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On the Complexity Reduction of Laser Fault Injection Campaigns using OBIC Measurements

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13.09.2015, Fault Diagnosis and Tolerance in Cryptography, FDTC 2015, Saint Malo, France.

Motivation

Fault injection into integrated circuits

- Clock glitches
- Voltage alterations
- EM
- Light (UV, flash lamps, **laser**)

Parameters for **successful** fault injection

- Timing (clock cycle and time within clock cycle)
- Length
- Physical intensity

Additional parameters for laser fault injection

- Focus (/spot size) (z)
- Location (x/y)
- **Doubled** for two-spot systems

➔ **Large search space, exhaustive search might be infeasible**

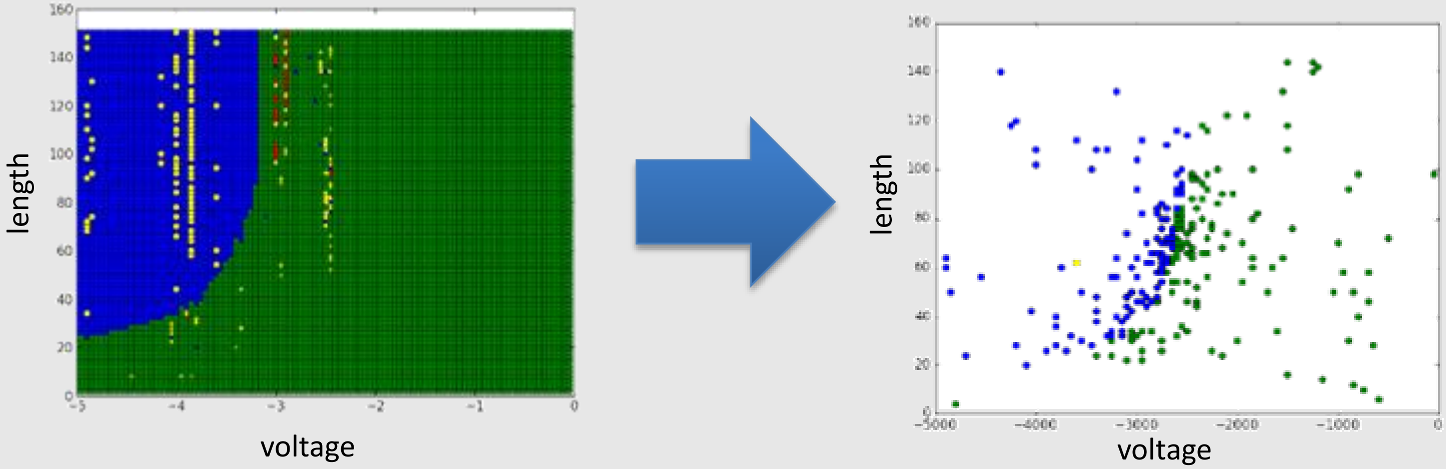
Reducing Search Space (1)

Carpi et al.: “Glitch It If You Can: Parameter Search Strategies for Successful Fault Injection”, CARDIS13

Picek et al.: “Evolving genetic algorithms for fault injection attacks”, MIPRO14

Picek et al.: “Fault Injection with a new Flavor: Memetic Algorithms make a difference”, COSADE15 (*)

Idea: Use machine learning for finding parameters



Hardly applicable to all parameters (timing, laser location)

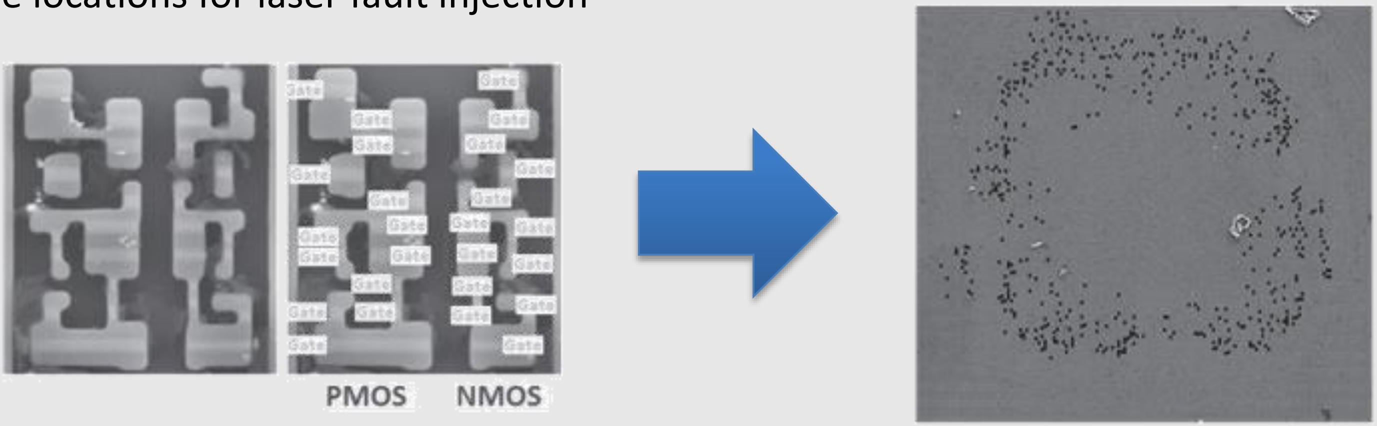
(*) Image Source

Reducing Search Space (2)

Franck Courbon et al.: “Increasing the efficiency of laser fault injections using fast gate level reverse engineering”, HOST14

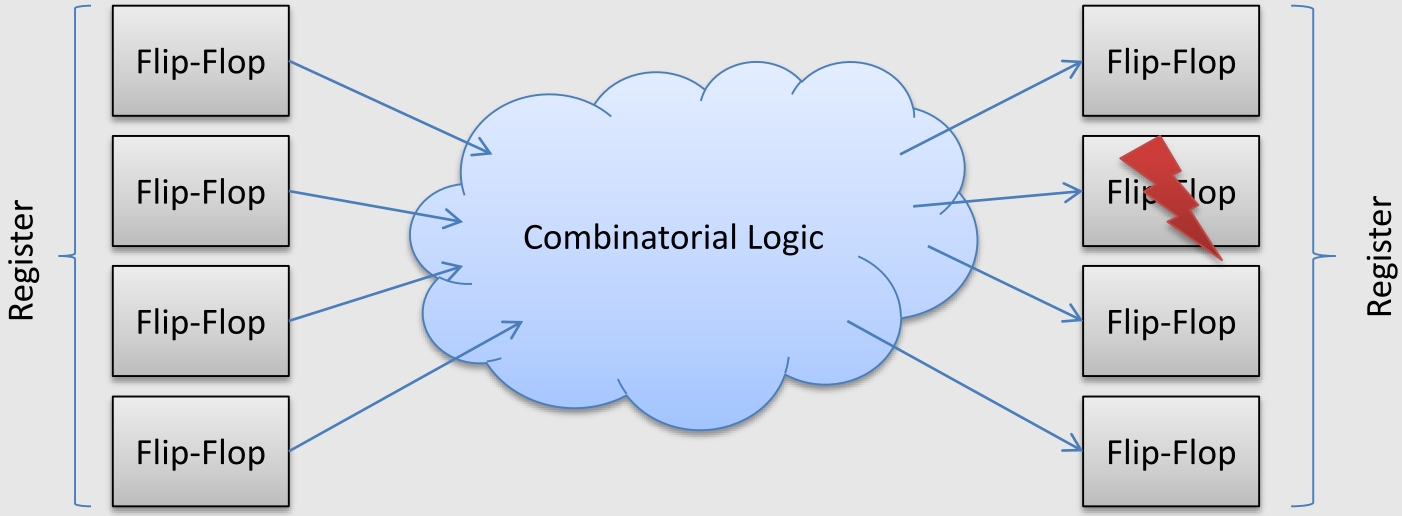
Idea:

1. Grind/polish down to doped area
2. Capture SEM images, identify **flip-flops**, find all other instances by correlation
3. Use locations for laser fault injection



Requires access to SEM, profiling sample gets destroyed

Importance of Flip-Flops



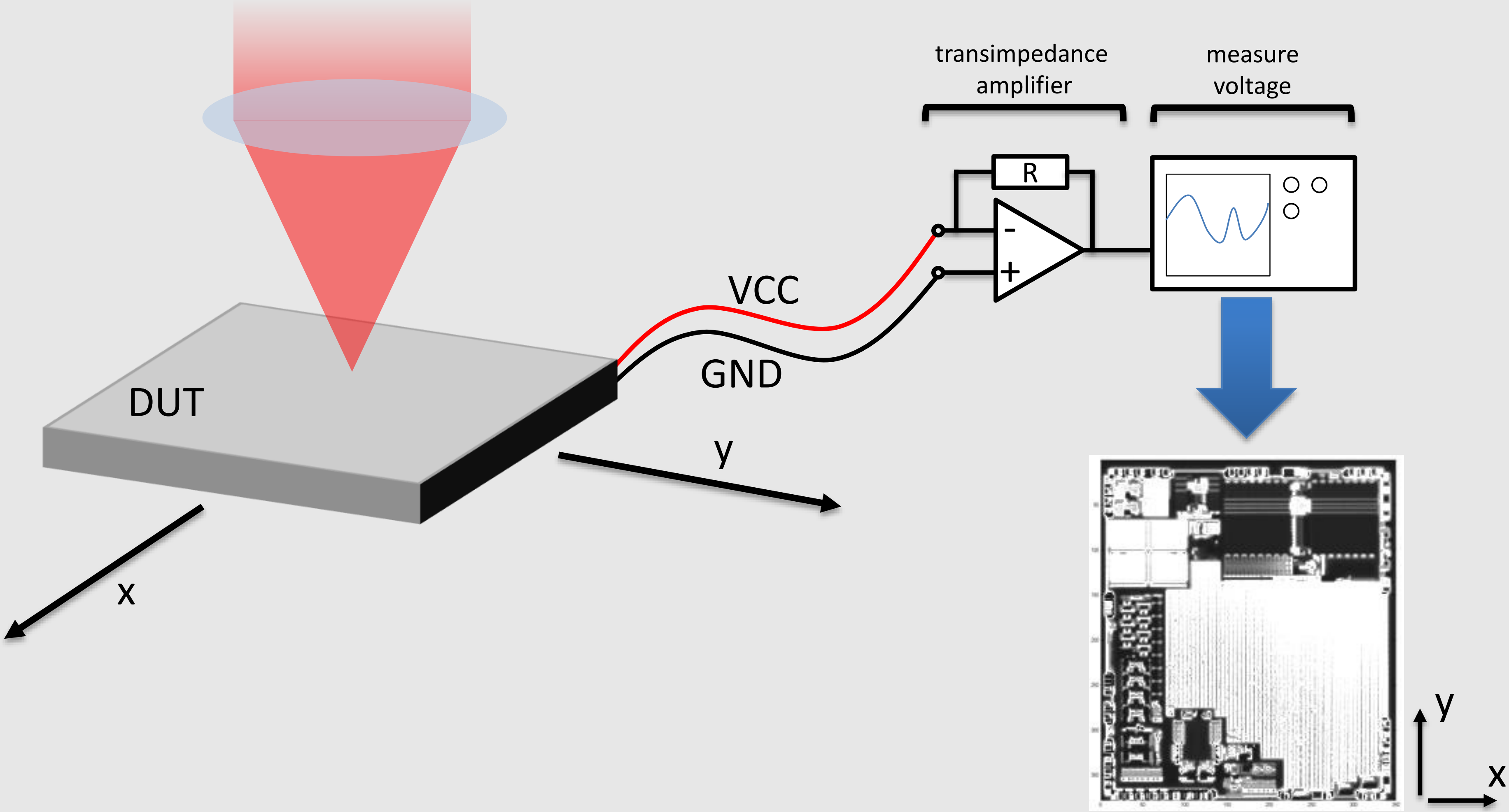
Fault has to be stored by a register, otherwise no effect

By directly targeting flip-flops

- Every possible single bit fault
- However, no multi bit faults

Optical Beam Induced Current

In a nutshell:
Use DUT as “really bad” photodiode → Measure current created at pn-junctions



Our Proposal

Optical Beam Induced Current (OBIC) as imaging technique

- High resolution
- Identify locations (x,y,z)
- Find flip-flops

→ Reduces number of *Points of Interest* drastically

Advantages:

- Independent of other parameters (e.g., power, delay, length)
- Chip is not powered → no countermeasures can be active
- Minimal equipment overhead
- Possible with “every” laser setup

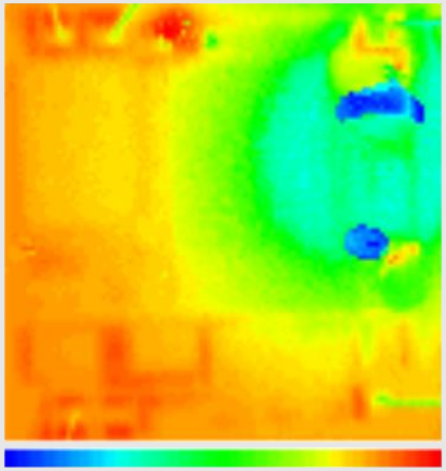
Disadvantage:

- Resolution not as powerful as SEM etc.

OBIC in Literature

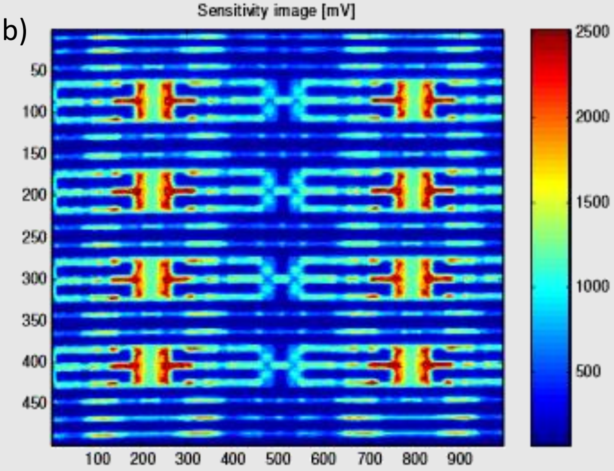
- Well-know in (production-) fault analysis
- Security context:

(a)



Unknown chip, backside!

(b)

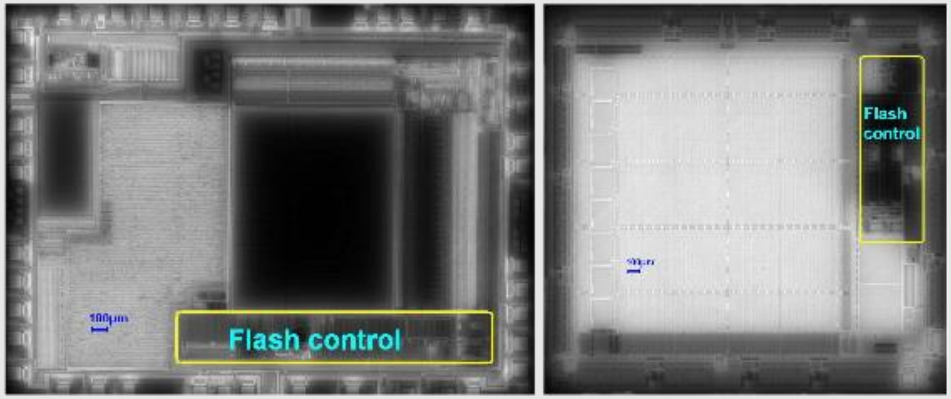


Motorola µC, SRAM, frontside

(c)

Microchip µC, 0.9µm, SRAM, frontside

(d)



NEC µC, 0.35µm, backside

Actel FPGA, 0.13µm, backside

Image Sources:

(a) van Woudenberg et al., Practical optical fault injection on secure microcontrollers, FDTC11

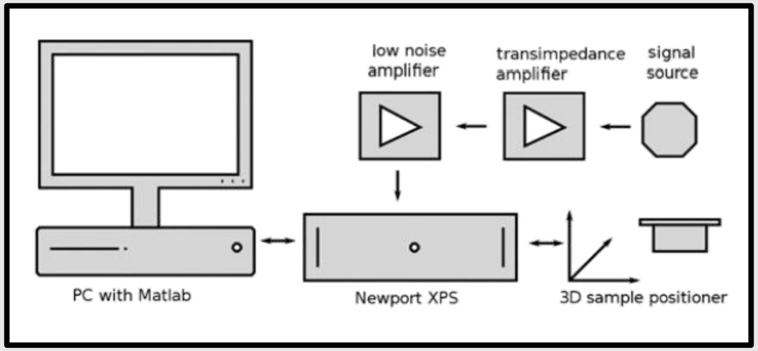
(b) Skorobogatov, Semi-invasive attacks - A new approach to hardware security analysis, 2005

(c) Skorobogatov, Optically enhanced position-locked power analysis, CHES06

(d) Skorobogatov, Flash memory 'bumping' attacks, CHES 2010

Setup

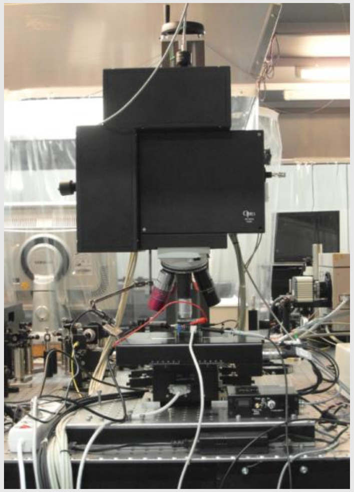
Measurement



Self-build setup

- Lumics laser diode at 1064nm, SMF
- Leica NIR objective (NA 0.75, 100x)
- Newport XPS with motorized stages
- FEMTO transimpedance amplifier connected to VDD/GND
- Stanford Research low noise amplifier

Fault Injection



Modified commercially available LFI setup

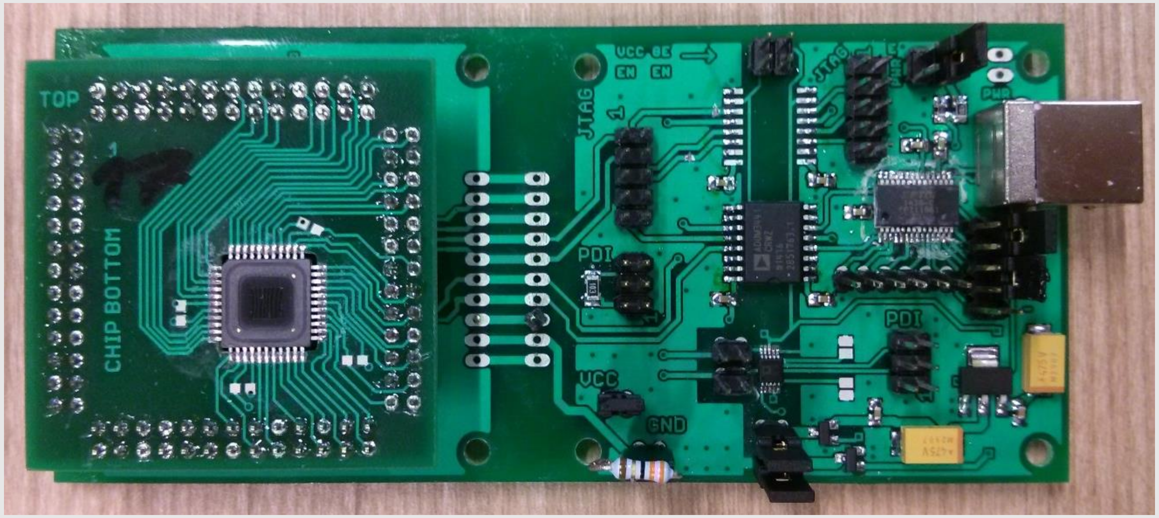
- Alphanov PDM 975nm 2W diode, SMF
- Mitutoyo Plan Apo NIR HR (NA 0.65, 50x)
- Märzhäuser and PI stages

Image Source: alphanov.com

Case Study: ATXMega16A4U

ATXMega16A4U, 250nm

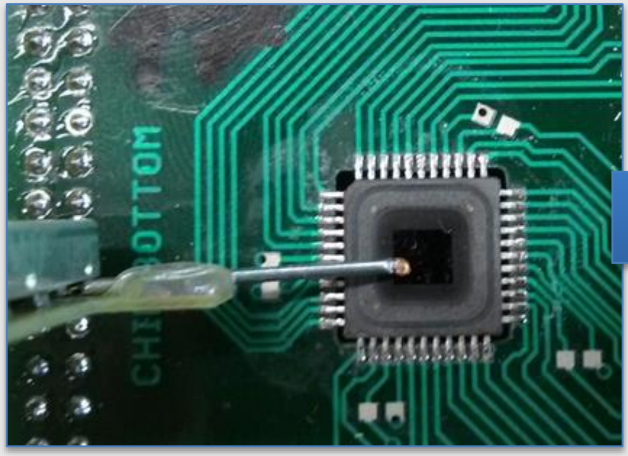
- Hardware Encryption
  - DES (“Round”-Instruction)
  - **AES** (Start/End-Flags)
- Backside thinned to approx. 20µm

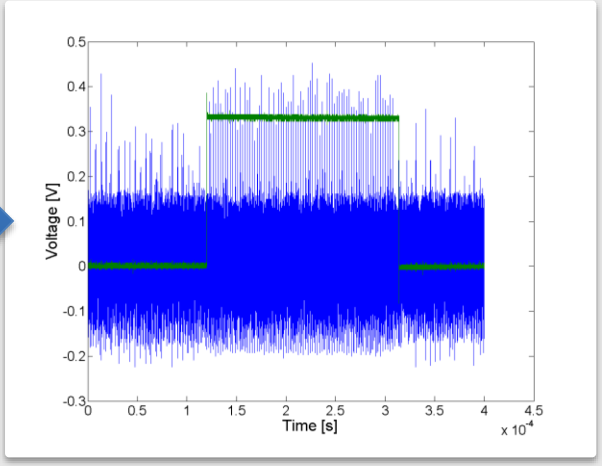


Case Study: ATXMega16A4U

(1) Rough estimation by EM analysis (optional)

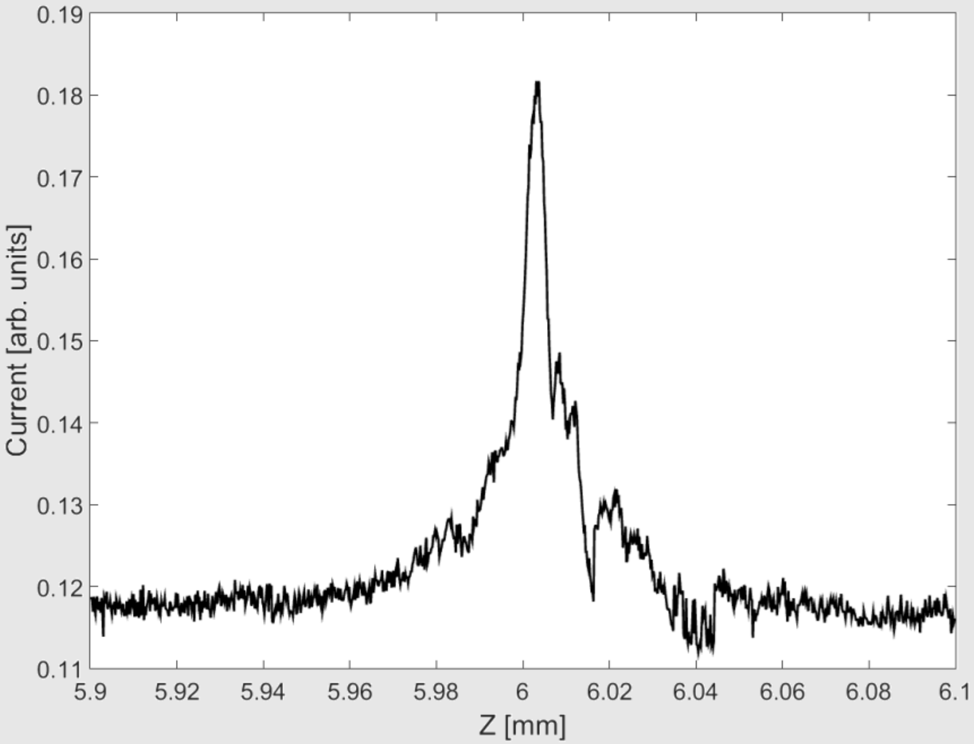
- Self-made probe with amplifier
- Trigger during encryption → clearly visible peaks





Case Study: ATXMega16A4U

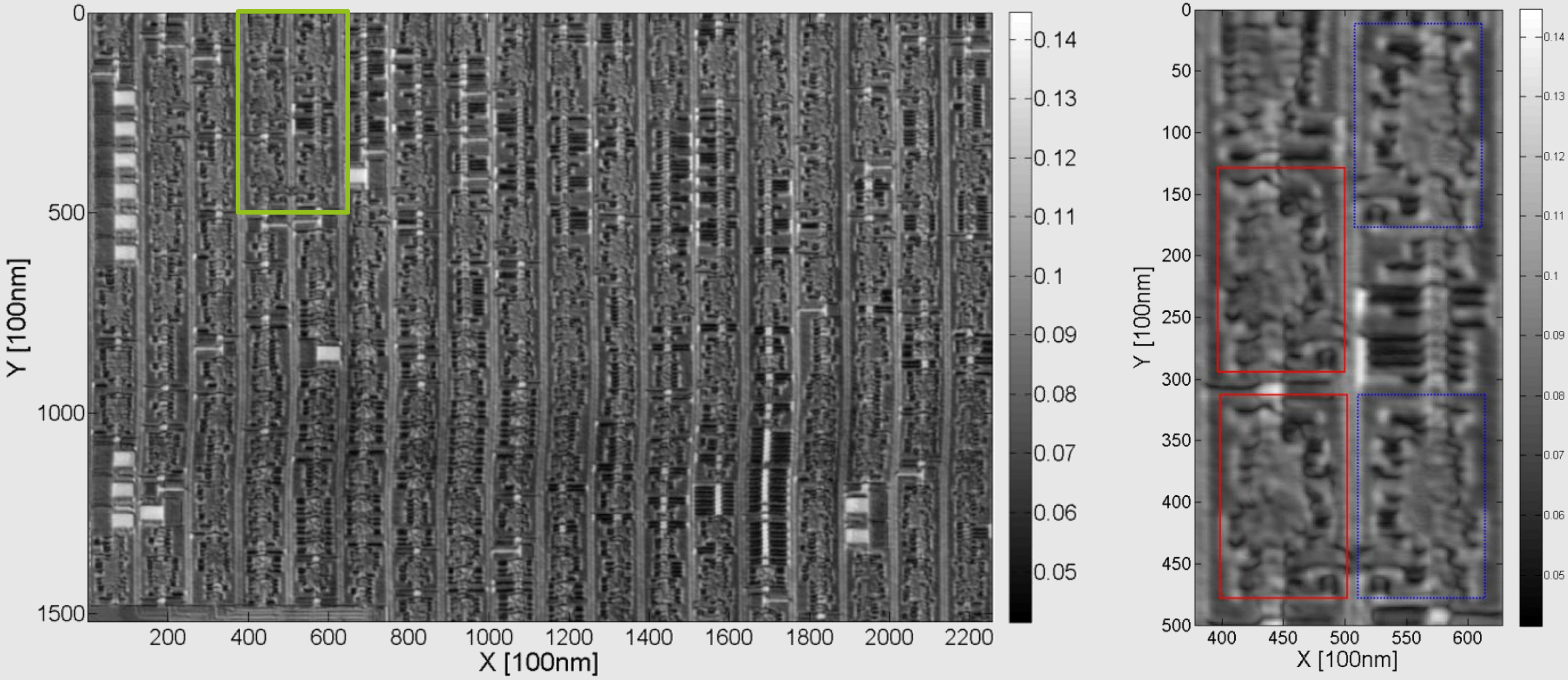
(2) OBIC Measurement around found area (z)



- Find focal plane resulting in maximum current
- → Optimal z-Position for OBIC and LFI
- Enables to account for tilted DUT with very high precision

Case Study: ATXMega16A4U

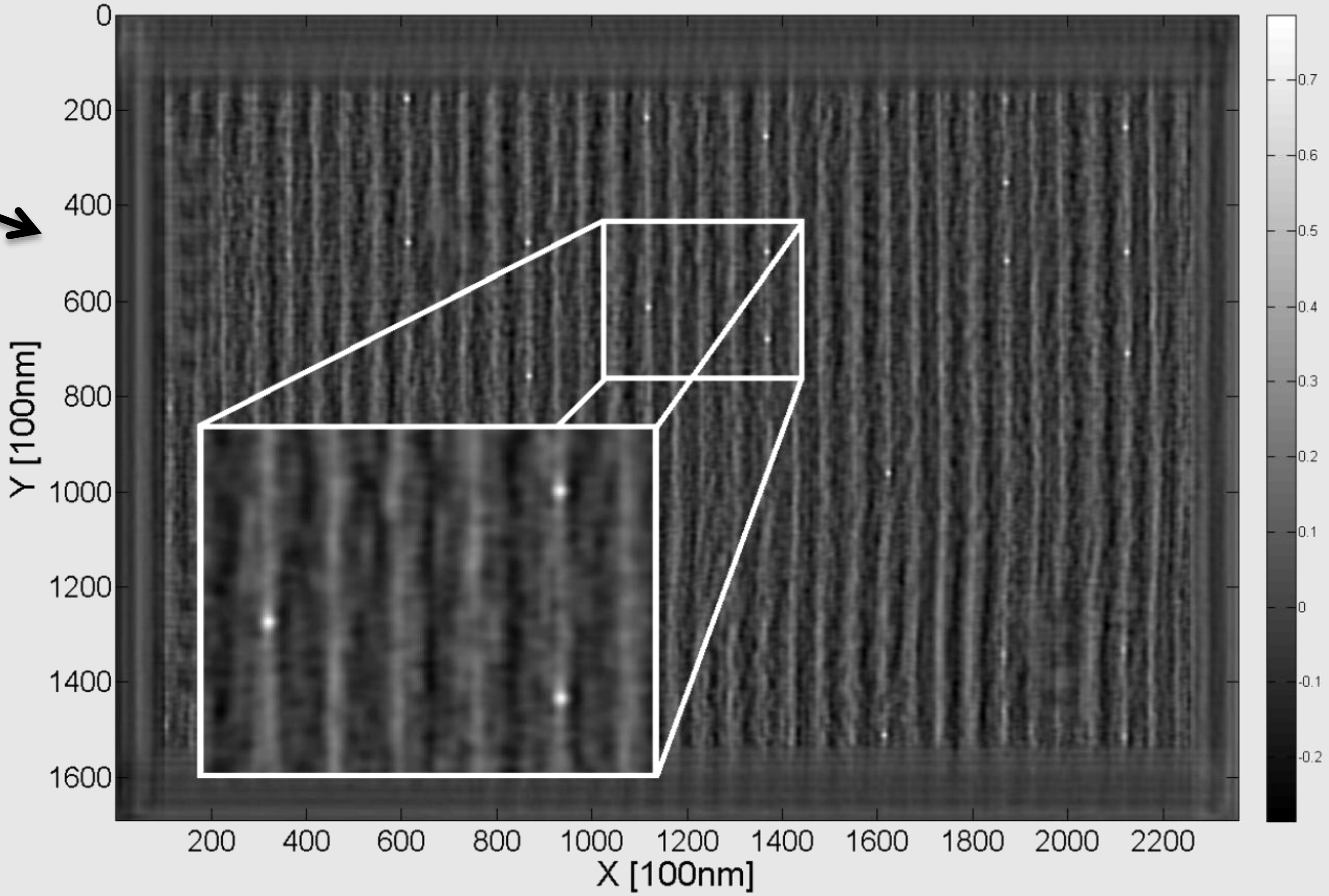
(2) OBIC Measurement around found area (x/y)



Case Study: ATXMega16A4U

(3) Correlation-Based Pattern Recognition

??



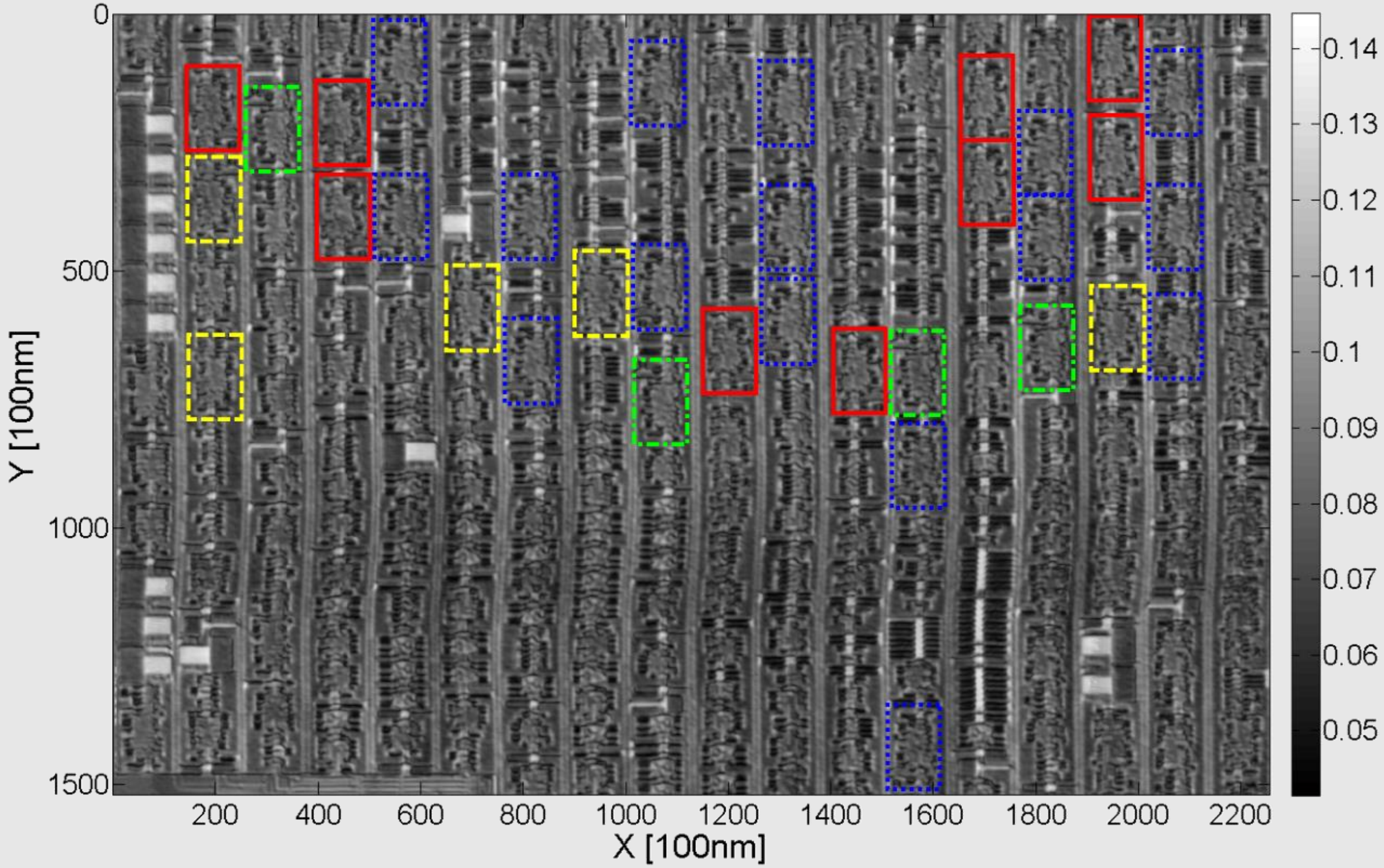
Pearson correlation 0.6 up to ~0.8

Four times for each orientation

In a matter of seconds

Case Study: ATXMega16A4U

(3) Correlation-Based Pattern Recognition



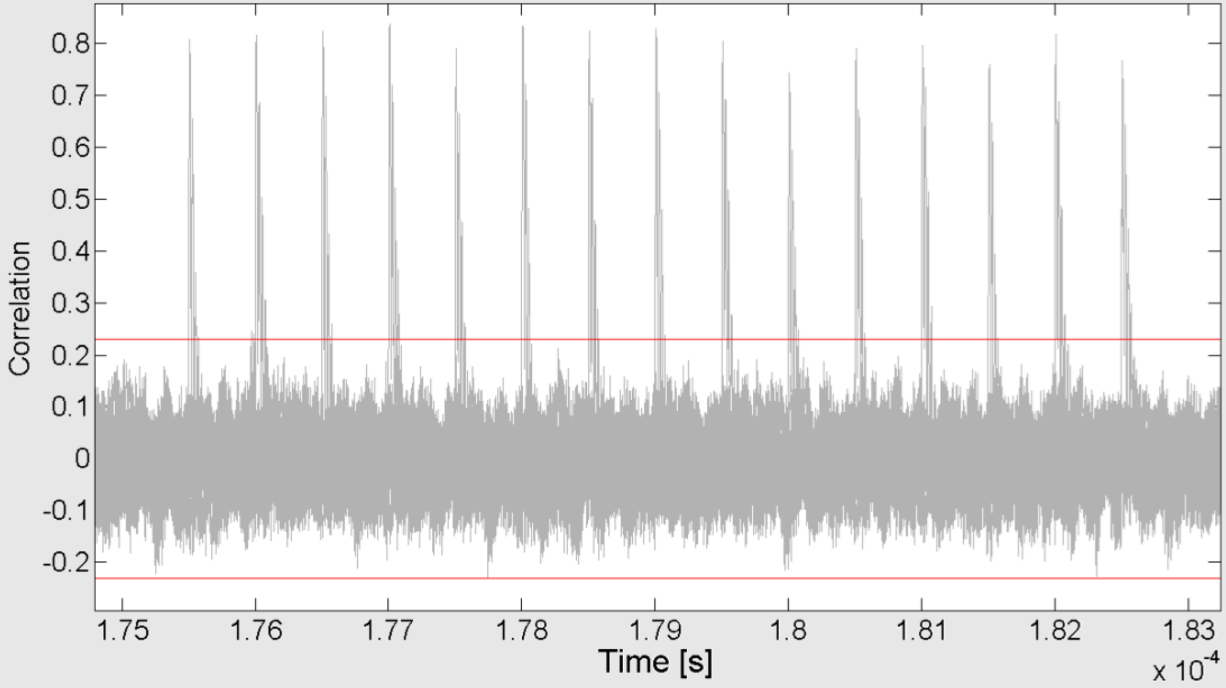
Colors consistent

Case Study: ATXMega16A4U

(4) Correct Timing (SHORTCUT)

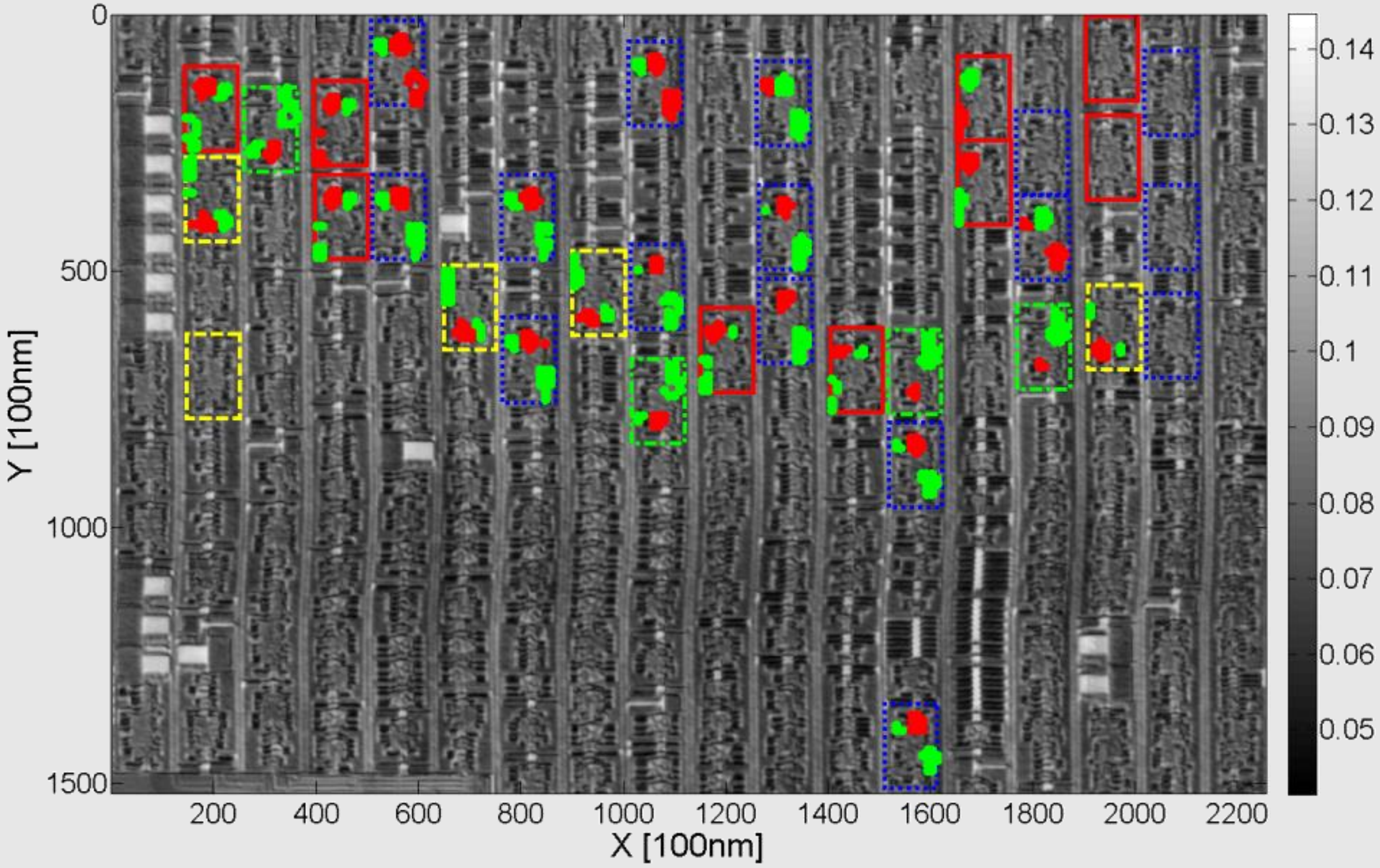
- Know-key correlation on intermediate values
- Example: Hamming Distance of state bytes s_i

  $HD(s_i, s_{i+1})$ at input of last round



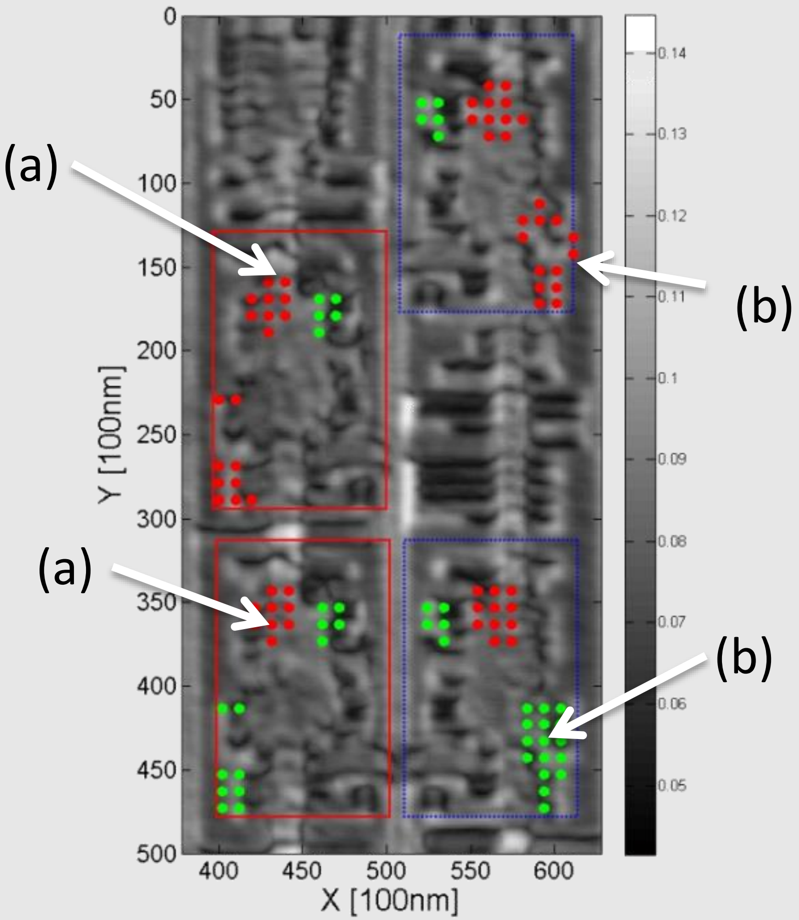
Case Study: ATXMega16A4U

(5) Laser Fault Injection



Case Study: ATXMega16A4U

(5) Laser Fault Injection - Detail



Calculated backwards based on known key

Green: Bit Set

Red: Bit Reset

(a) Complementary fault pattern consistent
→ Storage part?

(b) Changing third sensitivity zone
→ Clock input?
→ Reset?

Pattern identical when clock halted during LFI
→ Confirms flip-flop identification

Case Study: ATXMega16A4U

(6) Differential Fault Analysis

Straight-forward approach worked quite well:

1. Fault between MixColumns (9th round) and SubBytes (10th round) → **single byte faults at output**
2. Test for which key hypothesis the difference between faulty ciphertext and genuine ciphertext byte resolves to **single bit fault before SBox**

→ approx. two pairs ciphertext/faultytext per byte

Discussion (1)

Time Improvement

- Required time linearly depends on positions to test
- At 1µm steps for given area and 34 found flip-flops:
  - 255 * 150 = **38250** points exhaustive search
  - 34 * 17 * 10 = **5780** only flip-flop area
- Targeting only sensitive areas: 3 * 34 = **102**

Discussion (2)

Applicability

Influencing parameters

- Technology node (ATXMega16A4U: 250nm)
- Characteristic cell layout (ATXMega16A4U: 17µm*10µm area)
- *Effective* spot size (our setup: approx. 710nm calculated spatial resolution)

→ ATXMega16A4U: plenty of structural detail for given resolution

Smaller technology nodes:

- Averaging, fine-adjusting laser energy, 2-photon absorption, solid immersion lenses
- Potentially hard to *manually* identify flip-flops
- Autocorrelation?
- Future work..

Conclusion

- Used OBIC measurement as profiling to find flip-flops
  - Device shut off (no reactive countermeasures)
  - Independent of correct timing, pulse length (, energy)
- Reduced search space by factor of 6.6 or 375
- Successfully attacked ATXMega16A4U AES core

Countermeasures:

- Isolated power supply (probe bulk directly?)

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Thanks!
Questions?