

Contents

Preface	xiii
Emmanuel PROUFF, Guénaël RENAULT, Matthieu RIVAIN and Colin O'FLYNN	
Part 1. White-Box Cryptography	1
Chapter 1. Introduction to White-Box Cryptography	3
Pierre GALISSANT and Louis GOUBIN	
1.1. Introductory remarks	3
1.2. Basic notions for white-box cryptography	6
1.2.1. Unbreakability	6
1.2.2. Incompressibility	7
1.2.3. One-wayness	8
1.3. Proposed (and broken) solutions	9
1.3.1. Block ciphers	9
1.3.2. Asymmetric algorithms	10
1.4. Generic strategies to build white-box implementations	12
1.4.1. DCA and countermeasures	12
1.4.2. Using fully homomorphic encryption (FHE)	13
1.4.3. White-box solutions with the help of a (small) tamper-resistant hardware	14
1.5. Applications of white-box cryptography	15
1.5.1. EMV payments on NFC-enabled smartphones without secure element	15
1.5.2. Software DRM mechanisms for digital contents	16
1.5.3. Mobile contract signing	16
1.5.4. Cryptocurrencies and blockchain technologies	16
1.6. Notes and further references	17
1.7. References	19

Chapter 2. Gray-Box Attacks against White-Box Implementations	23
Aleksei UDOVENKO	
2.1. Introduction	23
2.2. Specifics of white-box side-channels	24
2.2.1. Determinism	25
2.2.2. Precise measurements	25
2.2.3. Data-dependency graph and attack windows	25
2.2.4. Computational model	26
2.2.5. Computational traces	28
2.2.6. Sensitive/predictable functions	28
2.3. Fault injections	30
2.3.1. Locating and removing pseudorandomness and dummy values	31
2.3.2. Detecting linear shares from output collisions	33
2.4. Exact matching attack	35
2.4.1. First-order exact matching attack	35
2.4.2. Higher order exact matching attack	37
2.5. Linear decoding analysis/algebraic attacks	39
2.5.1. Basic algebraic attack	39
2.5.2. Differential algebraic attack against shuffling	40
2.6. Countermeasures against the algebraic attack	43
2.6.1. Security model sketch	43
2.6.2. Nonlinear masking	45
2.6.3. Dummy shuffling	47
2.7. Conclusions	49
2.8. Notes and further references	50
2.9. References	50
Chapter 3. Tools for White-Box Cryptanalysis	53
Philippe TEUWEN	
3.1. Introduction	53
3.2. Tracing programs	55
3.3. Target recognition	57
3.4. Acquiring traces for side-channel analysis	59
3.5. Preprocessing traces	61
3.6. Differential computation analysis	62
3.7. Linear decoding analysis also known as algebraic attack	64
3.8. Injecting faults	65
3.9. Differential fault analysis	67
3.10. Coping with external encodings	69
3.11. Conclusion	70

3.12. Notes and further references	70
3.13. References	72
Chapter 4. Code Obfuscation	73
Sebastian SCHRITTWIESER and Stefan KATZENBEISER	
4.1. Introduction	73
4.1.1. Definition of obfuscation	73
4.1.2. Goals of obfuscation	74
4.1.3. Protecting against locating data	74
4.1.4. Protecting against locating code	74
4.1.5. Protecting against extraction of code	74
4.1.6. Protecting against understanding of code	75
4.1.7. Attacker models	75
4.1.8. Pattern matching	75
4.1.9. Automated static analysis	75
4.1.10. Automated dynamic analysis	76
4.1.11. Human-assisted analysis	76
4.2. Obfuscation methods	76
4.2.1. Data obfuscation	77
4.2.2. Static obfuscation	78
4.2.3. Dynamic obfuscation	84
4.3. Attacks against obfuscation	85
4.3.1. Principles of program analysis	85
4.3.2. Measuring the strength of obfuscations	86
4.4. Application of code obfuscation	87
4.4.1. Digital rights management	87
4.4.2. Intellectual property protection	88
4.4.3. Malware obfuscation	88
4.4.4. Hardware-software binding	88
4.4.5. Software diversity	89
4.5. Conclusions	89
4.6. Notes and further references	89
4.7. References	90
Part 2. Randomness and Key Generation	93
Chapter 5. True Random Number Generation	95
Viktor FISCHER, Florent BERNARD and Patrick HADDAD	
5.1. Introduction	95
5.2. TRNG design	96
5.3. Randomness and sources of randomness	97
5.3.1. Example: jitter of a clock signal as a source of randomness	99
5.3.2. Stochastic model of the phase of the jittered clock signal	99

5.4. Randomness extraction and digitization	100
5.4.1. Example: oscillator-based TRNGs	102
5.5. Post-processing of the raw binary signal	104
5.5.1. Algorithmic post-processing	104
5.6. Stochastic modeling and entropy rate management of the TRNG	105
5.6.1. Example: a comprehensive stochastic model of the EO-TRNG	107
5.6.2. Example: stochastic model of the MO-TRNG	108
5.7. TRNG testing and testing strategies	109
5.7.1. Generic (black-box) statistical tests used in cryptography	110
5.7.2. Online statistical tests	112
5.7.3. Example: dedicated online tests for the MO-TRNG	112
5.8. Conclusion	113
5.9. Notes and further references	113
5.10. References	114
Chapter 6. Pseudorandom Number Generation	115
Jean-René REINHARD and Sylvain RUHAULT	
6.1. Introduction	115
6.2. PRNG with ideal noise source	116
6.2.1. Standard PRNG	117
6.2.2. Stateful PRNG	118
6.2.3. Stateful pseudorandom generator with inputs	120
6.3. PRNG with imperfect noise sources	121
6.3.1. Extractors	122
6.3.2. Robustness model of Coretti et al. (2019)	124
6.4. Standard PRNG with inputs	125
6.4.1. General architecture of NIST PRNG with inputs	125
6.4.2. Security analysis and good practices	126
6.5. Notes and further references	128
6.6. References	129
Chapter 7. Prime Number Generation and RSA Keys	131
Marc JOYE and Pascal PAILLIER	
7.1. Introduction	131
7.2. Primality testing methods	133
7.3. Generation of random units	133
7.4. Generation of random primes	136
7.4.1. Probable primes	138
7.4.2. Provable primes	138
7.5. RSA key generation	140
7.6. Exercises	143

7.7. Notes and further references	144
7.8. References	146
Chapter 8. Nonce Generation for Discrete Logarithm-Based Signatures	151
Akira TAKAHASHI and Mehdi TIBOUCHI	
8.1. Introduction	151
8.2. The hidden number problem and randomness failures	153
8.2.1. From Schnorr to HNP	153
8.2.2. From ECDSA to HNP	154
8.3. Lattice attacks	154
8.3.1. Lattice basics	155
8.3.2. Expressing the HNP as a lattice problem	156
8.3.3. Some recent developments	158
8.4. Fourier transform attack	160
8.4.1. Quantifying bias using discrete Fourier transform	160
8.4.2. Stretching the peak width	162
8.4.3. Range reduction algorithms	165
8.5. Preventing randomness failures	166
8.6. Notes and further references	167
8.7. Acknowledgment	169
8.8. References	169
Chapter 9. Random Error Distributions in Post-Quantum Schemes	173
Thomas PREST	
9.1. Introduction	173
9.2. Why post-quantum schemes need random errors	174
9.2.1. Example 1: noisy ElGamal	175
9.2.2. Example 2: hash-then-sign	176
9.2.3. Example 3: Fiat–Shamir with aborts	177
9.3. Distributions for random errors	178
9.3.1. Uniform distributions	179
9.3.2. Fixed weight distributions	179
9.3.3. Variants of the binomial distribution	180
9.3.4. Discrete and rounded Gaussians	181
9.3.5. Randomized rejection sampling	182
9.4. Sampling algorithms	184
9.4.1. Table-based algorithms	184
9.4.2. Random permutations	186
9.4.3. Convolution-based algorithms	189
9.4.4. Polynomial approximation	190
9.4.5. Rejection methods	191

9.4.6. Masking the various algorithmic approaches	192
9.5. Notes and further references	193
9.6. References	197
Part 3. Real-World Applications	203
Chapter 10. ROCA and Minerva Vulnerabilities	205
Jan JANCAR, Petr SVENDA and Marek SYS	
10.1. The Return of Coppersmith’s Attack	206
10.1.1. Fingerprinting	207
10.1.2. Factorization attack	208
10.1.3. Practical impact and disclosure	210
10.1.4. Notes and further references	215
10.2. Minerva	216
10.2.1. Discovery and leakage	216
10.2.2. Cause	217
10.2.3. Attack	218
10.2.4. Impacted domains and disclosure	220
10.2.5. Notes and further references	222
10.3. References	222
Chapter 11. Security of Automotive Systems	225
Lennert WOUTERS, Benedikt GIERLICH and Bart PRENEEL	
11.1. Introduction	225
11.2. The embedded automotive attacker	226
11.3. An overview of automotive attacks	227
11.3.1. Proximity vehicle attacks	227
11.3.2. Remote vehicle attacks	229
11.3.3. Infrastructure attacks	230
11.4. Application of physical attacks in automotive security	231
11.4.1. Side-channel analysis	231
11.4.2. Fault injection	232
11.5. Case study: Tesla Model X keyless entry system	233
11.5.1. The key fob	234
11.5.2. The body control module	235
11.5.3. Putting it all together	235
11.6. Conclusion	237
11.7. References	237

Chapter 12. Practical Full Key Recovery on a Google Titan Security Key	245
Laurent IMBERT, Victor LOMNE, Camille MUTCHEL and Thomas ROCHE	
12.1. Introduction	245
12.2. Preliminaries	246
12.2.1. Product description	246
12.2.2. <i>Google Titan Security Key</i> Teardown	247
12.2.3. Matching the <i>Google Titan Security Key</i> with other NXP products	247
12.2.4. Side-channel observations	248
12.3. Reverse-engineering and vulnerability of the ECDSA algorithm	249
12.3.1. Reverse engineering the ECDSA signature algorithm	249
12.3.2. A sensitive leakage	251
12.4. A key-recovery attack	252
12.4.1. Recovering scalar bits from the observed leakage	253
12.4.2. Lattice-based attack with partial knowledge of the nonces	253
12.5. Take-home message	255
12.6. References	255
Chapter 13. An Introduction to Intentional Electromagnetic Interference Exploitation	257
José LOPES ESTEVES	
13.1. IEMI: history and definition	257
13.2. Information security threats related to electromagnetic susceptibility	259
13.3. Electromagnetic fault injection	260
13.4. Destruction, denial of service	261
13.5. Denial of service on radio front-ends	261
13.6. Signal injection in communication interfaces	262
13.7. Signal injection attacks on sensors and actuators	262
13.8. IEMI-covert channel	263
13.8.1. The air gap	264
13.8.2. Bridging air gaps	264
13.8.3. Threat model	266
13.8.4. Practical IEMI-covert channel on a PC	266
13.9. Electromagnetic watermarking	269
13.9.1. Threat model	269
13.9.2. EMW for forensic tracking	269
13.9.3. Practical EMW on a UAV	271
13.10. Conclusion	273
13.11. References	274

Chapter 14. Attacking IoT Light Bulbs	279
Colin O'FLYNN and Eyal RONEN	
14.1. Introduction	279
14.2. Preliminaries	280
14.2.1. ZLL (ZigBee Light Link) and smart light systems	280
14.2.2. Lamp hardware	281
14.2.3. Firmware updates	281
14.2.4. Hue Bridge hardware	282
14.3. Hardware AES and AES-CTR attacks	282
14.3.1. Application to ATMega128RFA1	283
14.3.2. Later-round attacks	285
14.4. AES-CCM bootloader attack	286
14.4.1. Understanding Philips OTA image cryptographic primitives . .	286
14.4.2. CPA attack against the CCM CBC MAC verification	289
14.5. Application of attack	293
14.6. Notes and further references	294
14.7. References	295
List of Authors	297
Index	301
Summary of Volume 1	305
Summary of Volume 2	313