Hardware attacks and software induced HW attacks and the need for separated trust anchors!

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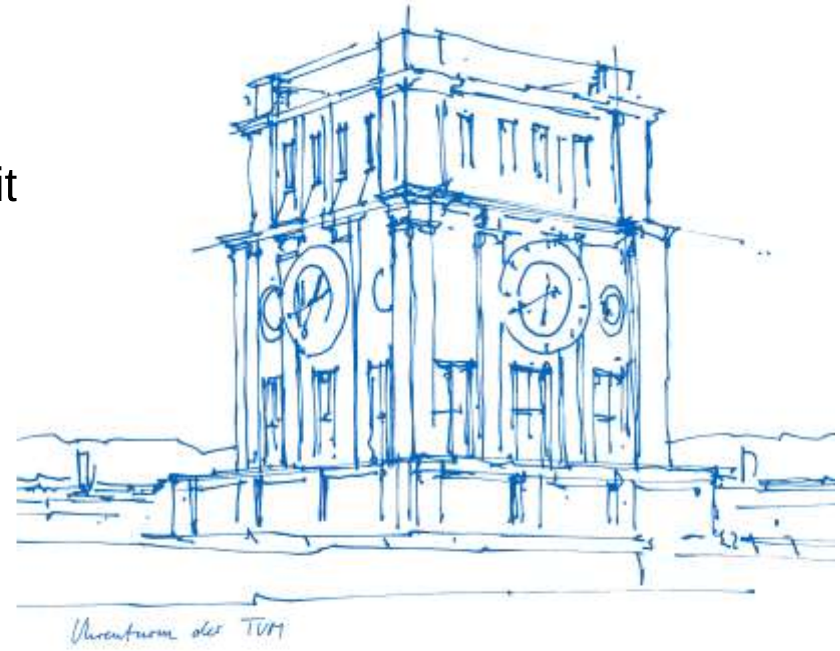
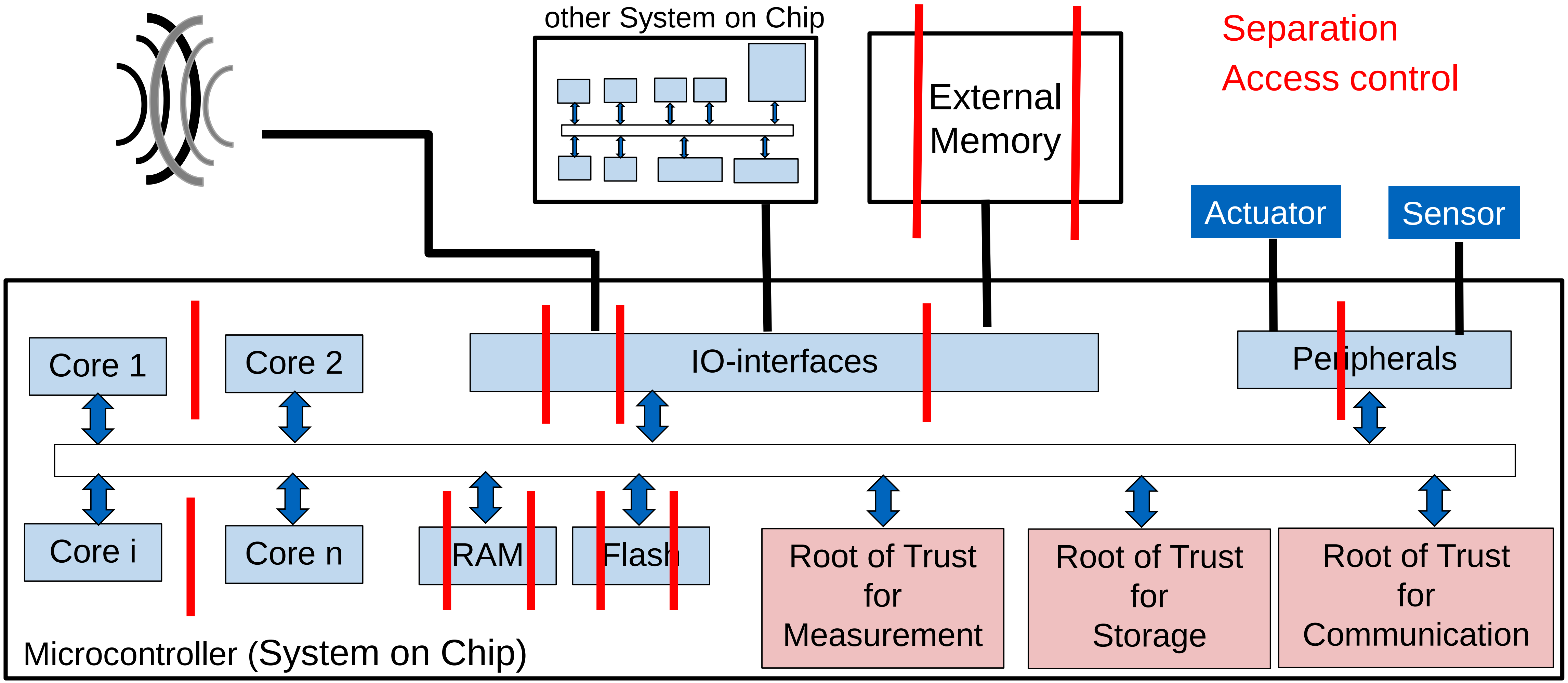


Security in Embedded Systems



Roots of Trust

- Root of Trust for Measurement
  - Program to measure code which runs on system in order to ensure system integrity
  - Program must not be changed by any attack and execution must be in a secure/isolated environment

- Root of Trust for Storage
  - Secret key which can be used to encrypt and authenticate externally stored information
  - Key should never leave SoC
  - Key must not leak to any other party

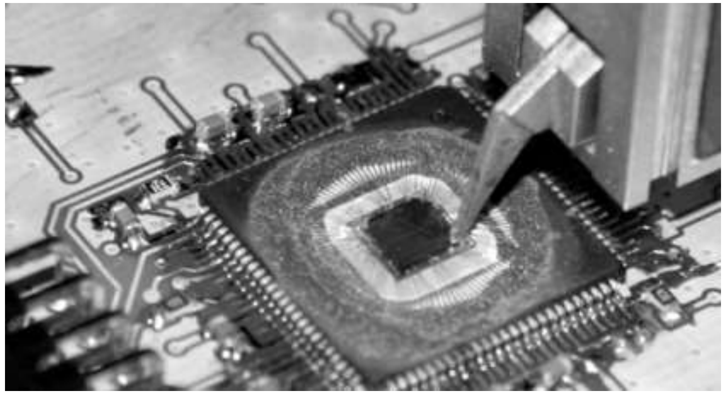
- Root of Trust for Communication
  - Asymmetric key pair for internet communication
  - Secret part of key pair must not leave SoC
  - Trusted public key of a certification authority

Attack types

- Hardware Attacks
  - Invasive
    - Reverse Engineering
    - Probing/Forcing (FIB)
  - Semi- and Non-Invasive
    - Fault Injection
    - Side Channel
- SW induced HW Attacks
  - Cache Attacks
    - Meltdown/ Spectre
    - Side Channel
  - Fault Attacks
    - Rowhammer
    - Clockskrew
- Software Attacks
  - Modification
    - Control Flow
    - Data
  - Information Extraction
    - Memory dump
    - Access control bypass

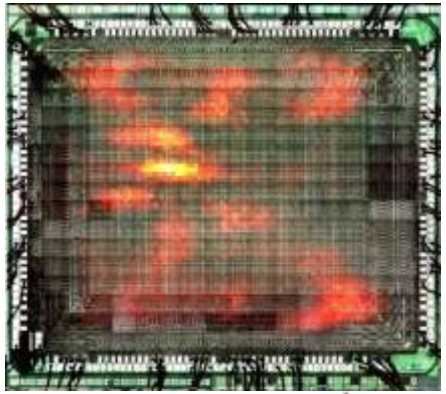
High-Resolution Magnetic Field Side-Channels

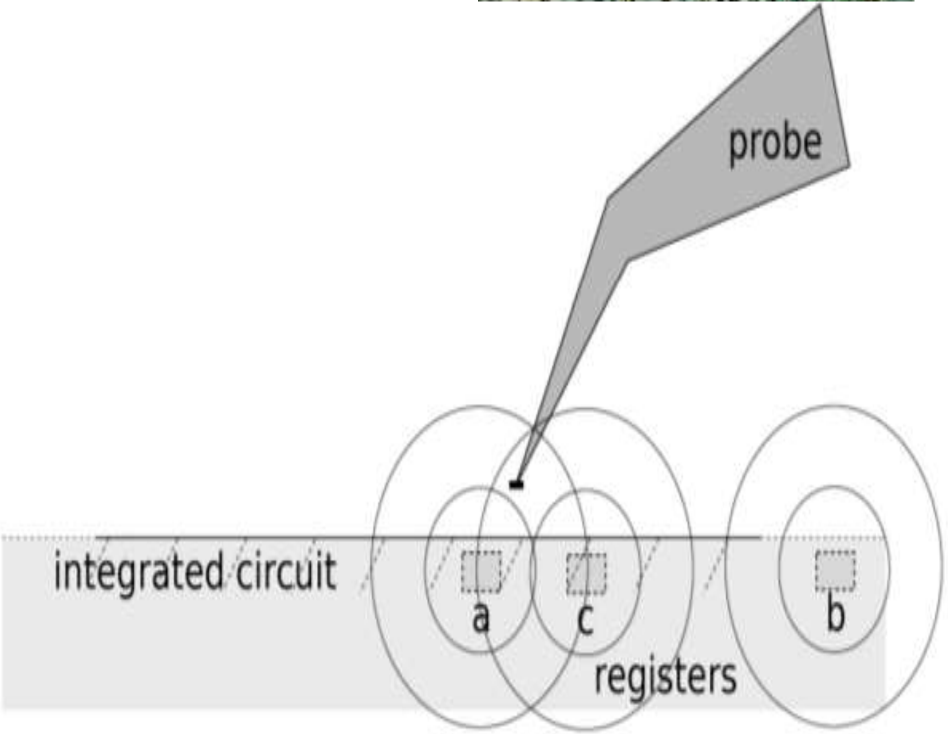
Localized EM against Asymmetric Crypto



Input: Secret $d = d_D d_{D-1} \ldots d_2 d_1$ with $d_i \in \{0, 1\}$

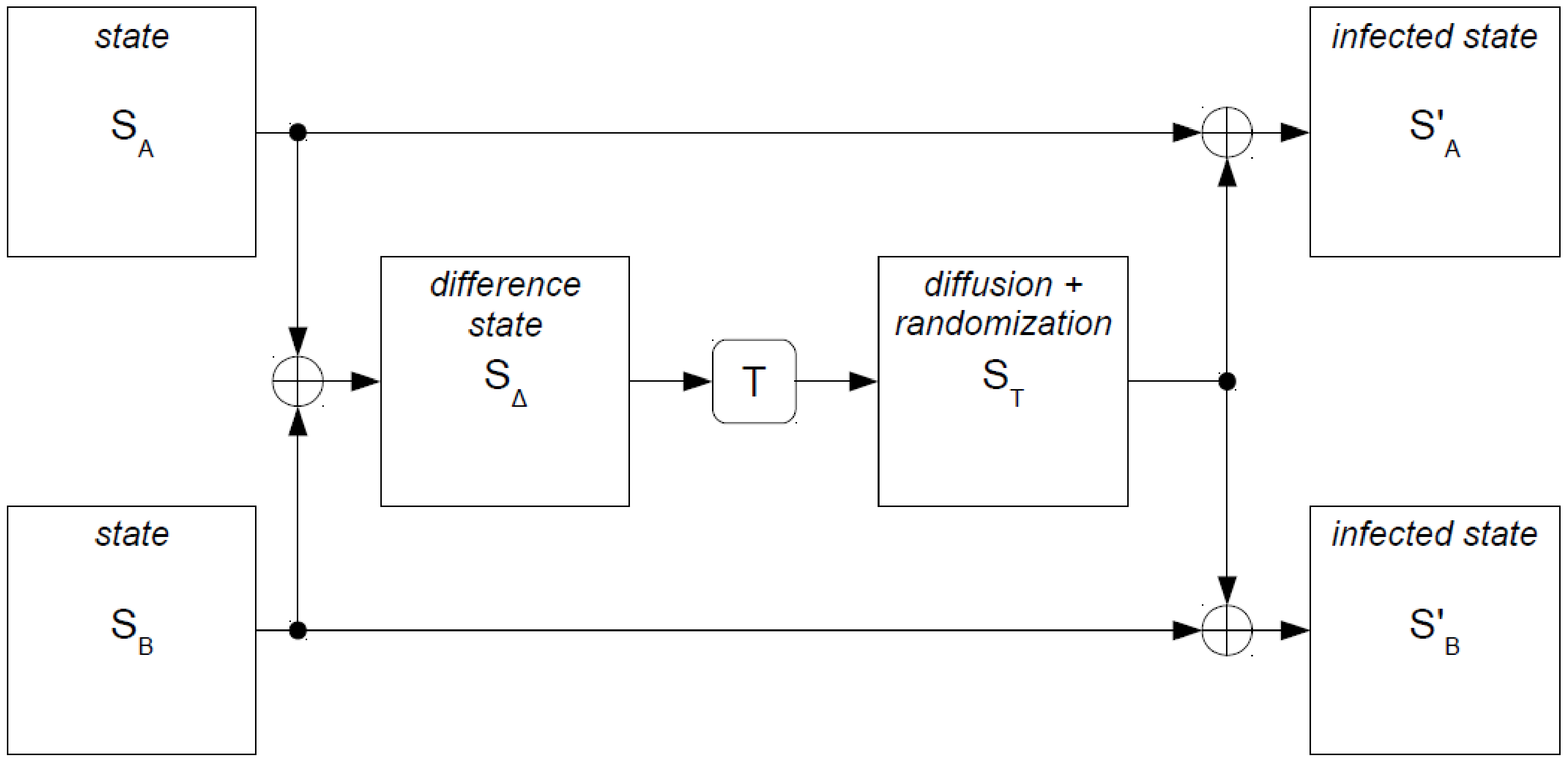
1: **for** $i = D$ downto 1 **do**
2:     **if** $d_i = 1$ **then**
3:         $c \leftarrow c^2 + a$
4:         $a \leftarrow c$
5:     **else**
6:         $c \leftarrow c^2 + b$
7:         $b \leftarrow c$
8:     **end if**
9: **end for**

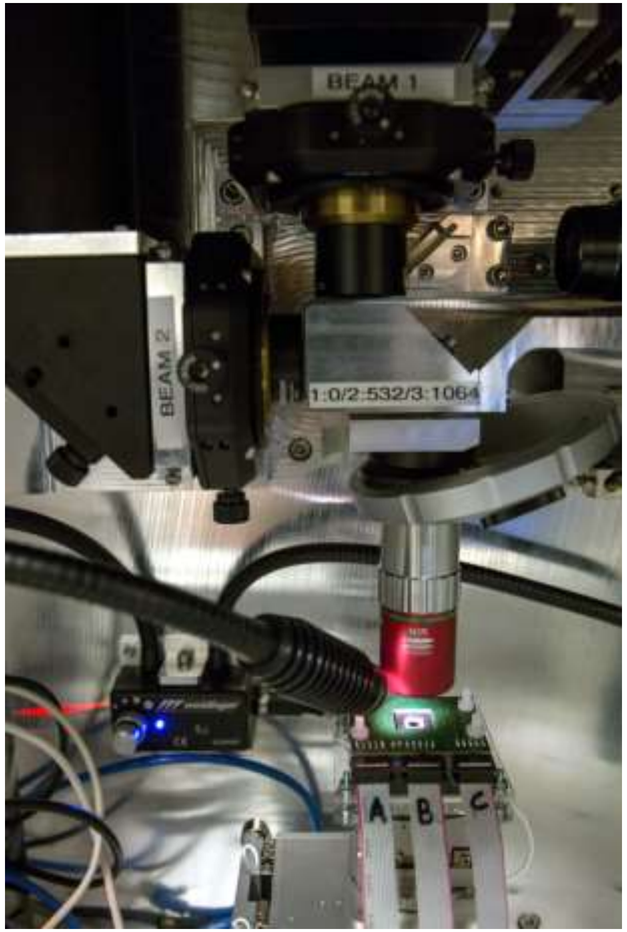




Heyszl, Johann; Mangard, Stefan; Heinz, Benedikt; Stumpf, Frederic; Sigl, Georg:
Localized Electromagnetic Analysis of Cryptographic Implementations. CT-RSA, 2012

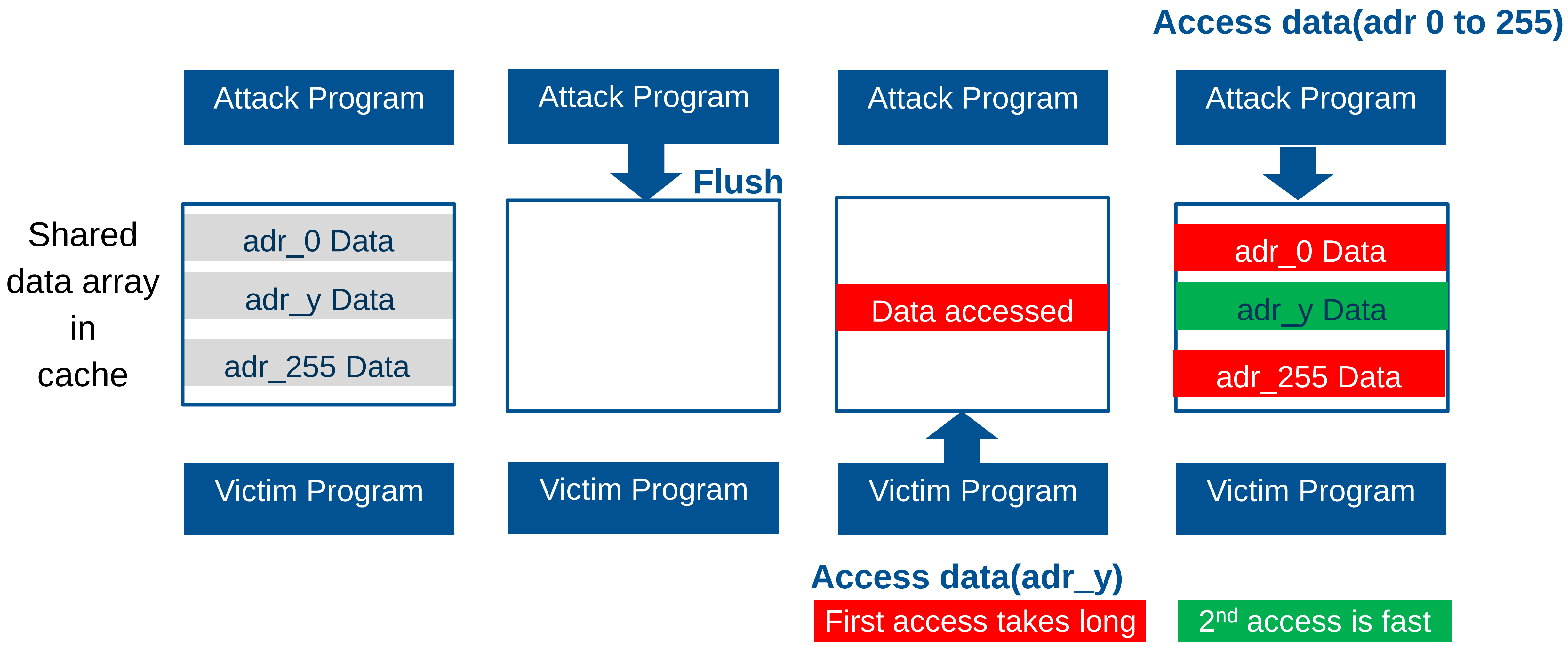
Fault Attack on an AES with a simple countermeasure



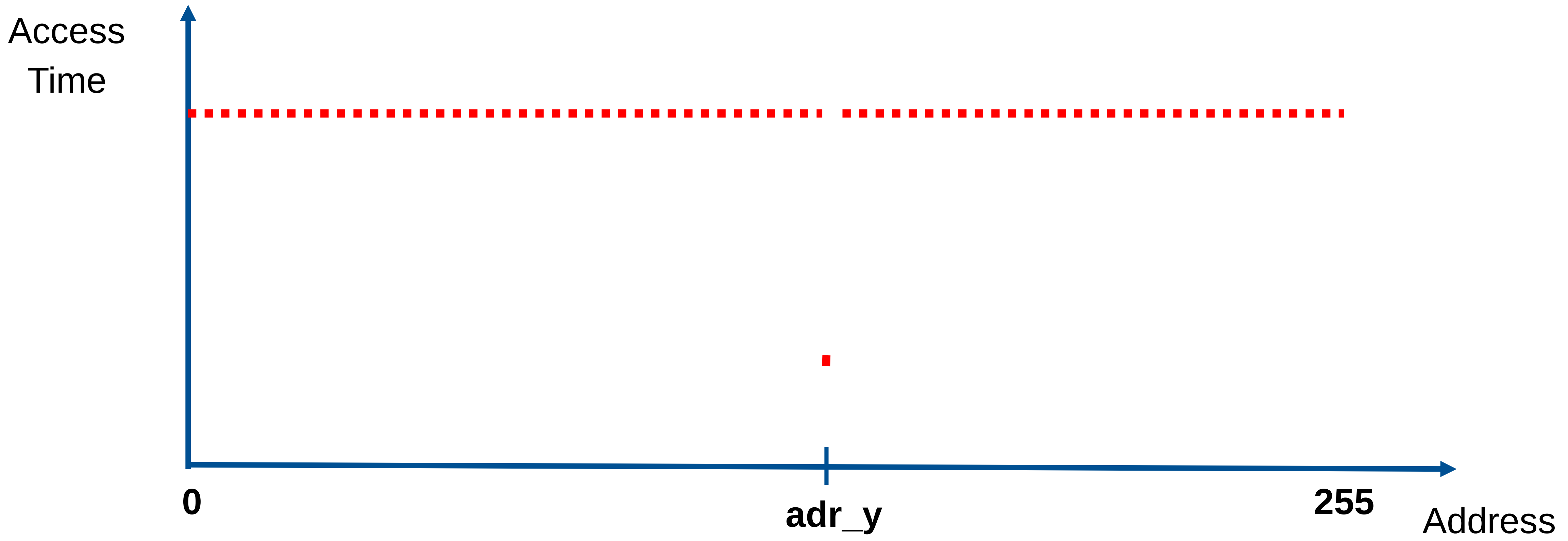


Selmke, Bodo and Heyszl, Johann and Sigl, Georg: Attack on a DFA protected AES by Simultaneous Laser Fault Injections. FDTC 2016 Fault Diagnosis and Tolerance in Cryptography, 2016

Cache Side Channel Attack: Flush & Reload



Cache Side Channel Attack: Flush & Reload



Cache Attack: Meltdown

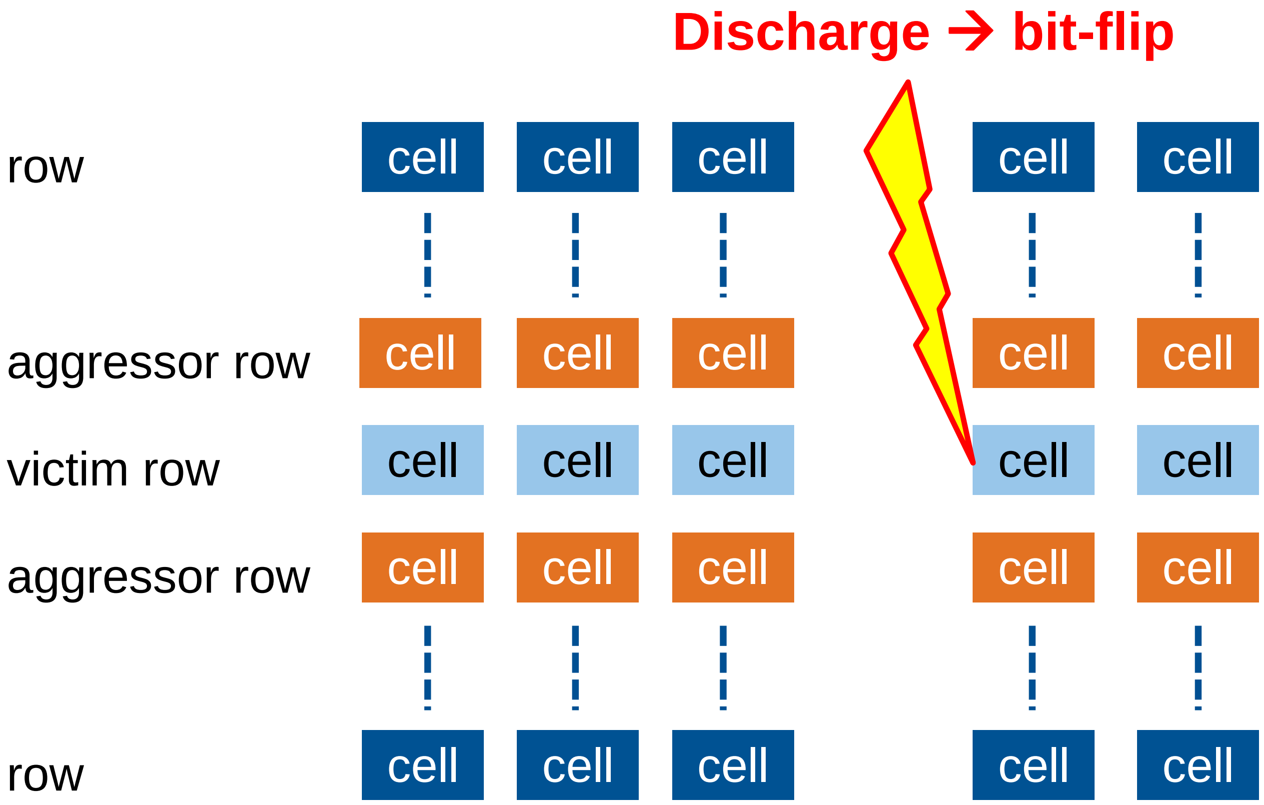
Security: MMU (Memory Management Unit) prevents data access for an attacker to the OS kernel
How to circumvent?

- Attacker trains the prefetcher with a dedicated program, e.g. a loop
- Attack program suddenly
  - accesses a byte at a memory address in kernel space
    → CPU prefetcher fetches one byte of data stored at this address in kernel space into cache
  - accesses an **array** with this byte value as index
- Then CPU detects that the branch prediction (with the access right violation) was wrong and reverts most actions, but **cache data are not deleted**
- Now the attacker accesses the complete **array** and measures access time
- The access with the shortest access time corresponds to the read byte value

Root Cause: Wrong assumption during CPU design that speculation can be undone

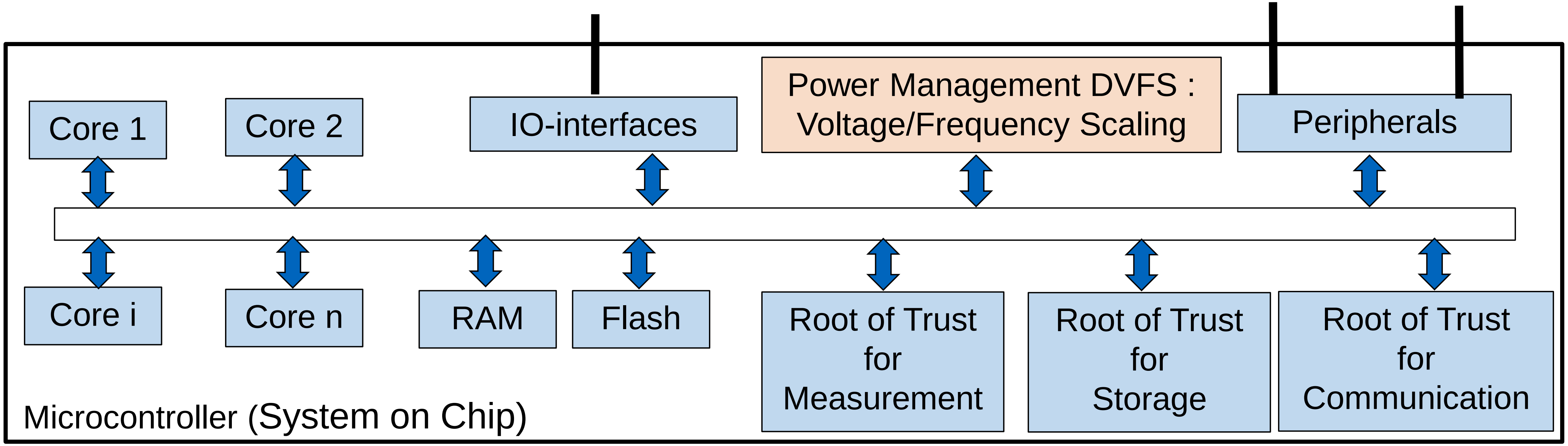
Software based fault attack: Rowhammer

- Reading frequently aggressor rows changes contents in victim
- Attacks
  - Change access rights
  - Escape sand boxes (from browser)
  - …
- Root Cause
  - DRAM considers average usage only not an attack
  - No error correction implemented (too expensive, performance?)



Flipping bits in memory without accessing them: An experimental study of DRAM disturbance errors. Y. Kim, R. Daly, J. Kim, C.Fallin, J. Lee, D. Lee, C. Wilkerson, K.Lai, O. Mutlu; 2014 ACM/IEEE 41st International Symposium on Computer Architecture (ISCA)

Software based fault attack: CLKskrew



“CLKSCREW: Exposing the Perils of Security-Oblivious Energy Management”. A.Tang, S. Sethumadhavan, and S. Stolfo, Columbia University, 26th USENIX Security Symposium, 2017

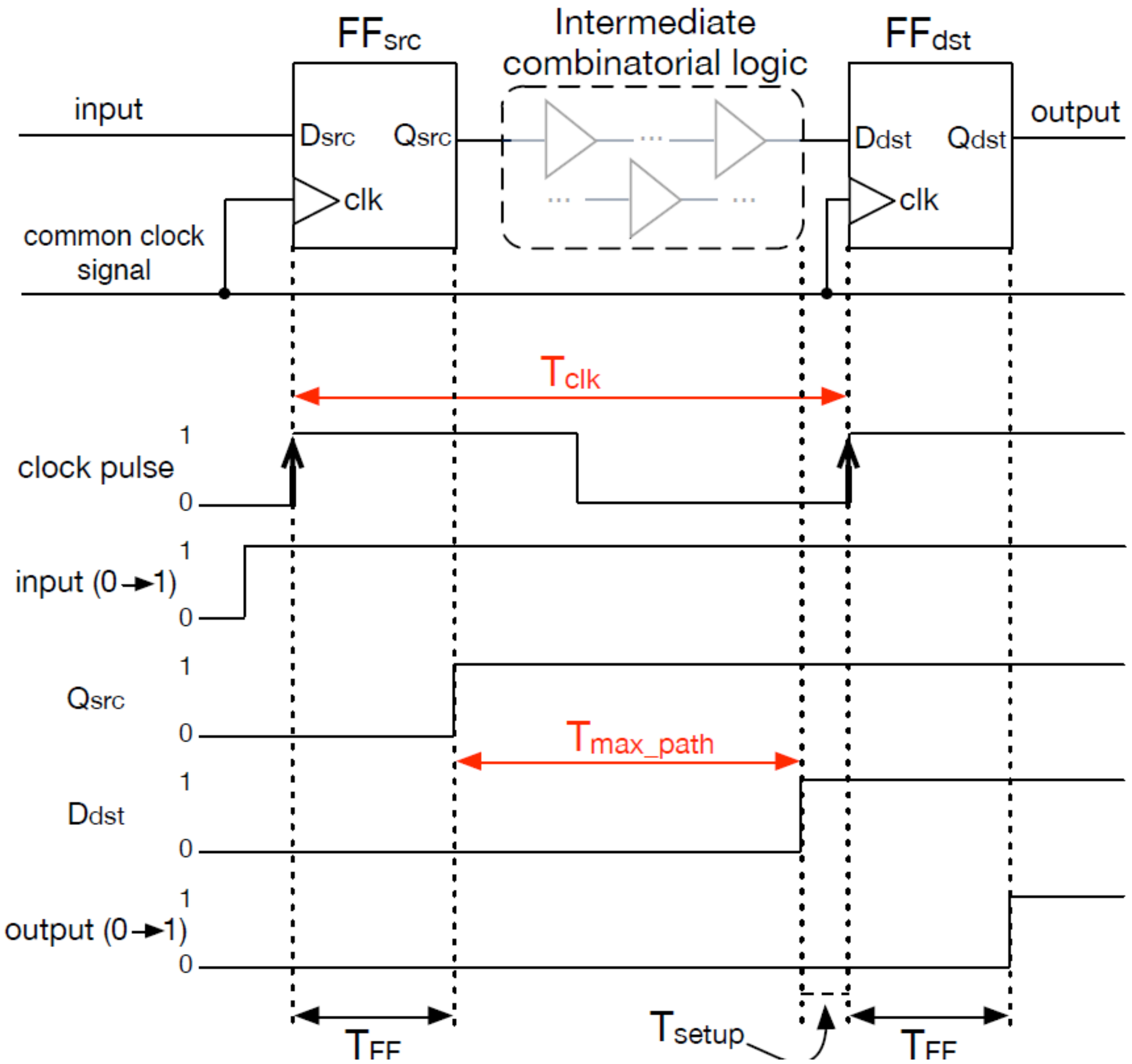
- Compromised OS kernel driver used to operate circuit beyond DVFS limits
- Faults are injected which reveal cryptographic keys and perform untrusted software download
- Attack demonstrated on ARM Trustzone in a Nexus mobile phone

The concept of voltage and frequency scaling

- Voltage reduction saves power, but
- Voltage reduction reduces performance
- → Operating frequency must be reduced

- If operating frequency is too high for a given voltage, faults occur

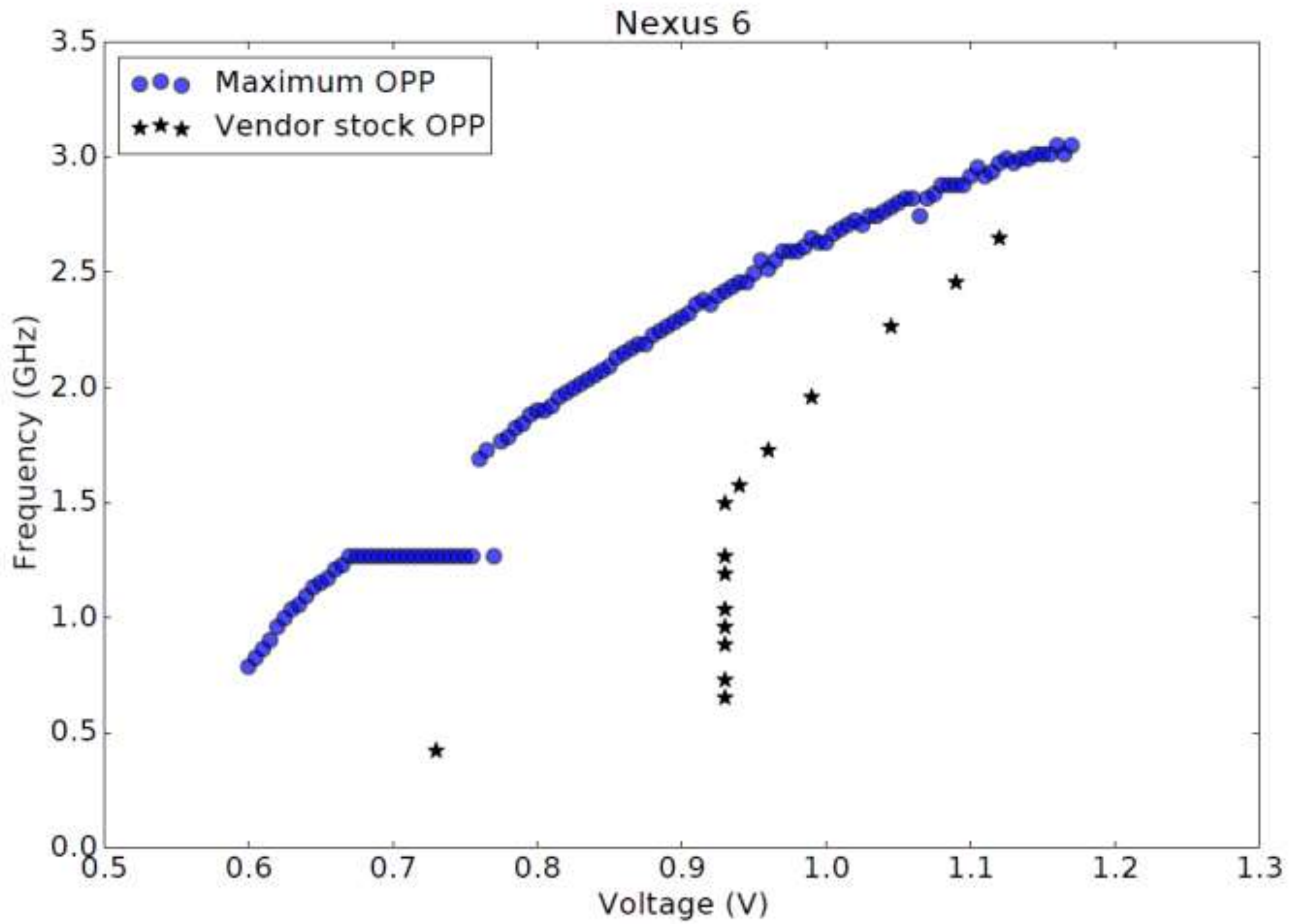
- Registers configure voltage and frequency
- In the attacked implementation voltage is configured for the complete system, but
- Clocks can be configured for each core individually



Example attacks performed with CLKskrew

- ARM TrustZone is supposed to provide an isolated trusted execution environment
- The OS kernel is able to change the clock and voltage values even when TZ code is running

- Two sample attacks have been performed:
  - Attacking AES keys of decryptions executed in TrustZone
  - Signature verification of software downloads



Intermediate conclusion

The risk is increasing!

- Increasing number of
  - Software controlled hardware features
  - Hardware functions at the reliability border
- Every software controlled hardware feature is a target for remote fault and side channel attacks
- Through side channels almost everything is observable