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Black-Box Characterization of The Effects of Laser Pulses on ATmega328P

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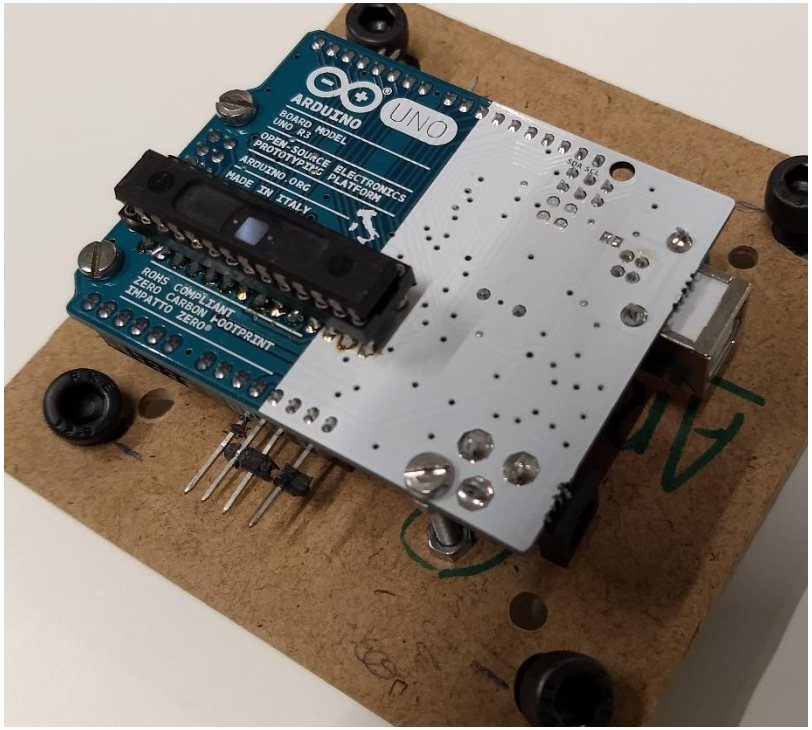
Introduction

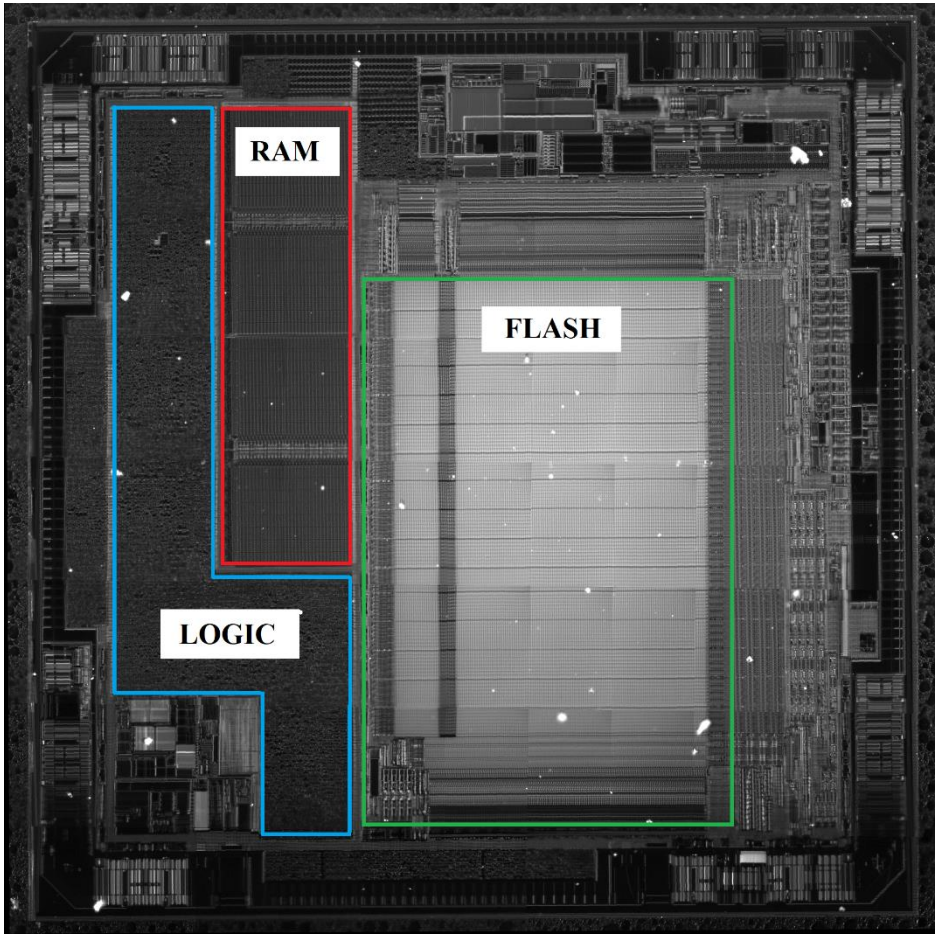
- Movitation :
  - Fault model descriptions for actual devices are rare
  - Assumed fault model for microcontroller is often instruction skip, while the reality is more complex

- Aim: find fault model for ATmega328p microcontroller

- Atmega328p is built in a rather old technology but still widely used

Atmega328P





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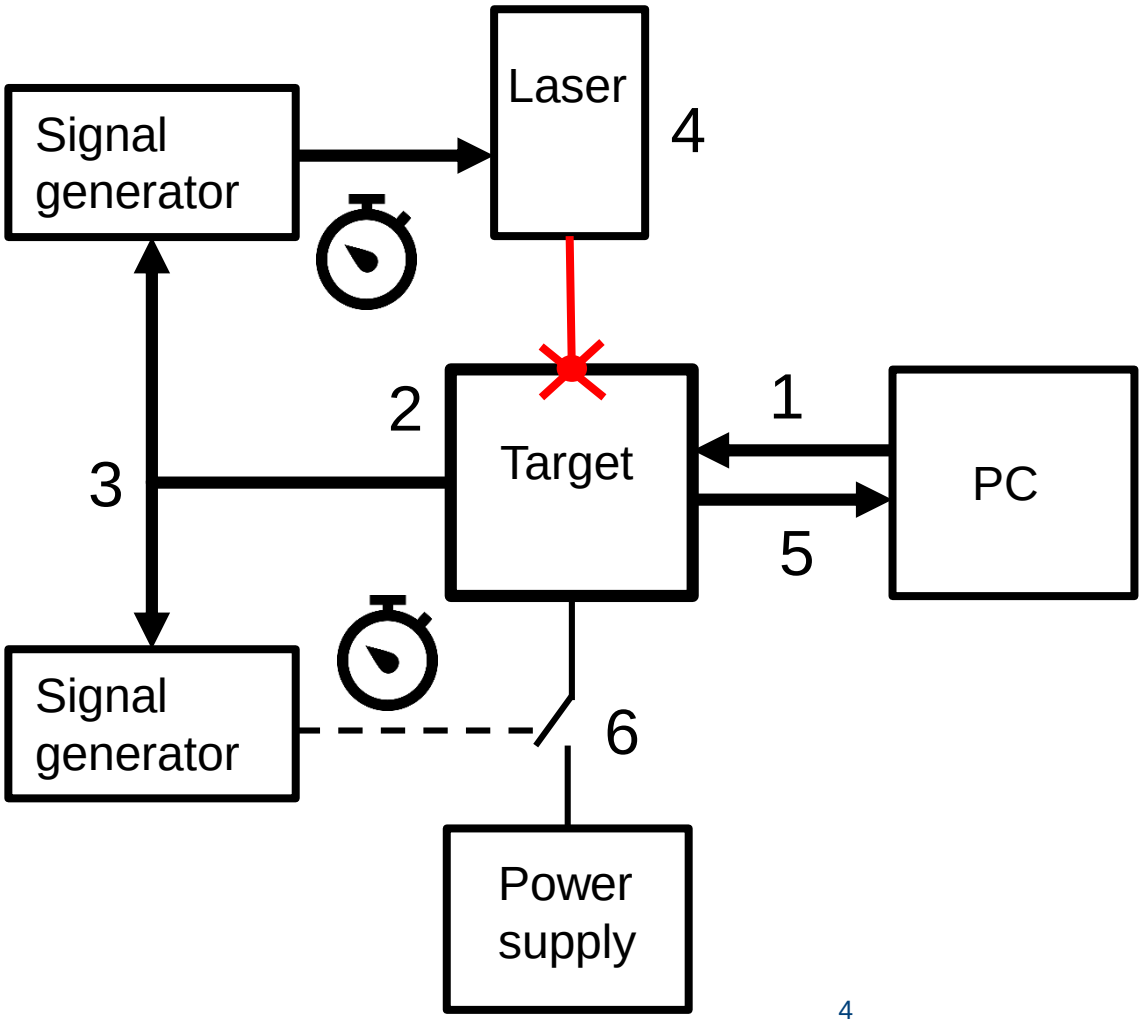
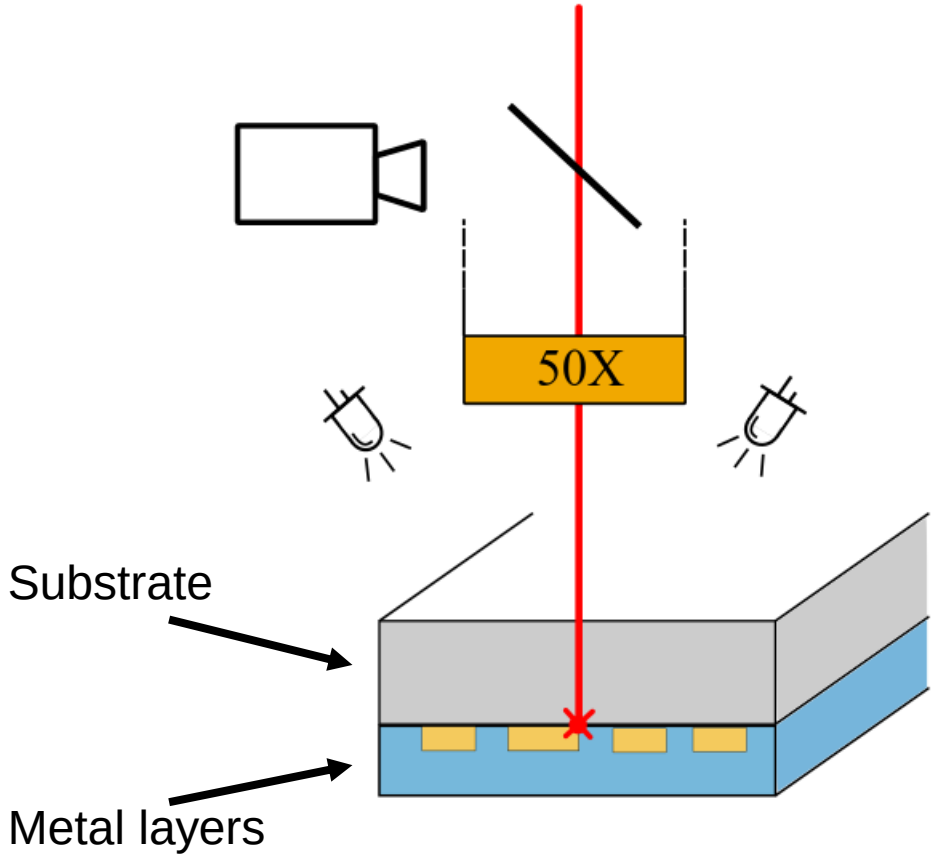
Fault injection setup



1. Start command
2. Execute target code
3. Send trigger
4. Enable laser FI
5. Send back result
6. Reset target

Laser setup

- Wavelength = 1064nm
- 50X magnification
- NIR lighting system
- XYZ stepper table, 0.1µm resolution
- Throug substrate fault injection
- CMOS NIR camera



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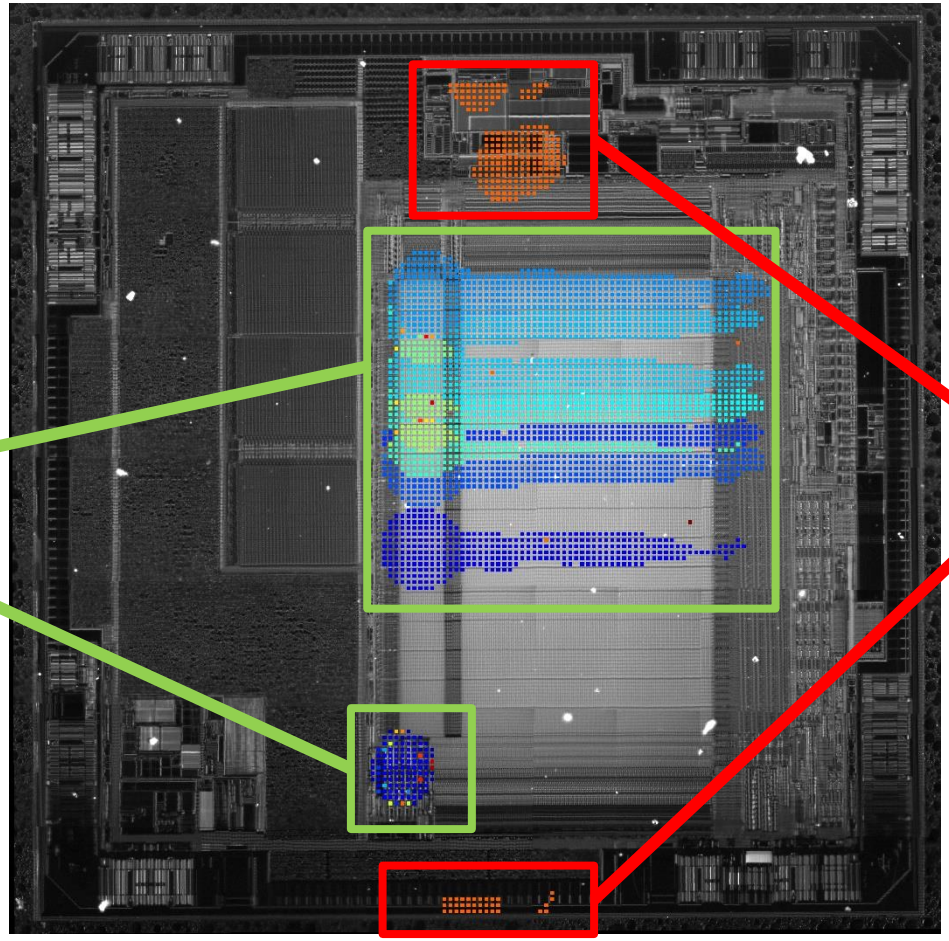
Characterization strategy

Cycle	Instruction
1	sbi 0X0B, 7 // trigger
2	nop
3	nop
4	target
5	nop
6	nop

- ATMega328p has a two stage pipeline: fetch and execute
- Put the register file to a known state
- After laser pulse read out register file content
- After a laser pulse injection the microcontroller is always reset to a known state

Full chip scan: muls r23,r27



Exploitable faults

Device crashes

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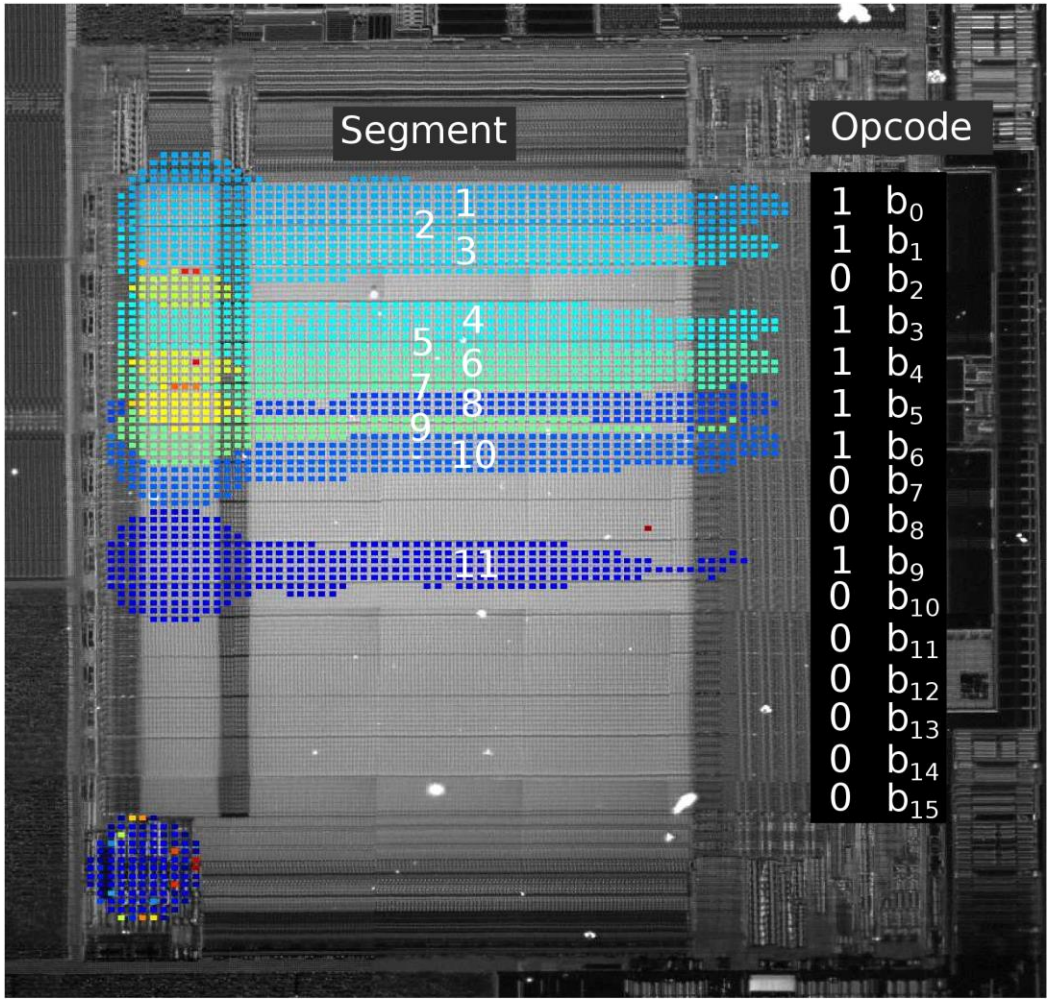
Muls r23,r27



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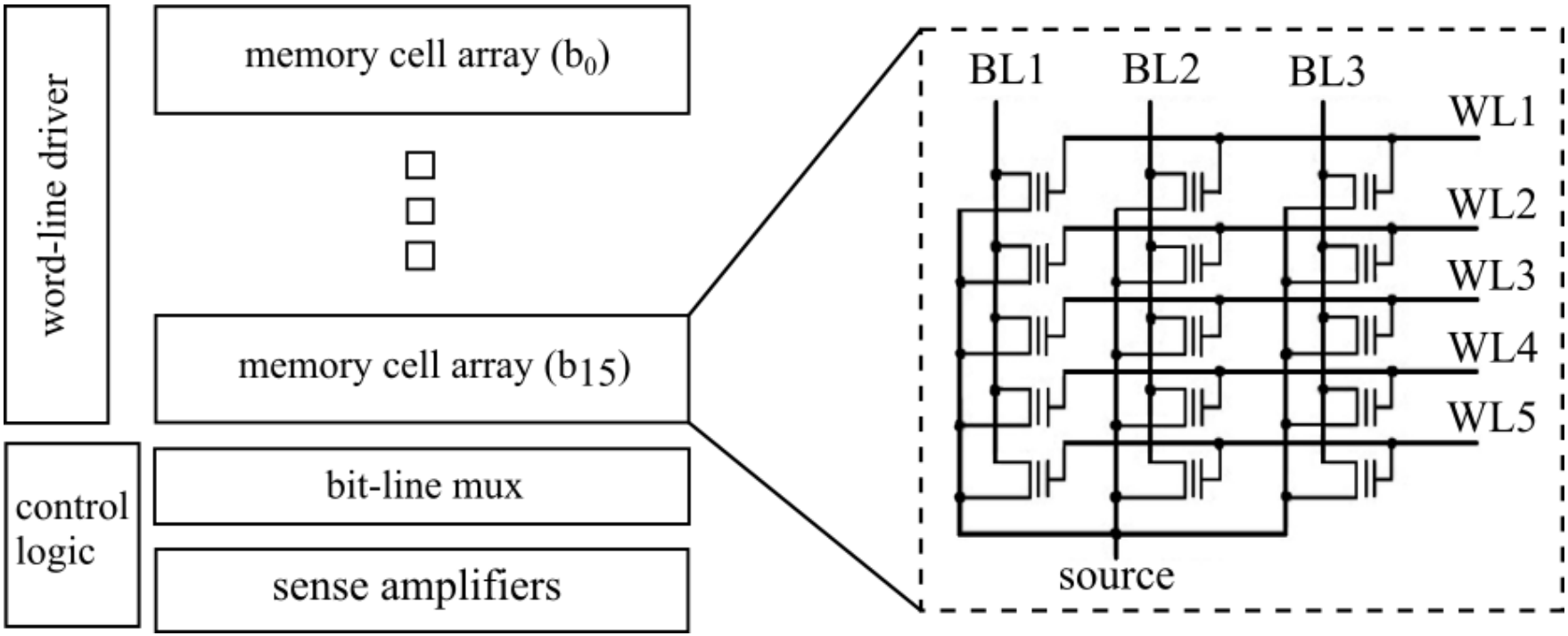
Target instruction: muls r23,r27

Segment	Cycle	Instruction	Opcode(bin)	Bit(s) Reset
	i	nop	0000 0000 0000 0000	
	i+1	muls r23, r27	0000 0010 0111 1011	
1	i+1	muls r23, r26	0000 0010 0111 1010	b_0
2	i+1	muls r23, r24	0000 0010 0111 1000	b_0 & b_1
3	i+1	muls r23, r25	0000 0010 0111 1001	b_1
4	i+1	muls r23, r19	0000 0010 0111 0011	b_3
5	i+1	muls r22, r19	0000 0010 0110 0011	b_3 & b_4
6	i+1	muls r22, r27	0000 0010 0110 1011	b_4
7	i+1	muls r20, r27	0000 0010 0100 1011	b_4 & b_5
8	i+1	muls r21, r27	0000 0010 0101 1011	b_5
9	i+1	muls r17, r27	0000 0010 0001 1011	b_5 & b_6
10	i+1	muls r19, r27	0000 0010 0011 1011	b_6
11	i+1	nop*(Invalid)*	0000 0000 0111 1011	b_9

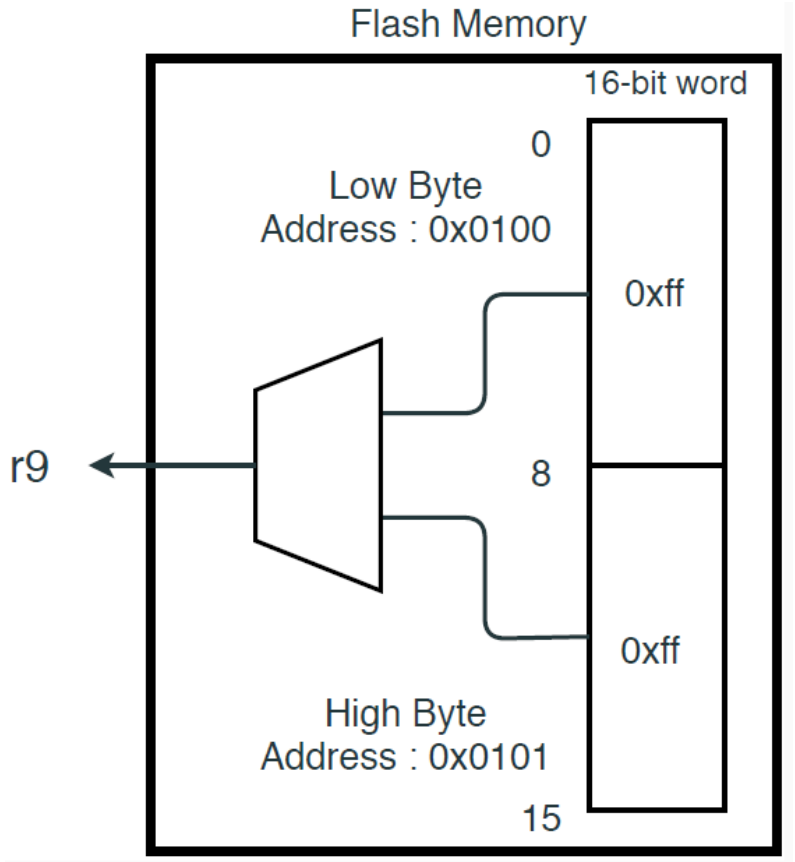
Flash memory structure



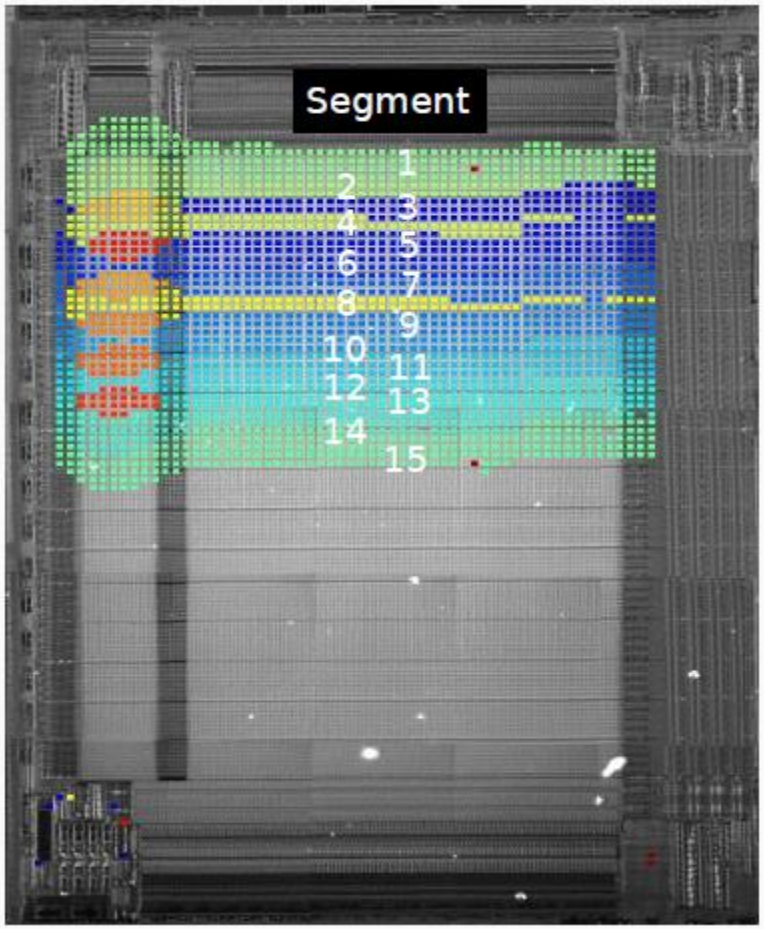
Loading data from program memory

Instruction: lpm r9, Z

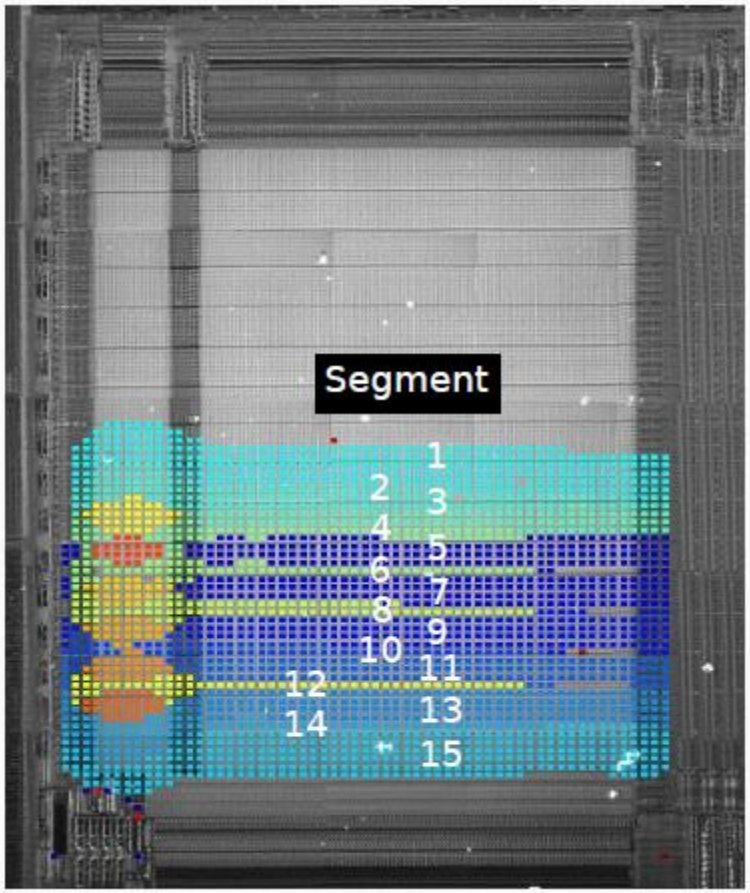
- Flash memory stores 16-bit words
- Z pointer is a byte address



Loading data from program memory

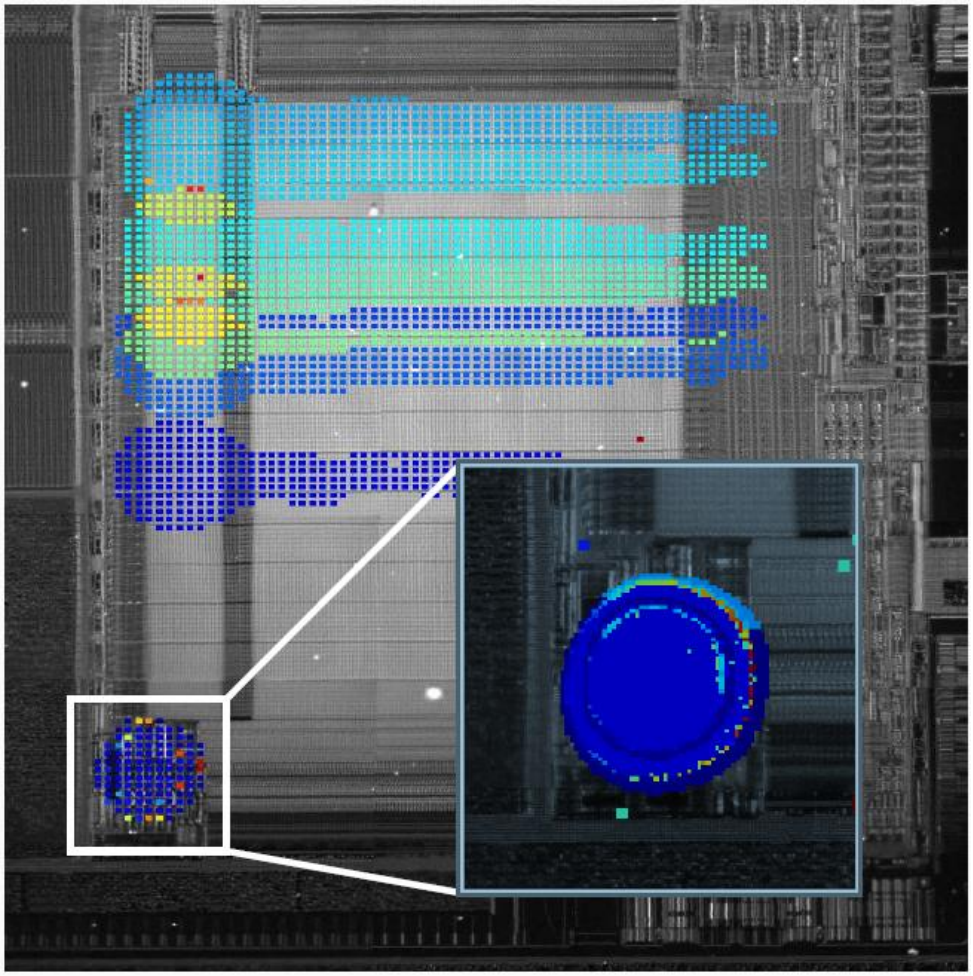


Z = 0x0100



Z = 0x0101

Second sensitive region

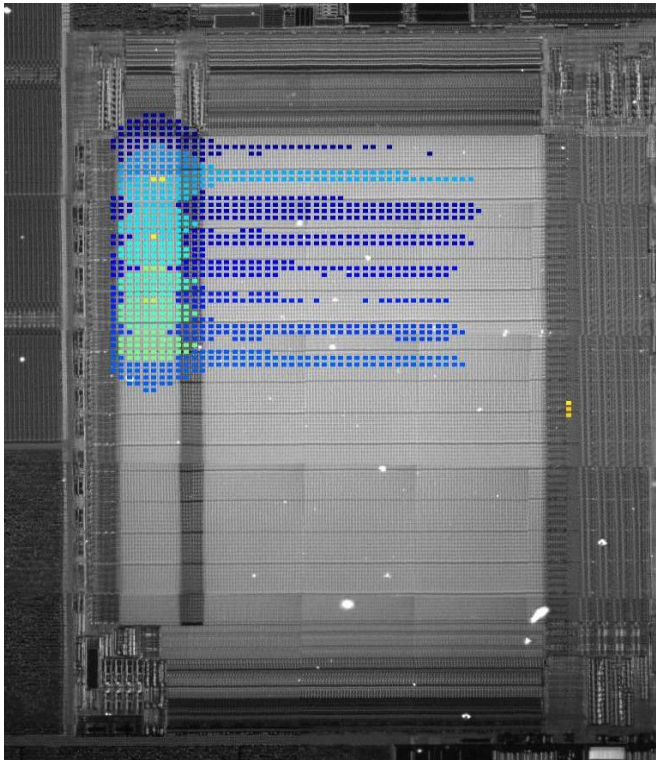


- nop
- muls r16, r16
- and r0, r16
- or r0, r18
- or r0, r16

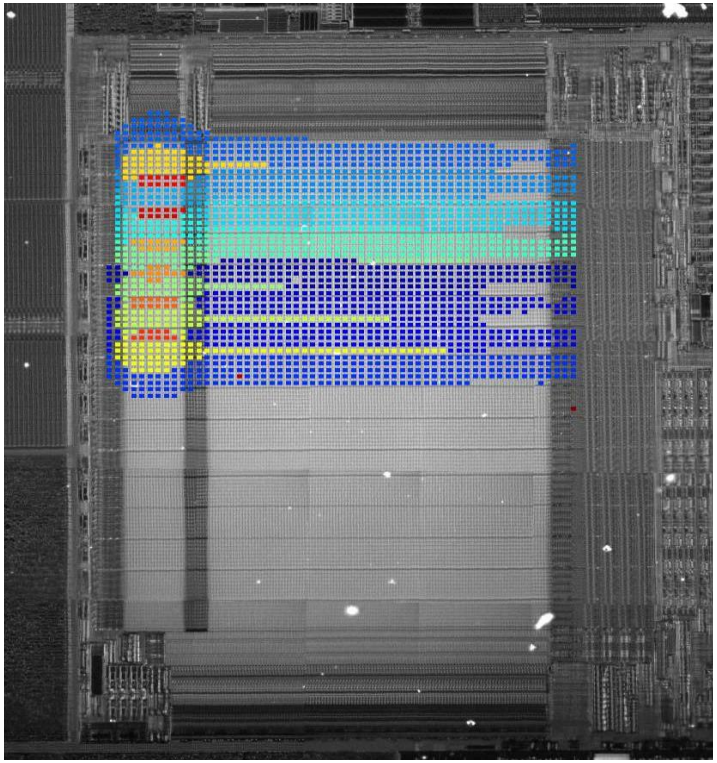
Influence laser parameters

Laser energy = pulse duration X laser power

70ns X 0.6W



70ns X 1.2W



Fault exploitation

- Fault model = stuck at 0 faults for data read out from flash memory
- No permanent faults

Program flow faults:

BRNE 1111 01kk kkkk k001
BREQ 1111 00kk kkkk k001

Data faults:

Fault loading of S-box values ➡ classical DFA

Conclusion

- Able to fault data and instructions loaded from flash memory
- The induced faults are deterministic
- An in depth knowledge of the fault model can lead to powerfull attacks

Questions?

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