MUNI
FI

CROCS
Centre for Research on
Cryptography and Security

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CHES
2020

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Systematic analysis of lattice attacks on noisy leakage of bit-length of ECDSA nonces

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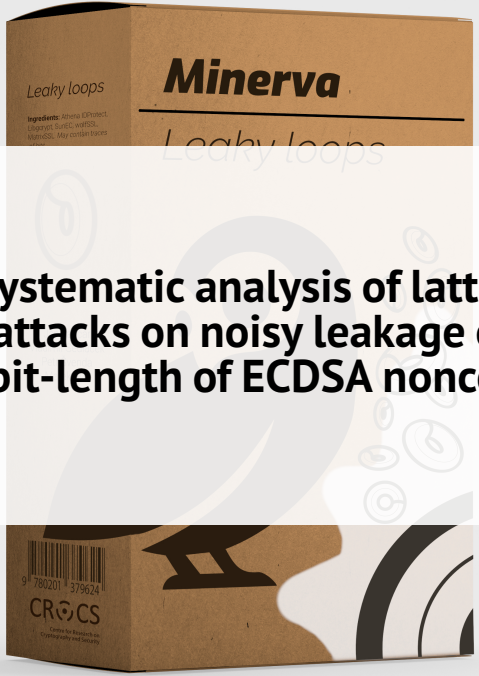
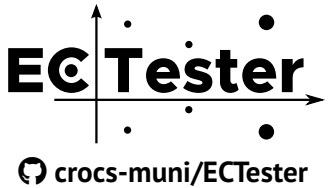


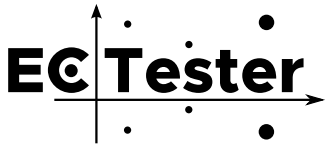
CHES 2020

Discovery



- Tool for testing black-box ECC implementations
  - JavaCards
  - Software libraries (15 supported)

Discovery



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- 12 test suites (invalid curve attacks, …)

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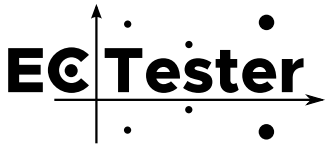


- Tool for testing black-box ECC implementations
  - JavaCards
  - Software libraries (15 supported)
- 12 test suites (invalid curve attacks, …)
- Decided to test timing of **ECDH** and **ECDSA**!

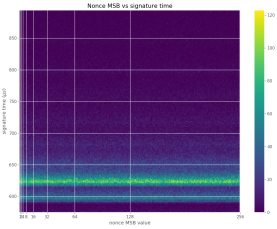
ECDSA

Sign(message m, private key x)

1. $k \xleftarrow{\$} \mathbb{Z}_n$ (nonce)
2. $r \equiv ([k]G)_x \mod n$
3. $s \equiv k^{-1}(H(m) + rx) \mod n$
4. Output (r, s)

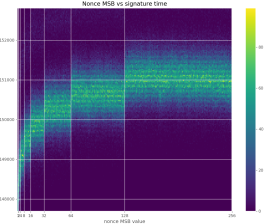
Leakage

t


Nonce MSB vs signature time
signature time (µs)
nonce MSB value
MSB(k)

Leakage

Athena IDProtect



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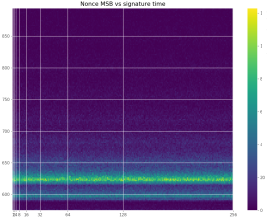

MSB(k)

Leakage

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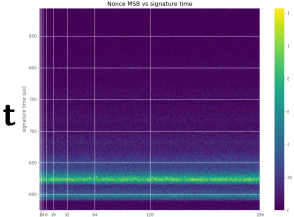

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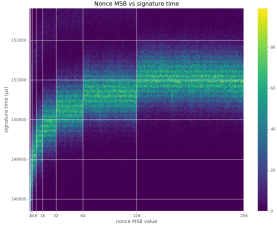
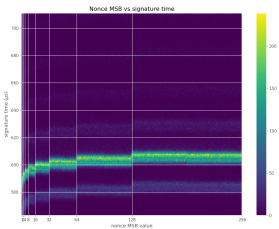
MSB(k)



SunEC/Java



Leakage

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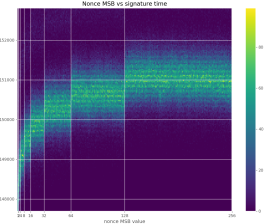
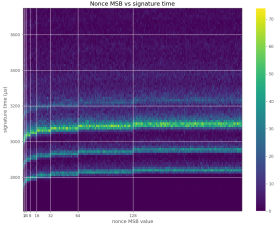


libgcrypt



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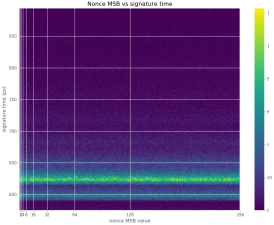

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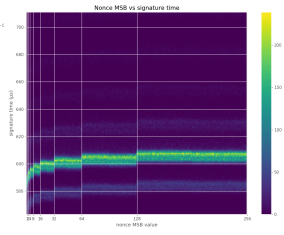

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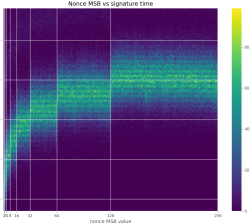
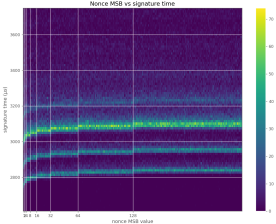


libgcrypt



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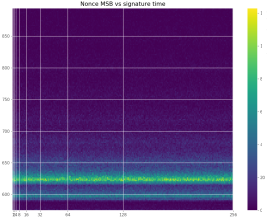
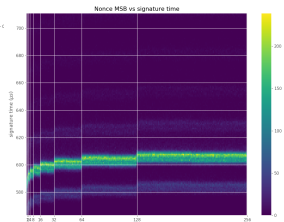
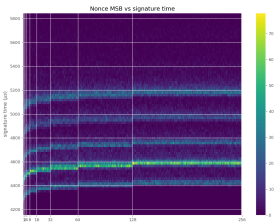


MSB(k)

SunEC/Java



MatrixSSL



Leakage

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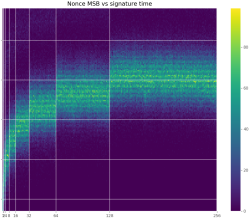
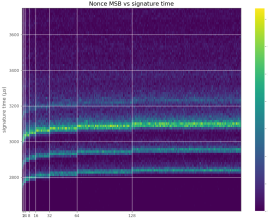
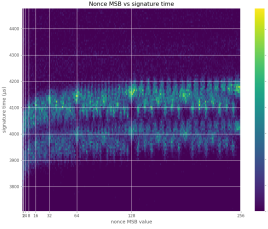


libgcrypt



Crypto++



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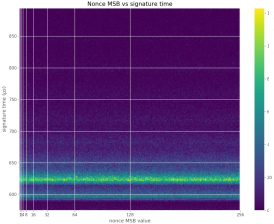

MSB(k)

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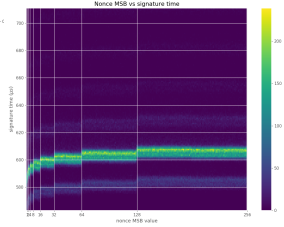

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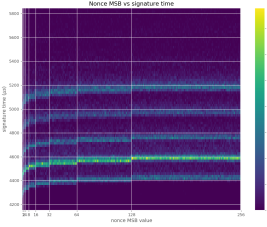
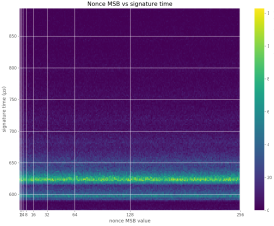


Leakage



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MSB(k)

FIPS VALIDATED 140-2 ™

Common Criteria

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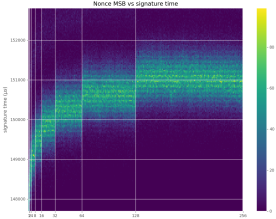
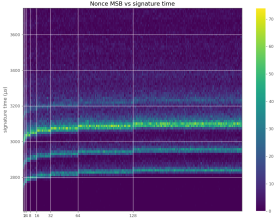
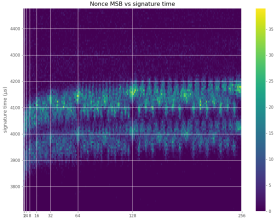


libgcrypt



Crypto++



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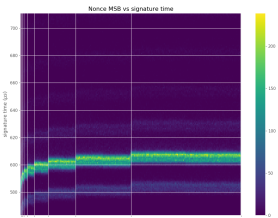
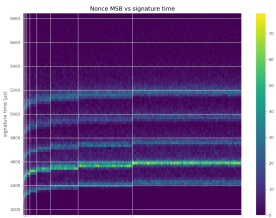
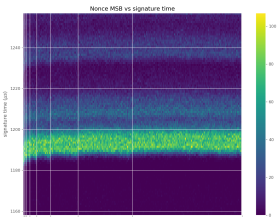


MatrixSSL

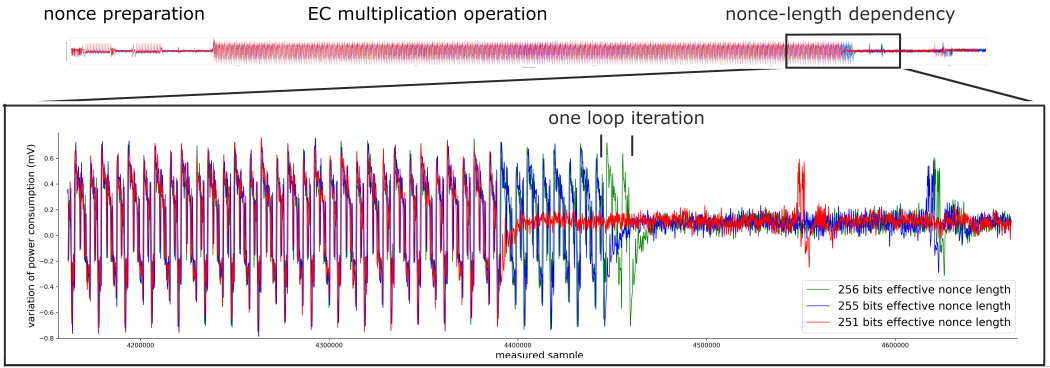


WolfSSL



Leakage

[k]G


nonce preparation
EC multiplication operation
nonce-length dependency
one loop iteration
variation of power consumption (mV)
measured sample
256 bits effective nonce length
255 bits effective nonce length
251 bits effective nonce length

Exploitation

Noisy bit-length of $k \rightarrow$ HNP [1] $\rightarrow$ CVP or SVP $\rightarrow$ private key

- Collect N signatures, take d fastest
- Assume bounds l_i
- Form inequalities $|k_i| = |t_i x - u_i| < n/2^{l_i}$
- Construct HNP lattice and target vector
- Solve via CVP/SVP
- Get the key!

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Recentering?

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- Solve via CVP/SVP **Which?**
- Get the key!

Recentering?

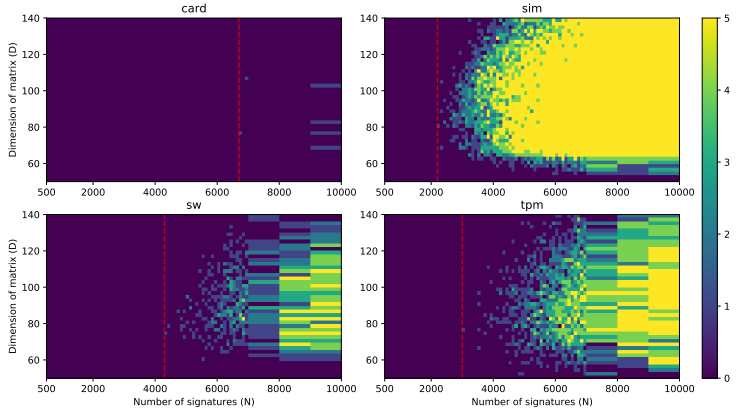
Nonce differences?

Random subsets?

u-bitflips?

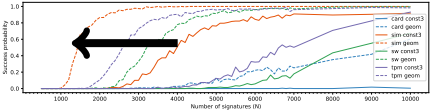
Analysis

- 4 datasets of signatures, varying noise, `secp256r1` curve
- Run attack 5 times for grid of (N, d)



#Successes
(out of 5)

Analysis



- **Bounds** l_i
  - Constant or geometric (✸ **new**)

Analysis

- **Bounds** l_i
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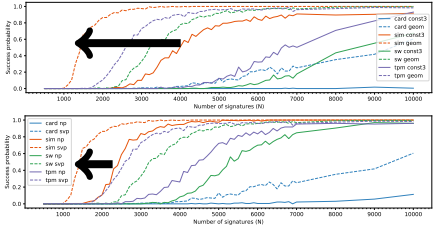
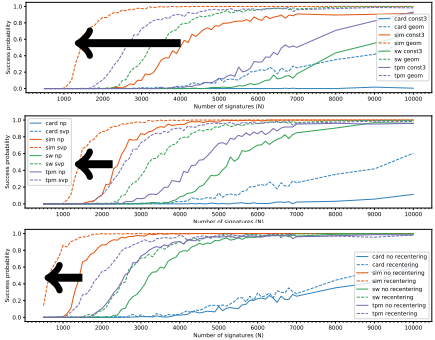
- **CVP/SVP**
  - CVP via Babai or embedding into SVP



Analysis

- **Bounds** l_i
  - Constant or geometric (✸ **new**)
- **CVP/SVP**
  - CVP via Babai or embedding into SVP
- **Recentering**
  - $|k_i - n/2^{l_i+1}| < n/2^{l_i+1}$



Analysis

- **Bounds** l_i
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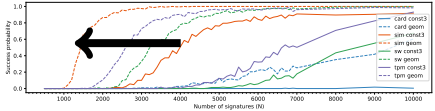
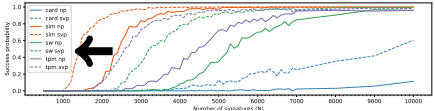
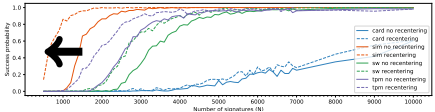
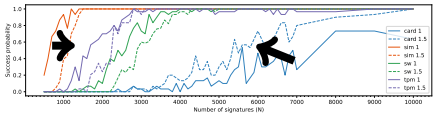
- **CVP/SVP**
  - CVP via Babai or embedding into SVP
- **Recentering**
  - $|k_i - n/2^{l_i+1}| < n/2^{l_i+1}$, yes
- **Random subsets**
  - random d out of $1.5d$ fastest



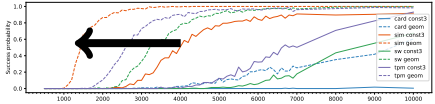


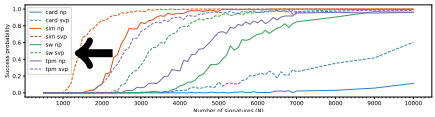


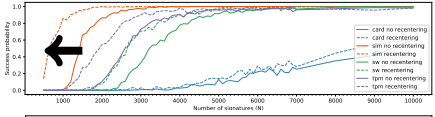


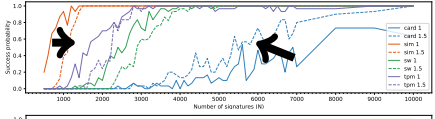
Analysis

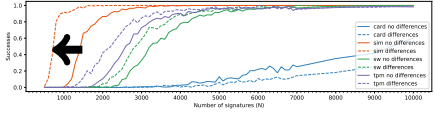
- **Bounds l_i**
  - Constant or geometric (✹ **new**)
- **CVP/SVP**
  - CVP via Babai or embedding into SVP
- **Recentering**
  - $|k_i - n/2^{l_i+1}| < n/2^{l_i+1}$, yes
- **Random subsets**
  - random d out of $1.5d$ fastest, yes, if ↑ errors
- **Nonce differences**
  - $|k_i - k_j| < n/2^{min(l_i,l_j)}$





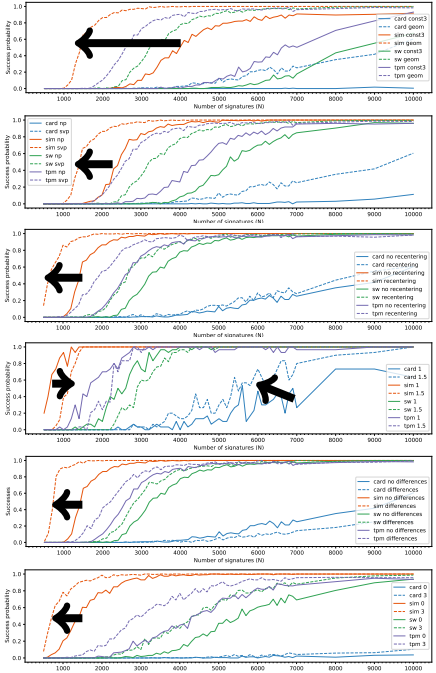






Analysis

- **Bounds l_i**
  - Constant or geometric (✹ **new**)
- **CVP/SVP**
  - CVP via Babai or embedding into SVP
- **Recentering**
  - $|k_i - n/2^{l_i+1}| < n/2^{l_i+1}$, yes
- **Random subsets**
  - random d out of $1.5d$ fastest, yes, if ↑ errors
- **Nonce differences**
  - $|k_i - k_j| < n/2^{min(l_i,l_j)}$, like recentering
- **u-bitflips with CVP** (✹ **new**)
  - Brute-force and CVP solve



Analysis

- **Bounds l_i**
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- **CVP/SVP**
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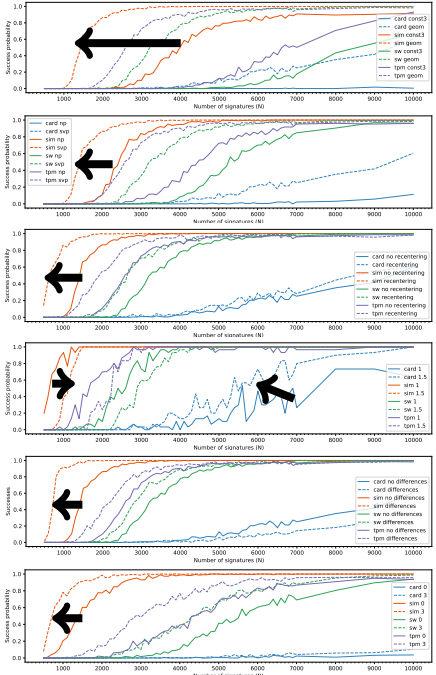

Conclusions

- Private key extraction in ECDSA
  - CC EAL4+ smartcard, 5 libraries
- Two new methods
  - Geometric bounds
  - *u*-bitflips
- Systematic analysis of lattice attacks on bit-length leakage
- Attack on data from the TPM-FAIL paper [3], with only 900 signatures, instead of 40 000

Thanks!

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The paper: minerva.crocs.fi.muni.cz

Icons from Noun Project & Font Awesome

Photos from Unsplash

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