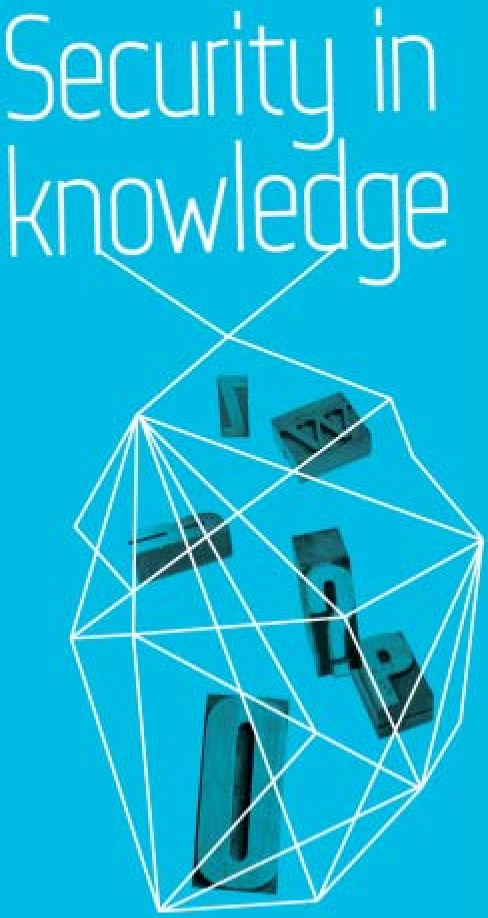
RSA CONFERENCE 2013

Is your design leaking keys? Efficient testing for side-channel leakage



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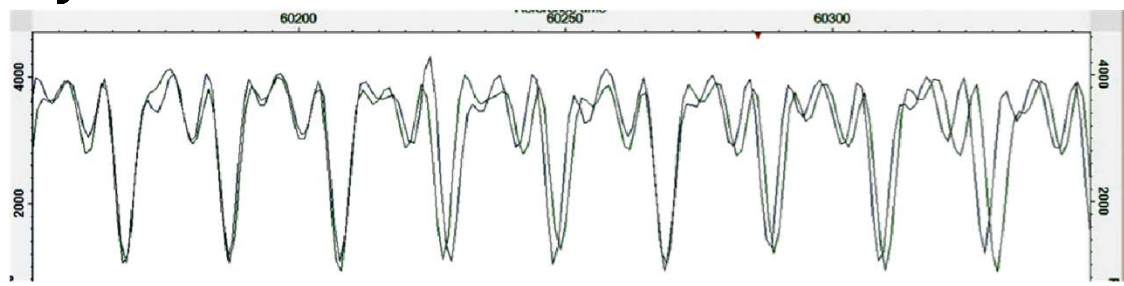
Session Classification: Advanced

Side-channels: The current state of (in)security

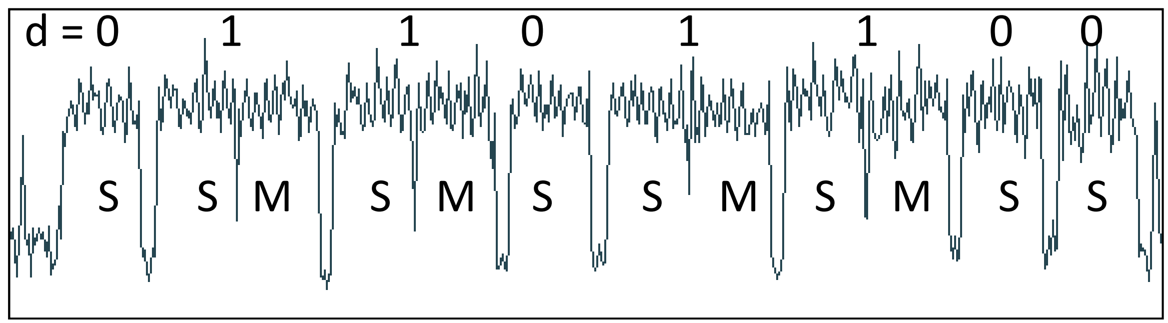
- From HSMs to mobile devices, cryptographic implementations easily succumb to side-channel attacks



RSA: Electromagnetic side-channel information leakage from a modern FIPS 140-2 Level 3 HSM. EM emissions traces from the HSM are different for two different keys

RSA Private Key Operation:
Computing **M^{d}** mod N

For each bit of secret exponent **d**
  if bit == 0, perform **Square (S)**
  if bit == 1, perform **Square (S)**
    followed by **Multiply (M)**
EndFor



RSA: Side-channel vulnerability on modern smart phone EM trace shows Square(S)/Multiply(M) operation sequence during modular exponentiation , revealing secret exponent d

Side-channel (in)security: What's being done

- Side-channel resistance requirements are being added to security standards
  - E.g., FIPS 140-3 Draft
- But testing seen as a challenge
  - Vulnerabilities cross many abstraction layers
  - Countermeasures can't be applied and verified at a single layer
    - Cannot be validated without physical testing
  - Evaluation-style side-channel testing is the norm
    - E.g.: Common Criterion, EMVCo
    - Costly, time consuming & requires high degree of lab expertise

Testing styles: Validation vs. Evaluation

Validation

- E.g., FIPS 140-2
- Demonstrate conformance to specification
- Structured test/check methodology

+ **Defined tasks**
+ **Lab consistency**
+ **Cost effective**
- New vulnerabilities not addressed
- No penetration testing
- Only as good as spec and test plan coverage

Evaluation

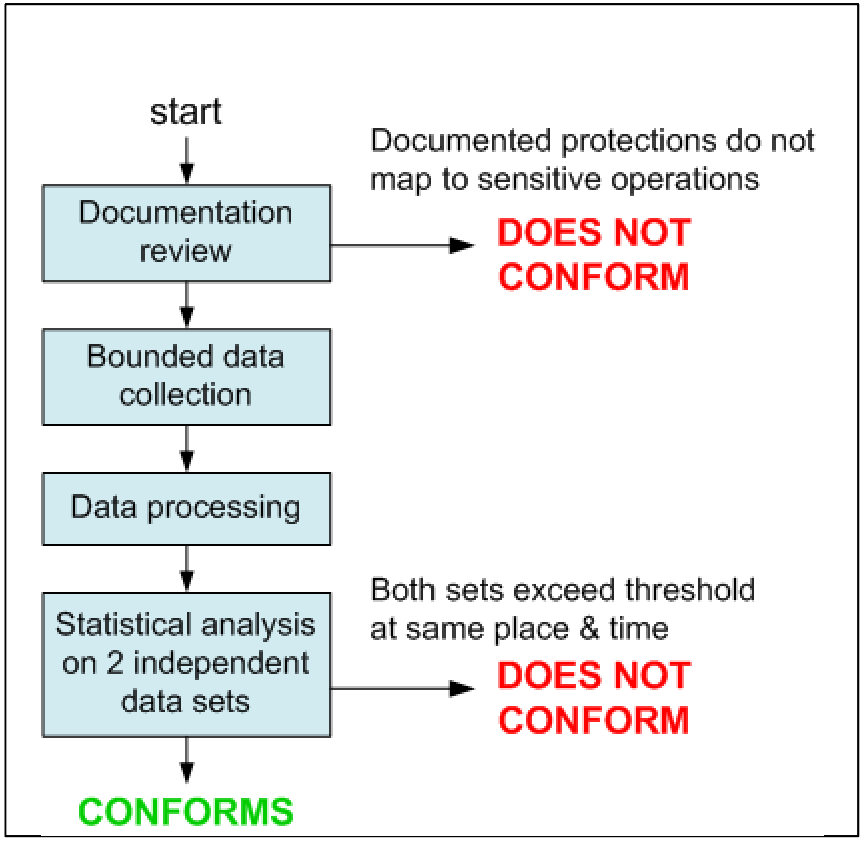
- E.g., Common Criteria
- Defined security environment and threat model
- Intrinsic risk assessment

+ **Threat based analysis**
+ **Best use of lab expertise**
+ **Flexibility**
- Limited by lab expertise
- Potential inconsistency of evaluations
- Higher cost

With a good specification and test coverage, validation approach can be low-cost, yet effective

Effective, low cost, validation-based side-channel testing is possible

- Test vector leakage assessment (TVLA) methodology
- Highlights
  - Pre-specified set of test vectors, chosen by experts
  - Pre-specified set of tests on collected data, designed by experts
  - Standard statistical test of significance, with clear pass/fail criteria
- Main idea: focus on identifying statistically significant information leakage, not key extraction
  - Detecting leakages is much easier
  - With (much) additional effort, leakages lead to key extraction attacks



Core statistical test (Univariate leakage)

- Each test specifies and compares two subsets A & B of collected traces
  - Some sensitive Intermediates will be different in subsets A and B if the implementation not properly protected
  - Statistically significant difference between subsets → sensitive information leakage → device fails
- Statistical test: Welch's t-test for significance of "difference of means"

$$t(I) = \frac{X_A(I) - X_B(I)}{\sqrt{\frac{S_A^2(I)}{N_A} + \frac{S_B^2(I)}{N_B}}}$$

- Test performed twice on two independent data sets
  - Failure must occur at the same time-instant in both tests

AES testing specification: moderate resistance

Data collection:

- Specified number of side-channel traces to collect:
  - Trace based: “at least 1,000,000 traces”
  - Time based: “up to 1 day of data collection by attacker”
- Test vectors for AES (AES 128, 192, 256)
  - Fixed key K
  - “Random” data set
    - Successive AES encryptions starting from a fixed plaintext block
  - “Fixed” data set
    - Repeated encryptions of the same fixed plaintext block
    - Selected to trigger special conditions within AES

AES testing specification: cont

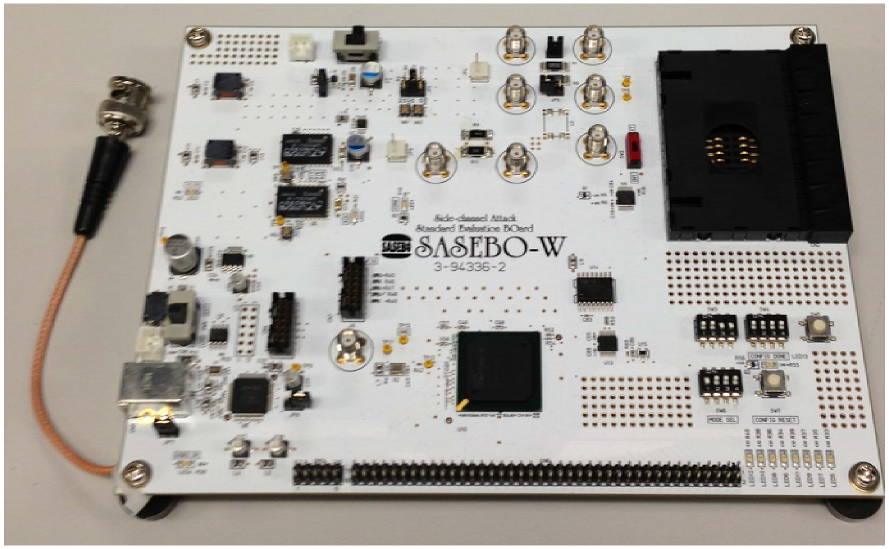
Tests: Six Categories

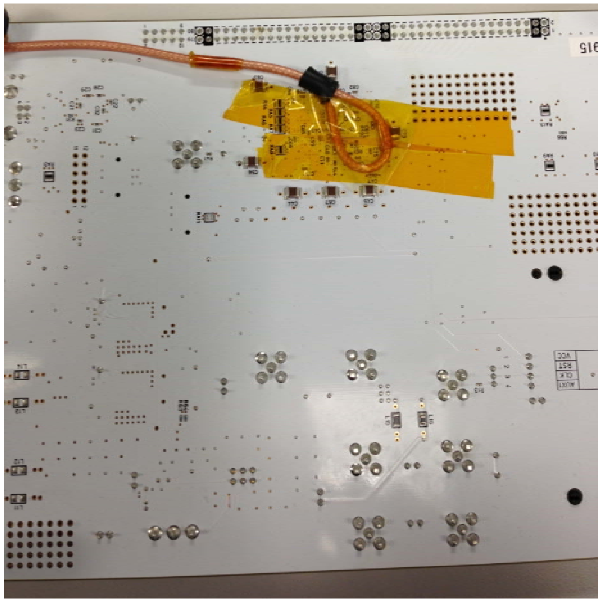
- **Non-specific** leakage test: fixed vs. varying data
  - Examine middle third of operation
- Five varying data tests targeting **specific leakages**
  - XOR of round input and output
  - S-box outputs in a round
  - Round output
  - Value of 1^{st} byte of round output
  - Value of 2^{nd} byte of round output

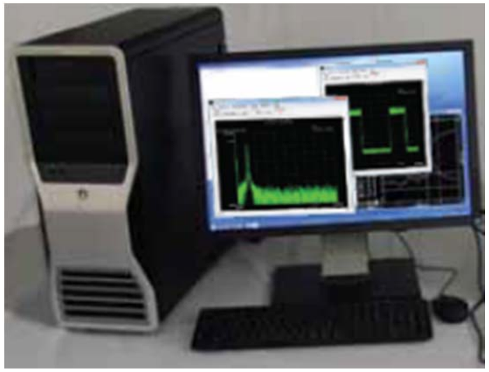
Pass/Fail criteria:

- Fail if t-statistic exceeds ±4.5 for two independent data sets at the same point in time

Live Demo: Testing unprotected AES on FPGA







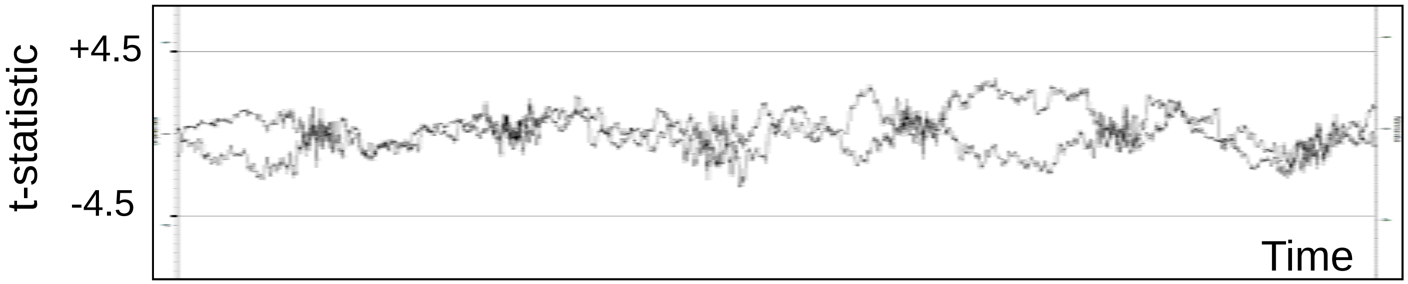
Failure condition reached within in 2 minutes of data collect/analysis

Example: Masked AES on FPGA

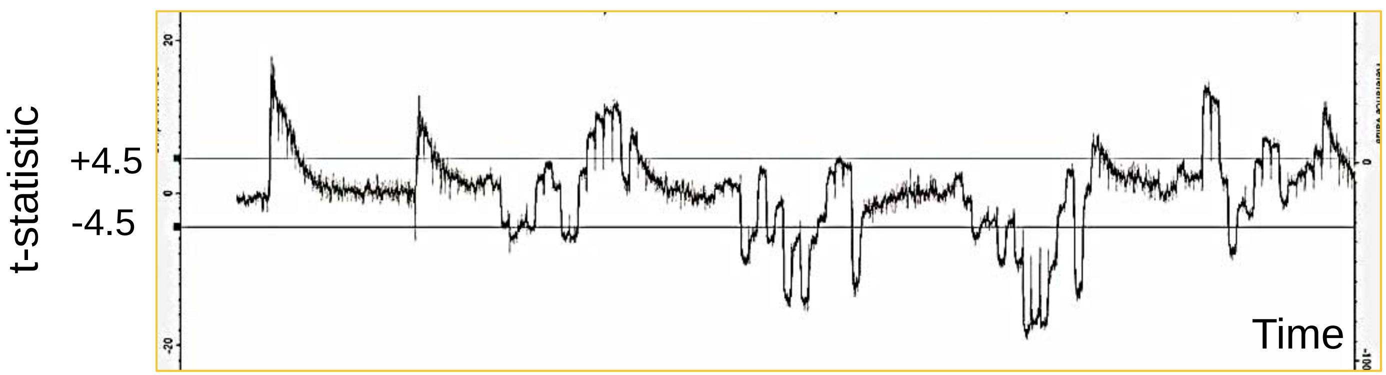
- DUT: Hardware AES implementation on FPGA with masking countermeasure
  - Countermeasure not fully effective
- Automated data collection
  - DUT supports 20 traces/second
  - Bulk ECB encryption allows 10000 ops/2 minutes
  - Overnight data collect using ECB mode: 3 million AES ops

- Result is a **definitive FAIL**
  - Passed all specific leakage tests
  - **Failed non-specific Fixed vs. Random test**
- **Less than 24 hours data collect + analysis**

Masked AES: Passing and failing tests



T-test traces for two independent data sets for XOR leakage: t-statistic remains between +/- 4.5 throughout the round: PASS



T-test trace for FIXED vs. RANDOM leakage test: t-statistic has large excursions beyond +/- 4.5: FAIL !

Test specification for RSA

Test Vectors Sets

- Set 1
  - Constant key, constant ciphertext
  - Baseline
- Set 2
  - Same constant Key, varying ciphertext
- Set 3
  - Varying key, same constant ciphertext
- Set 4
  - Same constant key, ciphertext from a set of "special values" (28 different cases used in our experiments)
- Set 5
  - Same constant key, ciphertext corresponding to small messages

Tests

- Test 1: t-test Set 2 vs. Set 1
- Test 2: t-test Set 3 vs. Set 1
- Test 3: t-test Set 4 vs. Set 1
- Test 4: t-test Set 5 vs. Set 1

Alignment at multiple points

- start, end, middle (CRT)

Pass/Fail criteria

- **t-statistic exceeds +/- 4.5** for two independent data sets A and B at same time location

Example: DUT implementing RSA exponent and data blinding, but not prime blinding

Conclusion

- Low-cost and effective testing for side-channel resistance is possible

- Proposed tests for detecting leakage also useful to product designers implementing countermeasures
  - Specialized attack knowledge not required to perform tests
  - Non-specific tests capture large classes of leakages
  - Quick turn-around
  - Failed tests provide feedback to designers about remaining leakages

Thank You !

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