coils, 46–48
Firewire bus, 94
fixed point numbers, 70–71
flags (serial communication bits), 92–93. *See also* internal relays
flashing light with timers (example), 235, 235*f*
flip-flops, 73, 75, 75*f*, 194–198, 198*f*
floating point numbers, 70–71, 72
flowcharts, for program development, 295–298, 296*f*
flow controls for serial communications, 91
fluid flow meters, 41
flyback diodes, 89
force sensor, strain gauge as, 39–40
forcing, for testing inputs and outputs, 305–306, 305*f*
FOR...DO iteration, in ST, 171, 380
forms, controller, 1–3
full graphic form, ladder diagrams, 118–119
function block diagrams (FBDs), 130–138, 130*f*, 134*f*
  basic diagramming symbols, 131*f*
  example programs, 138–141
  logic gate blocks, 133*f*
function blocks
  in ST, 173–174
  symbols for, 376–377
function boxes, 218–220, 219*f*

G

gauge factor, 39
gauge pressure, 40
GEM-80 PLC, 108
General Electric GENET network, 100
General-Purpose Instrument Bus, 94
GENET network (General Electric), 100
GND line (IEEE-488), 96*t*
Grafset language, 163
Gray code, 33
greater-than comparison, 282
greater-than-or-equal-to comparison, 282

H

handheld programming devices, 19
handshaking, 94, 97*f*
hardware of PLCs, 7–8
Hewlett-Packard Instrumentation Bus, 94
hexadecimal system, 1–3, 64–65, 66
  examples of numbers in, 67*t*
hierarchies of communications, 100, 100*f*
high-level languages, 115
high sensitive roller plunger, 28

www.newnespress.com

holding torque (stepper motors), 51
host networks, 99
hybrid stepper motors, 51
hysteresis error, 23, 24*f*

I

I^{2}C bus, 94
IEC 61131 standard, 17–18, 103
IEC 61131-1 standard
  timers, 226*f*
IEC 61131-1 standard
  sequential function chart, 163
IEC 61131-3 programming languages, 17
IEC 61131-3 standard
  counters, 246*f*
  PID control function, 289*f*
  shift registers, 272*f*
IEC 61131-3 standard, 379
  for battery-backed relay circuits, 193*f*
  for function block diagrams, 130
  for instruction lists (IL), 151, 152*t*, 157
  for ladder diagrams, 118–119
  one-shot operation, 194*f*
IEC 61131-5 standard, 18
IEC 61508 standard, 299–300
IEEE-488 bus, 94, 95*f*, 96*t*
IEEE Project 802, 102
IEEE 802.3 standard, 102
IEEE 802.4 standard, 102
IEEE 1451.4 standard, 43
IFC line (IEEE-488), 96*t*
IF statement, in ST, 169, 380
IL (instruction lists), 151–159
  branch codes, 155–158
  code mnemonics, 152*t*
  multiple rungs, 158
  programming examples, 159
increment encoders, 31, 32*f*
individual voltage supply, 85, 85*f*
inductive proximity sensors, 43
inductive proximity switches, 30
inductors, output protection, 89
initial values, defining in ST, 173
input devices, 23–43
  encoders, 31–33
  fluid flow meters, 41
  liquid-level detectors, 28, 41
  monitoring system, 55, 55*f*
  mechanical switches, 26–28, 26*f*
    ladder diagram for (example), 116, 116*f*
  position/displacement sensors, 37–38
  pressure sensors, 40–41
    strain gauges as, 39–40
  proximity switches, 29–30
  sensors ranges, 43
  smart sensors, 42–43
  strain gauges, 38–40
    differential amplifiers with, 87, 88, 88*f*
  temperature sensors, 33–37, 283
  testing, 305
  ultrasonic proximity sensors, 42
input levels, 10–11, 79
input/output units, 9–11, 12, 79–85
inputs
  arithmetic operations on, 284–285
  internal relays with multiple input conditions, 188–190
  to I/O processing, 106–108
  in ladder diagrams, 117, 128*f*
  sourcing and sinking, 11, 79–80, 80*f*
  testing (program development), 305–306
input section of PLCs, 8
instruction lists. *See* IL (instruction lists)
integers (INTs), 71–72
integral action time, 288
integral mode (closed loop control), 287*f*, 288
integrated chip as temperature sensor, 342–343
Inter-IC Communication (I^{2}C) bus, 94
internal architecture of PLCs, 9–11, 10*f*
  central processing unit (CPU), 7, 9, 12, 79
internal relays, 187–214, 188*f*
  battery-backed, 192, 193*f*
  with ladder programs, 188–192
    latching programs, 190–191
    multiple input conditions, 188–190
    response time, 191–192
  master control relays, 199–204
  one-shot operation, 193–194, 193*f*
    set-reset function for, 197–198
  set and reset functions, 194–198. *See also* flip-flops
    program examples, 198
  shift registers. *See* shift registers
inverters. *See* NOT logic gates
inverting amplifiers, 86–87
I/O addresses, 108
I/O modules, 14
I/O processing, 79–114
  commercial systems, examples of, 103–106
  input/output units, 9–11, 12, 79–85
  inputs, 106–108
  networks, 99–103
    distributed systems, 100
    standards for, 101–103
  remote connections, 89–98, 89*f*, 90*f*
  signal conditioning, 85–89
    changing voltage levels, 86–88, 88*f*
    op-amp comparators, 88–89
    output protection, 89
ISO/OSI model, 101, 101*f*
iteration statements, in ST, 171–172, 380

J

JK flip-flops, 75, 75*f*
jump instruction, 215–217, 216*f*
  jumps within jumps, 216–217, 217*f*
  subroutines, 217–220
    function boxes, 218–220

L

LAD. *See* ladder programming (LAD) and ladder diagrams
ladder programming (LAD) and ladder diagrams, 20, 115–119, 116*f*, 134*f*. *See also* specific company for ladder diagram standards (e.g., Siemens)
  arithmetic operations, 18

www.newnespress.com

ladder programming (LAD) and ladder diagrams *(Continued)*
basic diagramming symbols, 118–119, 118*f*, 375
diagramming conventions, 117–118
electrical wiring diagrams, 20
entering programs, 129–130
example programs, 138–141
function block diagrams, 18
inputs in, 117, 128*f*
instruction lists and, 152*t*, 153–155. *See also* IL (instruction lists), multiple rungs
multiple rungs, 158
internal relays, 188–192
latching programs, 190–191
multiple input conditions, 188–190
response time, 191–192
jumping over. *See* jump instruction
latching relays, 127*f*
logic of. *See* logic systems (logic gates)
master control relays, 200*f*, 204*f*, 205*f*
outputs in, 117, 127–129, 128*f*
SET and RESET coils, 195
SFCs (sequential function charts), 18, 162*f*, 165*f*
structured text (ST), 18
structured text (ST) versus, 174
writing pseudocode and translating
conditional flow, 297, 297*f*
loops, 298, 299*f*, 300*f*
sequences, 296
ladder symbols, 130
last cylinder action, diagnostic program for, 312*f*
last output set (fault detection technique), 309, 310*f*
latches, 73–75
latching relays, 44, 127
internal relays for, 190–191
layers of ISO/OSI model, 101–103
least significant bit (LSB), 64
less-than comparison, 282
less-than-or-equal-to comparison, 282
lifts, 53
light curtains, 304
light-emitting diodes (LEDs), 31
limit sensors, 43
limit switches, 27
linear positioning with stepping motors, 49, 49*f*
linear position sensors. *See* resistive linear and angular position sensors
linear potentiometers, 37
linear variable differential transformers (LVDTs), 37–38, 38*f*
liquid-level detectors, 28, 41
monitoring system, 55, 55*f*
liquid-level switches, 28
listeners (parallel communications), 94
LLC (Logical Link Control) layer, 102
LM3911N circuit, 36*f*
LM35 package, 36*f*
loading system example, 199*f*
local area networks (LANs), 99
Logical Link Control (LLC) layer, 102
logical variables, 73
logic systems (logic gates), 63, 73, 120–126, 377–378
Boolean algebra, 135–138
combinational, 63, 72–73
example programs, 138–141
in function block diagrams, 130–134
AND logic, 120–121, 121*f*, 132*f*
functional blocks, 133*f*
instruction lists, 157*f*
instruction lists for, 153*f*
NAND logic, 26–27, 27*f*, 123–124, 124*f*, 132*f*
instruction lists for, 155*f*
NOR logic, 125, 125*f*, 132*f*
functional blocks, 133*f*
instruction lists for, 154*f*
NOT logic, 123–124, 123*f*, 132*f*
OR logic, 121–123, 122*f*, 132*f*
functional blocks, 133*f*
instruction lists for, 154*f*
sequential, 63, 73–75
symbols for, 132*f*
XOR (exclusive OR) logic, 126, 126*f*, 132*f*
functional blocks, 133*f*
instruction lists for, 155–158
long real numbers (LREALs), 72
loop statements
in pseudocode, 298, 299*f*, 300*f*
in ST, 171–172
LREAL data (long real numbers), 72
LSB (least significant bit), 64
LVDTs (linear variable differential transformers), 37–38, 38*f*

M

machine code, 115
machine interlock system, 72, 72*f*
machine language, 129
MAC (Media Access Control) layer, 102
20 mA loops, 94
mantissa, 71
manufacturing automation protocol (MAP), 103–104, 104*t*
Manufacturing Message Service (MMS), 104
MAP (manufacturing automation protocol), 103–104, 104*t*
markers. *See* internal relays
mass I/O copying, 106–107
master control relays (MCRs), 199–204, 200*f*
ladder programs for, 200*f*, 204*f*, 205*f*
multiple, 202–203
program examples, 203–204
master networks, 99
math, binary. *See* arithmetic with binary numbers
maximum value, selecting, 284*f*
MCR. *See* master control relays (MCRs)
measurement error (sensors), 23
mechanical switches, 26–28, 26*f*
ladder diagram for (example), 116, 116*f*

Media Access Control (MAC) layer, 102
MELSEC FX3U compact PLC (Mitsubishi), 13, 13*f*, 108
MelsecNET network (Mitsubishi), 100
MELSOFT language, 19
memory
  for data bits. *See* registers
  program storage, 313
memory box, 196
memory unit, 8
  storage capacity of, 9
metal resistance strain gauges, 38, 39*f*
microprocessor-controlled systems, 4–5. *See also* programmable logic controllers
minimum value, selecting, 284*f*
Mitsubishi
  MELSEC FX3U compact PLC, 13, 13*f*, 108
  MelsecNET network, 100
  MELSOFT language, 19
  monitor mode, 307
Mitsubishi ladder diagrams
  battery-backed relay circuits, 192
  conditional jumps, 216*f*
  conveyor belt control program (example), 362–363
  counters, 255*t*
  data movement, 281*f*
  greater-than comparison, 282*f*
  instruction code mnemonics, 152*t*
    AND gates, 153*f*, 157*f*
    NAND gates, 155*f*
    NOR gates, 154*f*
    OR gates, 154*f*
    XOR gates, 156*f*
  internal relays with multiple input conditions, 189*f*
  master control relays, 200
  notation for, 119
  on-delay timers (TON), 226–228, 227*f*
  one-shot operation, 193*f*
  shift registers, 268, 269, 270*f*
  subroutines, 217–218, 218*f*
  valve sequencing program (example), 349–352
    car barrier program, 354*f*
    inputs and outputs, 356
mixing process control program (example), 364–366
MMS (Manufacturing Message Service), 104
mobile phone touch screens, 30
modular (rack) systems, 13, 16*f*, 81
  I/O addresses, 108
monitoring systems
  liquid-level detectors, 55, 55*f*
  protected door monitoring, 303
monitor mode (Mitsubishi), 307
most significant bit (MSB), 64
  sign bit, 69
Motorola MPX100AP sensor, 25–26, 40
motors, 46–49
  in distributed networking systems, 100
  output protection, 89
  stepper motors, 49–53, 49*f*
  stop switch locations, 140–141
  timers with (examples), 228, 229*f*, 235, 237*f*
  unipolar versus bipolar, 52–53
moving data between locations, 280–281
MPX100AP sensor (Motorola), 25–26, 40
MSB (most significant bit), 64
  sign bit, 69
multiplexers, 81, 81*f*
multiplication operation, 284–285
MX100AP pressure sensor, 25–26

N

NAND logic gates, 26–27, 27*f*, 124–125, 124*f*, 132*f*
  instruction lists for, 155*f*
NC switches, 26
  in ladder diagrams, 118
NDAC line (IEEE-488), 95, 95*f*, 96*t*
negated input, in function block diagrams, 131*f*
negative binary numbers. *See* signed binary numbers
negative transition-sensing coils, 194, 194*f*
nested jumps, 216–217, 217*f*
network layer (ISO/OSI model), 101
networks, 99–103
  distributed systems, 100
  standards for, 101–103
noninverting amplifiers, 87
nonlinearity error, 23, 24*f*
nonvolatile memory, 42
NOR logic gates, 125, 125*f*, 132*f*
  functional blocks, 133*f*
  instruction lists for, 154*f*
normally closed (NC) contacts, 3–4, 43–44
normally closed (NC) switches, 26
  in ladder diagrams, 118
normally open (NO) contacts, 3–4, 43–44
normally open (NO) switches, 26
  in ladder diagrams, 118
NO switches, 26
  in ladder diagrams, 118
NOTIFY, 103
NOT logic gates, 123–124, 123*f*, 132*f*
NOT operation
  algebra with, 135
  in structured text (ST), 168*t*
NRFD line (IEEE-488), 95, 95*f*, 96*t*
NTC semiconductors, 35, 35*f*
number systems. *See* binary systems; denary system; hexadecimal system; octal system

O

octal system, 64–65
  examples of numbers in, 67*t*
off-delay timers (TOF), 225, 226*f*, 231–232
Omron
  CP1L, 12*f*
  IL code mnemonics, 152*t*
Omron E4C-DS30 ultrasonic proximity sensor, 42
Omron E4C-DS80 ultrasonic proximity sensor, 42
Omron E4C-DS100 ultrasonic proximity sensor, 42

www.newnespress.com

Omron E2F sensor, 30
Omron E2K-X capacitive sensor, 30
Omron Industrial Automation, 28
Omron sensors, 42
on-delay timers (TON), 225, 226–230, 226*f*, 376–377
  cascaded, 228–229
  creating off-delay timers with, 231, 231*f*
  on/off cycle timers, 230, 230*f*
  sequencing, 228
one's complement, 69–70
one-shot operation, 193–194
  set-reset function for, 197–198
on/off cycle timers, 230, 230*f*
on-off mode (closed loop control), 286, 287*f*
on/off temperature control (example), 346
op-amp comparators, 88–89
open systems interconnection (OSI). *See* ISO/OSI model
operational amplifier. *See* amplifying voltage levels
operations, arithmetic, 284–285
operators, structured text (ST), 168*t*, 379–380
optoisolators (optocouplers), 9, 10, 10*f*, 80
orifice flow meters, 41, 42*f*
OR logic gates, 121–123, 122*f*, 132*f*
  functional blocks, 133*f*
  instruction lists for, 154*f*
OR operation
  algebra with, 135
  in structured text (ST), 168*t*
OSI. *See* ISO/OSI model
output devices, 43–53
  motors. *See* motors
  relays. *See* relays
output levels, 79
  RS232 interface, 93*f*
outputs
  changing voltage from sensors, 86–88
    op-amp comparators, 88–89
  internal relays with latching circuit, 188–190
  in ladder diagrams, 117, 127–129, 128*f*
  protection of, 89
  pulse size, 84–85
  sourcing and sinking, 11, 11*f*, 82–83, 83*f*
  testing (program development), 305–306
output section of PLC system, 8
output units. *See* input/output units

P

packages on conveyor belt systems, detecting, 55–56
parallel branching, 163, 164*f*
parallel communications, 90–91, 94–95, 109
parity checks, 97
peer-to-peer networks, 99
permanent magnet stepper motors, 49–50, 50*f*
personal computers, for programming PLCs, 19
phase (stepper motors), 51
Phillips I^2C bus, 94
photoconductive cells, 31
photodiodes, 31
photoelectric sensors, 43
  and switches, 30–31, 30*f*
phototransistors, 31
physical layer (ISO/OSI model), 101
PID control, 288, 289*f*
piezoelectric crystals, 40
25-pin D-type connectors, 91, 92*f*
pin plunger, 28
plastic rod, 28
position sensors, 37–38
positive binary numbers. *See* signed binary numbers
positive transition-sensing coils, 194, 194*f*
potential dividers, 86, 86*f*
potentiometers, 37, 37*f*
power (floating point numbers), 71
power supply unit, 7
presence sensing sensors, 43
presentation layer (ISO/OSI model), 102
present, timer, 225
present value, for counters, 245, 247
pressure sensors, 40–41
  liquid-level detectors, 28, 41
    monitoring system, 55, 55*f*
  strain gauges as, 39–40
processor unit, 7
production lines. *See* conveyor belts
PROFIBUS DP network (Siemens), 100
Profibus (Process Field Bus) system, 106
program development
  commissioning, 304–308
    simulation, 307–308
    software-checking, 306
    testing inputs and outputs, 305–306
  documentation, 313–335
  fault finding, 308–313
    detection techniques, 308–312
    program storage, 313
  flowcharts and pseudocode, 295–298
  safe systems, 298–304
    emergency stop relays, 302–303
    safety functions, 303–304
    safety PLCs, 304
programmable logic controllers
  control machines and processes, 5–6, 5*f*
  design. *See* designing PLC systems
  PLCs, about, 5–7
  systems, about, 12–15, 20
programming devices, 8, 19–20
programming methods. *See* function block diagrams (FBDs); IL (instruction lists); ladder programming (LAD) and ladder diagrams; SFCs (sequential function charts); ST (structured text)
programs for PLCs, 16–20
programs, specific, 341–374
  conveyor belt control, 357–364
    bottle packing, 358–364
  process control, 364–366
  valve sequencing, 347–357

car park barrier operation (example), 352–356
controlled cylinder reset, 356–357
cyclic movement, 347–348
sequencing, 348–352
program storage, 313
Project 802 (IEEE), 102
proportional mode (closed loop control), 287, 287*f*
protected door monitoring, 303
protocols, communication, 91, 96–98
with networking, 99, 101–103
proximity switches, 29–30
pseudocode, 295–298
PTC semiconductors, 35
pull-in rate (stepper motors), 52
pull-in torque (stepper motors), 51
pull-out rate (stepper motors), 52
pull-out torque (stepper motors), 52
pulse functions, 197–198, 198*f*
pulse size, output, 84–85
pulse timers (TP), 225, 226*f*, 232–234, 376–377
pulse width modulation (PWM), 46–48, 48*f*
PWM. *See* pulse width modulation (PWM)

Q

quantization levels, 81

R

rack systems. *See* modular (rack) systems
RAM. *See* random-access memory (RAM)
random-access memory (RAM)
battery failure and, 313
range, sensor, 24
RCV block, 103
READ block, 103
REAL data, 72
real numbers, 72
reducing voltage levels, 86–88, 86*f*
reed switches, 29, 29*f*
reflective photoelectric sensors, 30–31
registers, 267, 279–280
moving data between, 280–281
relay-controlled systems, 3–4, 3*f*
control red and green lights, 4, 4*f*
versus PLCs, 6
relays, 10, 43–44, 44*f*, 83
battery-backed, 192, 193*f*
emergency stop relays, 302–303
internal. *See* internal relays
latching relays, 44, 127
internal relays for, 190–191
master control relays, 199–204
ratchet type, 28
reversing motor rotation, 48
relay symbols, 3–4, 3*f*
reliability, measurement system, 25
remote connections
ASCII codes, 98
examples of, 98*t*
protocols for, 96–98
remote I/O modules, 89–98, 89*f*, 90*f*
REMOTE_VAR, 103
REN line (IEEE-488), 96*t*
repeatability, measurement system, 25
REPEAT...UNTIL iteration, in ST, 172, 380
replication, 311
RESET coils, 194–198, 195*f*. *See also* flip-flops
for one-shot operation, 197–198
program examples, 198
resetting counters, 245, 246*f*, 249
resistive linear and angular position sensors, 37
resistive temperature detectors (RTDs), 34–35
resolution (voltage), 81–82
response speed, PLC, 108
response time
with internal relays, 191–192
sensor, 24
retentive memory coils, 192, 193*f*
retentive relays, 192
retentive timers (RTO), 234
RETURN statement, in ST, 174
reversing motor rotation, 48
ring networks, 99, 99*f*
rise time, sensor, 24
robot control systems, 54–55, 54*f*
Rockwell Automation, 28
Allen-Bradley PLC-5, 13–15, 20, 104–105
RSLogix language, 20
roller-actuated limit switch, 27, 28*f*
roller plunger, 28
rotary potentiometers, 37, 37*f*
RS function blocks, 220, 220*f*
RS232 interface, 91
RTS and CTS signals, 97
RS422 interfaces, 93, 93*f*
RS423 interfaces, 93, 93*f*
RS485 interfaces, 106
RSLogix language, 20
RTDs (resistive temperature detectors), 34–35
RTO. *See* retentive timers (RTO)
RTS (ready-to-send) signal, 97
rungs. *See* ladder programming (LAD) and ladder diagrams

S

SAA 1027 circuit, 52–53, 52*f*
safe systems, 298–304
emergency stop relays, 302–303
safety functions, 303–304
safety PLCs, 304
safety interlock switches, 43
safety mats, 304
SCADA (supervisory control and data acquisition systems), 100
scanning ladder diagrams, 117, 117*f*
scanning time, PLCs, 108
internal relay response time, 191–192
scientific notation, 71
sealed cross roller plunger, 28
sealed pin plunger, 28
sealed roller plunger, 28
secure PLC systems. *See* safe systems
security, 15
selection function blocks, 283
selective branching (SFC), 163, 163*f*
self-testing. *See* fault finding
semiconductors, 35
strain gauges, 38–40
differential amplifiers with, 87, 88, 88*f*

www.newnespress.com

semigraphic form, ladder diagrams, 118–119
SEND block, 103
sensitivity, measurement system, 25
sensors. *See also* switches
  changing voltage from, 86–88
    op-amp comparators, 88–89
  defined, 23
  in distributed networking systems, 100
  liquid-level detectors, 28, 41
    monitoring system, 55, 55*f*
  Omron E2F, 30
  Omron E2K-X capacitive, 30
  photoelectric sensors and switches, 30–31, 30*f*
  position and displacement sensors, 37–38
  pressure sensors, 40–41
    strain gauges as, 39–40
  response of, 24*f*
  smart sensors, 42–43
  strain gauges, 38–40
    differential amplifiers with, 87, 88, 88*f*
  switch sensors. *See* mechanical switches
  temperature sensors, 33–37, 283
  ultrasonic proximity, 42
sensors ranges, 43
sequencer, 256–258
  control, 257
  destination, 257
  file, 256
  length, 257
  mask, 257
  position, 257
sequencer output (SQO), 256, 258
sequencers, 254–258
sequences, programming, 296
sequencing
  with on-delay timers, 228
  piston movement (example), 348–352
  with shift registers, 270, 273*f*
sequential flowcharts, 296, 364
sequential function charts. *See* SFCs
sequential logic systems, 63, 73–75
serial communications, 90–94, 109
session layer (ISO/OSI model), 102
SET and RESET coils, 194–198, 195*f*. *See also* flip-flops
  for one-shot operation, 197–198
  program examples, 198
settling time, 24
SFC (SIMATIC S7-Graph) language, 19–20
SFCs (sequential function charts), 160–167, 352, 378
  actions, 165–167, 166*f*
  branching and convergence, 163–165
SHIELD line (IEEE-488), 96*t*
shift registers, 267–278, 269*f*
  for keeping track of items, 270–272, 274*f*
  in ladder diagrams, 268–272
  sequencing application example, 270, 273*f*
short-duration pulses, 249
short integer numbers (SINTs), 71–72
Siemens
  PROFIBUS DP network, 100
  Profibus (Process Field Bus) system, 106
  SIMATIC S7 addressing, 108
  SIMATIC STEP 7 language, 19–20
  test mode, 307
Siemens ladder diagrams
  addition operation, 285*f*
  conditional jumps, 217*f*
    subroutine function block, 219*f*
  conveyor belt control program (example), 363–364
  counters, 250*f*, 253*f*, 255*t*
  data movement, 281*f*
  function block diagrams, 134*f*
  greater-than comparison, 282*f*
  IL code mnemonics, 153
  instruction code mnemonics, 152*t*
    AND gates, 153*f*, 157*f*
    NAND gates, 155*f*
    NOR gates, 154*f*
    OR gates, 154*f*
    XOR gates, 156*f*
  internal relays with multiple input conditions, 189*f*
  master control relays, 201–202
  notation for, 119, 120*f*
  off-delay timers (TOF), 231, 231*f*
  on-delay timers (TON), 226–228, 227*f*
  set-reset function, 196, 197–198, 198*f*
  shift registers, 272*f*
  valve sequencing program (example), 351*f*
    car barrier program, 355*f*
    inputs and outputs, 356
Siemens S7-1200 system, 305–306
signal conditioning, 85–89
  changing voltage levels, 86–88, 88*f*
  op-amp comparators, 88–89
  output protection, 89
signal lamp task example
  instruction lists, 159, 159*f*
  ladder diagram, 139*f*
  last output set (fault detection technique), 309, 311*f*
  timers for, 235, 237*f*
signal levels, 10–11, 79
  RS232 interface, 93*f*
sign bit, 69
signed binary numbers, 69, 71–72
  one's and two's complements, 69–70
SIMATIC S7 addressing (Siemens), 108
SIMATIC STEP 7 language (Siemens), 19–20
simulation, 307–308
simultaneous convergence (SFC), 164*f*
single-acting cylinders, 46, 46*f*, 47*f*
single-box (brick) systems, 12
  I/O addresses, 108
single highway networks, 99, 99*f*
single pole/double throw (SPDT) switches, 26–27
sinking, 11
  input units, 79–80, 80*f*
  output units, 82–83, 83*f*

SINTs (short integer numbers), 71–72
slave networks, 99
slew range (stepper motors), 52
slot passing, 99
smart sensors, 42–43
software for PLCs, 19
  testing/checking, 306
solenoids as actuators
  directional control valves, 44, 45*f*
  output protection, 89
  relays, 43–44
sourcing, 11
  input units, 79–80, 80*f*
  output units, 82–83, 83*f*
spool valves, 44
SR function blocks, 219, 220*f*
SR latches, 74–75, 74*f*, 75*t*
SRQ line (IEEE-488), 96*t*
ST (structured text), 167–174, 379–380
  conditional statements, 169–171, 380
  iteration statements, 171–172, 380
  ladder diagrams versus, 174
  operators, 168*t*, 379–380
  programs, 172–174
stability, measurement system, 25
standard communication blocks, 103
star networks, 99, 99*f*
STATUS block, 103
step angle (stepper motors), 51
stepper motors, 49–53, 49*f*
ST (SIMATIC S7-SCL) language, 19–20
stop/start switch, ladder diagram for, 116, 116*f*
stop switches, 300–301
  emergency stop switches, 141, 141*f*, 302–303
  locations of, 140–141
storage capacity of memory units, 9
storage, program, 313
storage tank, 365–366, 366*f*
stored data. *See* internal relays; memory
strain gauges, 38–40
  differential amplifiers with, 87, 88, 88*f*
structured text. *See* ST (structured text)
subroutines, 217–220
  function boxes, 218–220
subtraction
  of binary numbers, 68, 70
  of data in data registers, 284–285
  in structured text (ST), 168*t*
switches. *See also* limit switches; logic systems (logic gates); mechanical switches; normally closed (NC) switches; normally open (NO) switches; photoelectric sensors; proximity switches; reed switches; stop switches; thumbwheel switch
  testing, 305
switching frequency, 346
symbols, 375–380
synchronization for serial communication, 91
system design. *See* designing PLC systems
system documentation, 313–335

T

talkers (parallel communications), 94
tasks appropriate for control systems, 1
Telemecanique
  debug mode, 307
  SET and RESET coils, 195–196
Telemecanique ladder diagrams
  notation for, 119, 120*f*
  on-delay timers (TON), 226–228, 227*f*
  set-reset function, 195–196, 197–198, 198*f*
temperature coefficients, 33–34, 35
temperature sensors, 33–37, 283
testing (program development)
  fault finding, 308–313
    detection techniques, 308–312
    program storage, 313
  inputs and outputs, 305–306
  software-checking, 306
test mode (Siemens), 307
Texas Instruments
  TIWAY network, 100
  TSL220 sensor, 31*f*
thermistors, 35*f*, 342–343, 343*f*. *See also* semiconductors
thermocouples, 36–37, 36*f*, 37*t*, 342–343
  accuracy of, 82
thermodiodes, 35–36
thermostat. *See* temperature sensors
thermotransistors, 35–36
three-track encoders, 32, 32*f*
three-wire circuits, 34–35, 34*f*
thumbwheel switch, 280, 280*f*
time duration data, 72
timers, 225–244
  with counters, 252–254, 254*f*
  off-delay (TOF), 225, 226*f*, 231–232
  on-delay. *See* on-delay timers (TON)
  programming examples, 235
  pulse timers (TP), 225, 226*f*, 232–234, 376–377
  retentive timers (RTO), 234
  types of, 225
  watchdog timers, 308
timing checks, 308
TIWAY network (Texas Instruments), 100
TOF. *See* off-delay timers (TOF)
toggles, 75
token passing, 99
TON. *See* on-delay timers (TON)
Toshiba ladder diagrams
  counters, 255–256, 255*t*
  on-delay timers (TON), 226–228, 227*f*
  sequencers, 255–256, 256*f*
  shift registers, 269, 271*f*
Toshiba PLC brick, 12
TP. *See* pulse timers (TP)
tracking items with shift registers, 270–272, 274*f*
traditional control systems, 1–3
traffic lights, sequence for, 160, 160*f*
  timers for, 235, 236*f*

www.newnespress.com

transducers, defined, 23
transistor-type output, 10, 83*f*
transition-sensing coils, 194, 194*f*
transmission rates, serial communications, 92–93
transmissive photoelectric sensors, 30–31
transparent latches, 73–74
transport layer (ISO/OSI model), 102
triac outputs, 10, 84*f*
truth tables, 63, 72, 73*t*
  for latches, 74
  AND logic, 120–121
  NAND logic, 124–125
  NOR logic, 125
  NOT logic, 123–124
  OR logic, 121–123
  XOR (exclusive OR) logic, 126
TSL220 sensor (Texas Instruments), 31*f*
tuning, 288
twisted-pair cabling, 90
two-channel emergency stop relays. *See* emergency stop switches
two-handed engaging, 303
two-position valves, 45*f*
two's complement, 69–70, 279
two-state variables, 73
two-step controls, 288
two-track encoders, 32
TYPE statements, in ST, 172

U

UARTs (universal asynchronous receivers/transmitters), 91
UDINT data, 71–72
UINT data, 71–72
ULINT data, 71–72
ultrasonic proximity sensors
  input devices, 42
ultrasonic sensors, 43
unipolar motors, 52–53
universal asynchronous receivers/transmitters (UARTs), 91
Universal Serial Bus (USB), 94
unsigned binary numbers, 69, 71–72. *See also* signed binary numbers
up-counters, 245, 246*f*, 376–377
  up-down counters, 251, 253*f*, 376–377
up-down counters, 246*f*
URCV block, 103
USB connections, 94
USEND block, 103
USINT data, 71–72
USTATUS block, 103

V

value checks, 311
valve operation program example
  full program, 347–357
    car park barrier operation (example), 352–356
    controlled cylinder reset, 356–357
    cyclic movement, 347–348
    sequencing, 348–352
  instruction lists, 159, 159*f*
  ladder diagram, 139*f*
  with master control relay, 203*f*
valves
  directional control valves, 44–46, 45*f*, 46*f*
  spool valves, 44
  4/2 valves, 45, 45*f*
4/2 valves, 45, 45*f*
vampire taps, 104
variable reluctance stepper motors, 51, 51*f*
variables, defining in ST, 172–173
voltage levels, changing, 86–88

W

washing machine, SFC for, 162*f*
watchdog timers, 308
Wheatstone bridges, 34–35, 34*f*
  differential amplifiers with, 87, 88, 88*f*
  with strain gauges, 39, 39*f*
WHILE...DO iteration, in ST, 171–172, 380
words (binary data), 71–72, 81, 279
words (binary words), 9
workplace safety. *See* safe systems
WRITE block, 103
writing documentation for PLC systems, 313–335

X

XON/XOFF protocol, 97
XOR (exclusive OR) logic gates, 126, 126*f*, 132*f*
  functional blocks, 133*f*
  instruction lists for, 155–158
XOR operation
  algebra with, 136
  in structured text (ST), 168*t*

Z

zero drift, 25