

INDEX

Numbers

3 dB point, 442

3D printer, 462

A

abstraction, 123, 403

AC (alternating current), 37

AC/DC (Australian rock band), 36

active shield countermeasure, 21

Advanced Encryption Standard. *See* AES

adversarial machine learning, 25

AES (Advanced Encryption Standard), 12, 308–310

AES-256, 363–364

cipher block chaining (CBC), 363–364

construction, 309

counter with cipher block chaining message authentication code (CCM), 395

Indexed Code Block (ICB) mode, 410

key schedule, 365

masked implementation, 407

modes of operation, 308

power analysis of, 310, 316, 395

Rijndael cipher, 308

aliasing, 440

alternating current (AC), 37

analog-to-digital converter (ADC), 66

anti-tamper mesh, 76

Apple M1, 172

arbitrary waveform generator (AWG), 460

Arduino, 160, 192

Arm Cortex JTAG pinout, 469

Arm JTAG pinout, 468

artificial neural network (ANN).

See neural network

assets, 7, 10, 22

asynchronous communication, 43

attackers, 10

attack resistance, 420

attacks, 10

attack surface, 4, 12

attack tree, 10, 403

AWG (arbitrary waveform generator), 460

B

BadFET, 461

balanced logic, 406

ball grid array (BGA), 91–95, 97, 431

flip-chip, 93

heat spreader, 94

plastic, 93

reballing, 432–434

thermally enhanced, 93

bare metal, 7

baud rate, 47

BBI (body biasing injection), 184–186

BBQ lighter, 191

BGA. *See* ball grid array

binwalk, 18, 109, 111–117

bitcoin wallet, 224

bitrate, 98

bits per second, 47

Black Magic Probe, 448

blinding, 408

body biasing injection (BBI), 184–186

boot attestation, 24

boot configuration, 85

bootloader, 5, 201, 225, 230, 362, 391, 395

boot ROM code, 5, 20, 201

- boundary scan, JTAG, 56, 106–108, 447–448
- brick, 8
- C**
- CAN (control area network), 447
 - capacitance, 38
 - carrier PCB, 92
 - CBC (Cipher Block Chaining). *See AES, cipher block chaining*
 - CC (Common Criteria), 31, 420–422
 - chain of trust, 6
 - challenge-response protocol, 410
 - chip-invasive attacks, 18
 - chip scale packaging (CSP), 94
 - ChipSHOUTER, 176, 236, 461
 - ChipWhisperer, 454, 459, 464
 - ChipWhisperer-Lite, 167, 218, 269, 366, 454, 459
 - ChipWhisperer-Nano, 196, 269, 284, 454
 - ChipWhisperer-Pro, 456, 459
 - chosen inputs, 333
 - circuits, 36
 - Cisco Trust Anchor attack, 76
 - CLKSCREW, 13
 - clock fault injection. *See glitching, clock clocking for communications*, 43
 - code read protection, 195, 203
 - common clock, 44
 - Common Criteria (CC), 31, 420–422
 - Common Vulnerability Scoring System (CVSS), 31
 - Common Weakness Scoring System (CWSS), 31
 - comparison, unsafe, 122, 248
 - compiler optimization, avoiding, 418
 - compression, trace, 341, 355
 - conditional leakage averaging, 326
 - conferences, 423
 - constants, nontrivial, 411
 - constant time, 404
 - control flow integrity, 415
 - controller area network (CAN), 447
 - CAN bus, 55
 - correlation power analysis (CPA), 311–319, 348, 369
 - calculation, 315
 - hypothetical, 315
 - leakage model, 315, 373
 - on AES-256, 364
 - correlation traces, 315, 348
 - countermeasures, 10, 26, 325, 402
 - avoiding compiler optimization, 418
 - balanced logic, 406
 - branchless code, 405
 - bypassability, 417
 - constant time, 404
 - constant time compare, 404
 - control flow integrity, 415
 - decoy operations, 409
 - double-checking, 414
 - dual-rail logic, 406
 - fault canary, 416
 - fault counter, 416
 - infective computing, 409
 - leakage-resistant protocol, 410
 - masking, 407
 - noise addition, 406
 - nontrivial constants, 411
 - randomized array access, 409
 - side channel, 325
 - square-and-multiply-always, 409
 - strength, 417
 - timing randomization, 405, 409, 414
 - unique status variables, 413
 - unstable clock, 406
 - CPA. *See correlation power analysis*
 - CRC (cyclic redundancy check), 366–367, 415
 - critical path, 149
 - crystal, 82–84, 103, 154, 393
 - crowbar, 163–168, 195
 - crypto libraries, 410
 - crypto test, 134
 - CSP (chip scale packaging), 94
 - current, 36
 - CVSS (Common Vulnerability Scoring System), 31
 - CWSS (Common Weakness Scoring System), 31
 - cyclic redundancy check (CRC), 366–367, 415

D

data bus, 294
data bus drivers, 294
data rate, 43
datasheets, 77
DC (direct current), 37
deallocated memory, 390
debug, 58–59, 448–449, 467
decapsulation, 178
decoupling capacitors, 100
decoy operations, 409
deep learning, 326, 355
depackaging, 178
desoldering, 429–431
device labels, 73
DFA (differential fault analysis), 121, 215–221
die markings, reading, 88
difference of means (DoM), 303–306, 377
differential amplifier, 339
differential cluster analysis, 326
differential fault analysis (DFA), 121, 215–221
differential power analysis (DPA), 293, 301, 374, 377
implemented in Python, 305
using with XOR, 374–376
differential probe, 268, 339
differential signaling, 45
digital logic power consumption, 295
digital oscilloscope, 65–69
direct current (DC), 37
disclosure, 33–34
distinguisher, 282
DMM, 64, 426
DoM (difference of means), 303–306, 377
double-checking, 414
double loop, glitching, 191
DPA. *See* differential power analysis
DRAM hammering, 13
dual-rail logic, 406
dump test, register or memory, 133

E

EAL (evaluation assurance level), 421
ECB (Electronic Code Book), 308
ECC (elliptic curve cryptography), 117
blinding, 408
power analysis of, 258
ECDSA (Elliptic Curve Digital Signature Algorithm), 258
EEPROM, 4, 51
electromagnetic analysis (EMA), 335
electromagnetic fault injection. *See* EMFI
electromagnetic probe, 335, 457
building, 335
chip-scale, 459
package-size, 457
preamplifier, 458
Electronic Code Book (ECB), 308
elliptic curve cryptography. *See* ECC
Elliptic Curve Digital Signature Algorithm (ECDSA), 258
embedded clock, 44
embedded multimedia cards (eMMCs), 53, 110
Ember Trace pinout, 470
EMFI (electromagnetic fault injection), 171–178, 191–194, 223, 236, 461
architectures, 175
coils, 173, 177
coupled drive, 175
direct-drive, 175
effects of shielding, 172
high- and low-side drive, 175
permanent damage, 177
EM-FI Transient Probe tool, Riscure, 461
eMMCs (embedded multimedia cards), 53, 110
EMVCo, 420
enlightenment, 419
entropy, 112
error correcting codes, 412
Ethernet, 63, 447
evaluation assurance level (EAL), 421
exploitation phase, 8, 30–31
external interfaces, 3
extracting firmware, 109

F

FaceDancer, 452
Farad (unit), 38
fault canary, 416
fault counter, 416
fault detection, 416
fault injection. *See* glitching
fault primitive, 132
fault response, 416
fault sensitivity analysis, 154
fault sensor, 416
fault simulation, 418
Federal Communications Commission Identifier (FCC ID), 72
FIB (focused ion beam), 21
filtering, trace, 352
FIPS 140-3, 421
firmware, 109, 395
 analysis, 111
 entropy, 112
 extraction, 111
 signature, 116
 update, 395
firmware re-hosting, 17
first-order attacks, 407
FiSim, 419
flash, 110, 452, 467
flash memory, 4
Flashrom, 453
flip-chip, 93
flux, 429
focused ion beam (FIB), 21
frequency filtering, 353
FTDI, 445, 448, 452
fuses, 5, 117
fuzzing, 17

G

G-code, 462
GDB (GNU Debugger), 448
Glasgow Interface Explorer, 446
Glib jocks quiz nymph to vex dwarf, 115
Glitch Amplifier, Riscure, 461
glitch delay, 128
glitching, 119, 147, 189, 223, 236
 body biasing injection (BBI), 184–186
 causes of, 151–154

clock, 126, 135, 138, 148–157, 459
crowbar, 163–168, 195
electromagnetic. *See* EMFI
 (electromagnetic fault injection)
laser. *See* LFI (laser fault injection)
memory corruption, 390
optical, 178–184, 461
parameter search, 131, 142–145, 239, 242
plotting results, 144
reading beyond array end, 227
reset, 393
sensitive operations, 122, 190
spark gap, 193
tools, 126, 189
triggering, 129–130, 186–187, 191, 200, 204
voltage, 158–171, 195, 210, 460

glitch length, 128

GlobalPlatform TEE certification, 421
global success rate (GSR), 327
GNU Debugger (GDB), 448
GreatFET, 446

H

Hamming distance (HD), 318
Hamming weight (HW), 297
harmonics, 346, 353
hash-based message authentication code (HMAC), 404
hash table (HTAB), 388
heat map, 338
heat spreader, 94, 172
Hello World, 219
henry (unit), 38
H-Field probe. *See* electromagnetic probe

higher-order attacks, 407–408
high impedance, 41
hill-climbing algorithm, 144
hot air gun, 431
hypervisor, 388

I

icWaves, Riscure, 456
IDA (interactive disassembler), 124, 228
identification phase, 8, 30, 31

- IEEE 802.15.4, 394
 impedance, 37
 inductance, 38
 Industry Canada (IC) code, 74
 infective computing, 409
 initialization vector (IV), 374
 input correlation, 348
 instruction synchronization barrier (ISB), 130
 intellectual property (IP) blocks, 3
 interactive disassembler (IDA), 124, 228
 inter-IC interface (I2C), 50–53
 addressing, 51
 EEPROM, 51
 intermediate correlation, 348
 ISO 17825, 422
 ISO 19790, 421
 IV (initialization vector), 374
- J**
 jitter. *See* noise, temporal
 Joint Hardware Attack Subgroup (JHAS), 421
 Joint Interpretation Library (JIL), 31, 420
 Joint Test Action Group (JTAG), 16, 56–59, 79–80, 106–108, 120, 232, 447–449
 for reverse engineering, 106, 448
 Joules (unit), 38
 JTAGulator, 447
 jumper, 101
- K**
 kernel, 389
 key enumeration, 262, 300
 key zeroization attack, 410
 known-key analysis, 349
- L**
 Langer EMV, 458
 leakage model, 315, 318
 leakage-resistant protocol, 410
 LFI (laser fault injection), 178, 461
 front- and backside, 180, 462
 preparation, 178
 wavelength, 181, 462
 linear regression, 326
- LNA (low noise amplifier), 458
 logic analyzer, 69, 443
 logic levels, 39
 logic thresholds, 40
 loop termination checking, 415
 loop test, 132
 low noise amplifier (LNA), 458
 LPC microcontroller, 195
 LUNA, 451
- M**
 magnetic probe. *See* electromagnetic probe
 Manchester encoding, 44
 marking code for small parts, 78
 masking, 407
 master key, 394
 memcmp, 404
 memory copy test, 133
 memory interfaces, 60
 memory protection, 231
 message blinding, 408
 metastability, 151
 microarchitectural attacks, 14
 microcontroller data bus, 294
 microscope, 435
 USB, 436
 mini-grabber, 453
 misalignment, 353
 modchips, 392
 modular exponentiation, 254–256, 409
 multimedia card (MMC), 53
 multimeter
 measuring continuity with, 65
 measuring voltage with, 64
 multiplexor, 159, 210
 mutual information analysis, 326
- N**
 neural network, 355–357
 noise addition, 406
 noise, amplitude, 324
 noise, temporal, 325
 noninvasive attacks, 18, 236
 nontrivial constants, 411
 nonvolatile memory, 3
 normalization, trace 352

O

Ohm's law, 37, 267
one-time-programmable (OTP) fuses, 4
open collector, 43
open drain, 43
OpenOCD, 448, 468
OpenSSH, 122
oscilloscope, 65–68, 266–267, 273–274,
 339–341, 437–442
 AC coupling, 66, 273
 aliasing artifacts, 440
 bandwidth, 66, 441
 input sensitivity, 453
 memory depth, 439
 PC attached, 453
 probes, 65, 68
 sample rate, 439, 455
 trigger out, 443
output correlation, 348
over-the-air (OTA), 395

P

parallel bus, 59–61
partial guessing entropy (PGE),
 328–329
partial success rate, 327
patents, 75
PCB. *See* printed circuit board
PCI Express (PCIe), 63, 449
Pearson's correlation coefficient, 312
PGE (partial guessing entropy),
 328–329
phase-locked loop. *See* PLL
Philips Hue, 393
PhyWhisperer-USB, 234, 451
PicoEVB, 449
PicoScope, 453
Piñata, 464
PIN code check, 246–252, 404
PKCS#1 v1.5 padding, 219
plastic quad flat pack (PQFP), 89
Platform Security Architecture
 (PSA), 421
PlayStation 3 hypervisor attack,
 388–391
PLL (phase-locked loop), 154–155
 PLL bypass, 391

power analysis, 204, 245, 265, 297, 395
 hardware implementation leakage
 model, 319
 initiating encryption, 332
 leakage assumption, 301
 leakage model, 315, 318
 measurement tools, 453
 metrics, 326
 signal processing for, 257
 without prior knowledge, 331
power consumption, 38
 data dependent, 297
power management IC (PMIC), 84,
 105, 162, 164
PowerPC JTAG pinout, 469
power rails, 165
power supply, 437
practical lab
 Arduino glitching, 190
 BBQ lighter, 191
 differential fault analysis, 215–222
 differential power analysis, 361
 ECDSA (Elliptic Curve Digital
 Signature Algorithm), 258
 power consumption simulation,
 299–300
 Raspberry Pi glitching, 164–171
 read protection bypass, 194–214
 RSA fault attack, 215–222
 SPA attack, 275–284
printed circuit board (PCB)
 components, 98–101
 mapping, 101–108
 modifying, 434
 photographing, 436
 power planes, 105
 reverse engineering, 102
 tracing, 81, 104
printer cartridges, 362
processor (central processing unit or
 CPU), 2
program counter control, 133
PSA (Platform Security Architecture),
 421
pulldown, 42
pullup, 42
push-pull, 42

Q

quad flat no-lead (QFN), 91, 95, 95–96
quad flat pack (QFP), 90
quantization error, 67
quantum attacks, 301

R

randomized array access, 409
read-only memory. *See* ROM
reference designator, 103
remote boot attestation, 24
removal alloy, 432
reset, target, 129
resistance, 37
resistor, 100
resynchronization, 353, 371
ringing, 45
Riscure Glitch Amplifier, 461
Riscure icWaves, 456
Riscure Spider, 460
Riscure VC Glitcher, 460
ROM (read-only memory), 4
 patching, 5
root of trust, 5
rotary tool, 434
Rotating S-boxes Masking (RSM), 407
Rowhammer attack, 13
RS-232, 47
RSA, 117, 215, 409
 blinding, 408
 CRT (Chinese Remainder
 Theorem), 215, 220
 MBED-TLS, 219, 256
 power analysis of, 254, 256
 windowing implementation, 256

S

SAD (sum of absolute differences), 288,
 353, 371, 456
SAKURA Project, 463
Saleae, 444
sampling rate, 67, 341
SASEBO Project, 463
scalar multiplication, 259
schematics, 77
Schneier’s law, 419
SDIO (Secure Digital Input/Output), 53

search strategy

big to small, 143
divide and conquer, 143
exercising patience, 144
intelligent search, 144
interval, 142
nesting, 142
random, 142
small to big, 143
second-order attacks, 407
secure boot, 391
Secure Digital card (SD card), 53, 111
Secure Digital Input/Output (SDIO), 53
security labs, 421
security nihilism, 8, 419
security objectives, 10
SEGGER J-Link, 449
self-clocking, 44
serial communications, 46–48, 445
 baud rate, 47
 for triggering, 445
serial interface, high speed, 61
Serial Peripheral Interface (SPI),
 48–50, 445, 452
 flash, 110, 452, 467
Serial Wire Debug (SWD), 16, 469
shunt resistor, 210, 267, 273, 334
side channel, 245–246
 countermeasures, 325
 power. *See* power analysis
 timing. *See* timing attack
signature, 116
silkscreen, 103
simple power analysis. *See* SPA
small outline integrated circuit (SOIC),
 89, 96, 452, 467
 clip adapter, 452
small outline no-lead (SON), 91
small outline package (SOP), 89
smartphone glitching, 194
SMD. *See* surface-mount device
SoC. *See* System-on-Chip
power supply, 165
soldering, 431
soldering iron, 427–429
 plating, 428
solder mask, 104
solder spheres, 433

- source synchronous clock, 44
SPA (simple power analysis), 253
 applying to RSA, 254–257
spectrogram, 345
spectrum analysis, 345
SPI (Serial Peripheral Interface),
 48–50, 445, 452
 flash, 110, 452, 467
Spider, Riscure, 460
sportsball, 9
square-and-multiply algorithm, 409
squinting at traces, 282
straps, 15, 16, 101
sum of absolute differences (SAD), 288,
 353, 371, 456
surface-mount device (SMD)
 ball grid arrays, 91
 leaded packages, 88
 leadless packages, 91
 marking code, 78
 rework, 431
SWD (Serial Wire Debug), 16, 469
switching-based injector, 159
symbols, communication, 39
synchronous communication, 44
synchronous sampling, 67, 342, 455
System-on-Chip (SoC), 2, 164
 power supply, 165
- T**
- TAs (trusted applications), 6
target, laboratory, 463–465
target, resetting, 129
TEE (trusted execution environment), 5
TEMPEST, 246
template attack, 326
test leads, 426
test points, 101
test vector leakage assessment (TVLA),
 349–352, 422
thin quad flat pack (TQFP), 89, 96
thin SON (TSON), 91
thin SOP (TSOP), 89
timing attack, 246–252, 257–258,
 384, 404
timing randomization, 405, 409, 414
timing violation, 150–154
Total Phase Beagle 480, 450
trace, 67
 compression, 341, 355
 filtering, 352
 normalization, 352
 visualization, 344
transistor-transistor logic (TTL), 40
Trezor One, 224
trigger, 68, 445, 456
tristate, 42
trusted applications (TAs), 6
trusted execution environment (TEE), 5
t-test, 349–350
TTL (transistor-transistor logic), 40
TTL serial, 47
TVLA (test vector leakage assessment),
 349–352, 422
- U**
- unicorn, 8
unique status variables, 413
Universal Asynchronous Receiver/
 Transmitter (UART), 46
Universal Serial Bus (USB), 62,
 226–227
 direct firmware upgrade
 (DFU), 109
Human Interface Device (HID), 62
from Python, 233
sniffer, 229, 233, 242, 450
 triggering on, 233
unstable clock, 406
USB isolator, 192
USB On-The-Go (OTG), 62
- V**
- VC Glitcher, Riscure, 460
vias, 102
visualization, trace, 344
volatile keyword, 418
volatile memory, 2
voltage, 36
voltage glitching, 158–171, 195, 210,
 460
voltage regulators, 105
voltmeter, 64

W

- wafer-level CSP (WLCSP), 94
- weaponize, 392
- wide small outline no lead (WSON), 91, 95, 467

X

- Xbox 360 attack, 391–393, 405
- XY scanning, 462
- XTAL. *See* crystal

Z

- Zigbee Light Link, 394