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► **To cite this version:**

Kévin Quénéhervé, William Pensec, Tanguy Philippe, Rachid Dafali, Vianney Lapotre. Exploring Fault Injection Attacks on CVA6 PMP Configuration Flow. Journée thématique sur les attaques par injection de fautes (JAIF), Oct 2024, Rennes, France. hal-04729617

**HAL Id: hal-04729617**

**<https://hal.science/hal-04729617v1>**

Submitted on 10 Oct 2024

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# Exploring Fault Injection Attacks on CVA6 PMP Configuration Flow



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## Context

Fault-Injection Attacks (FIA) [1] are **serious threats** to embedded systems. Nashimoto et al. [2] showed that clock glitching can change the **Physical Memory Protection (PMP)** configuration on RISC-V processors. In [3], we have **characterized** the effects of faults on PMP configuration. To better understand these faults, we used Error-Correction Code (ECC). We modified the ID pipeline stage with hardware modules to **filter** single bit-flip faults using **Hamming code**.

## Experimental setup

- **Chipwhisperer Lite**
- FPGA Arty A7-100T.
- **Clock glitching** with parameters Figure 2.
- **1,970,001 injections** per campaign
- Target pseudocode, cf. Figure 1.

- 1 **TRIGGER** high;
- 2 @ret = (&@base) » 2;
- 3 @ret &= (size » 3);
- 4 @ret |= ((size » 3) - 1);
- 5 csrw pmpaddr0, @ret;
- 6 csrs pmpcfg0, (0x99);
- 7 modify the protect value;

Figure 1: Target pseudo code

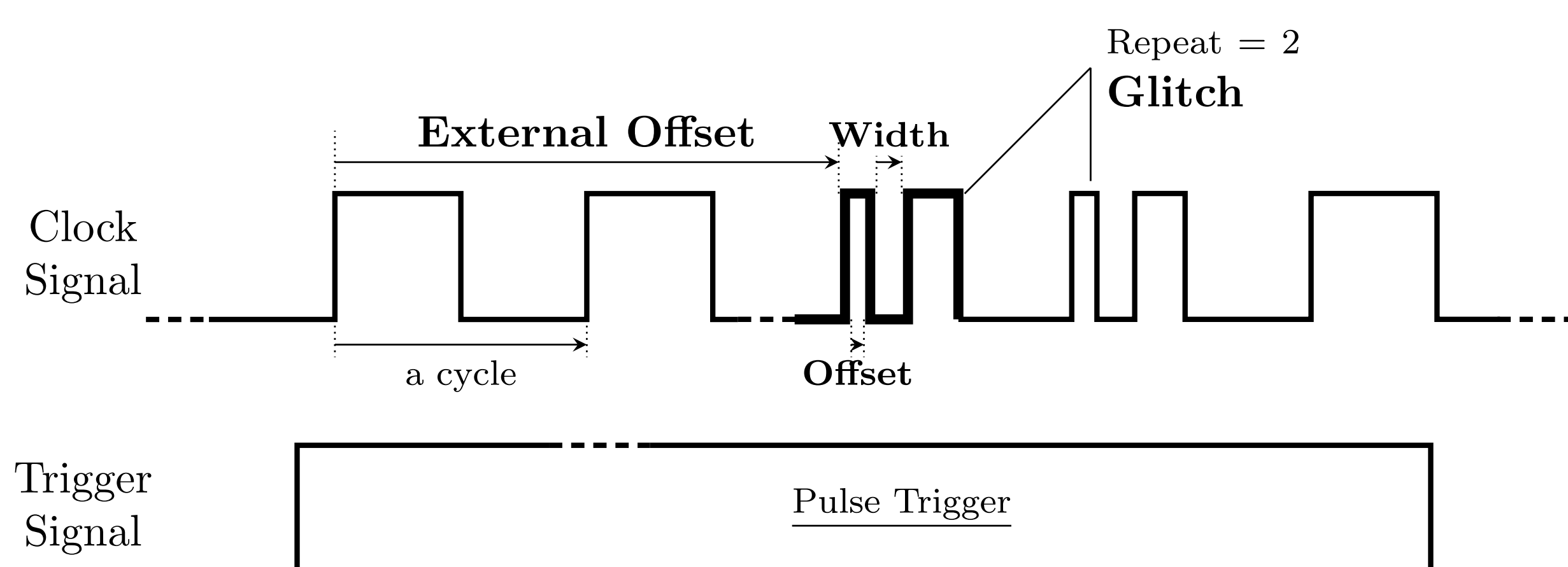
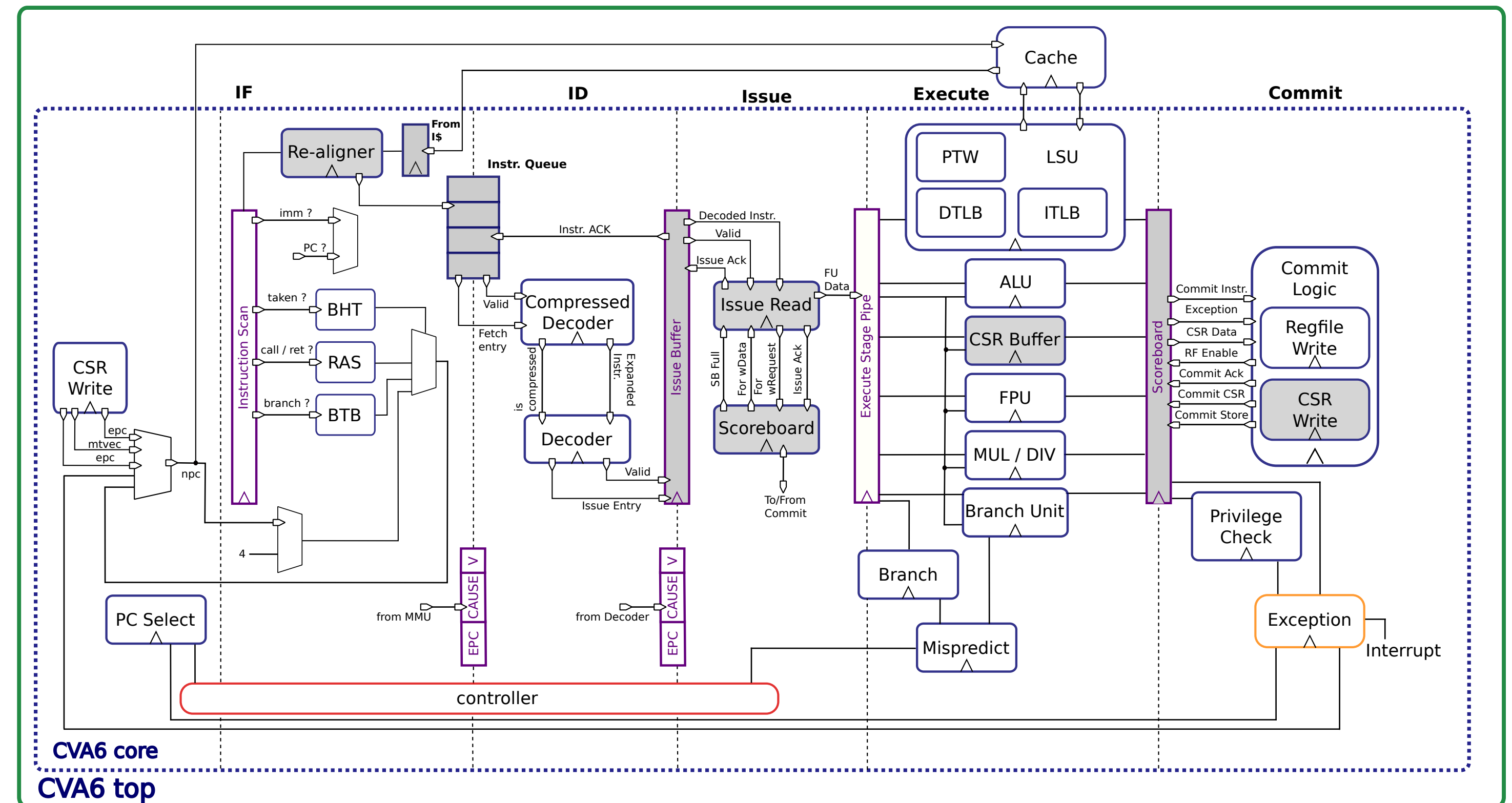
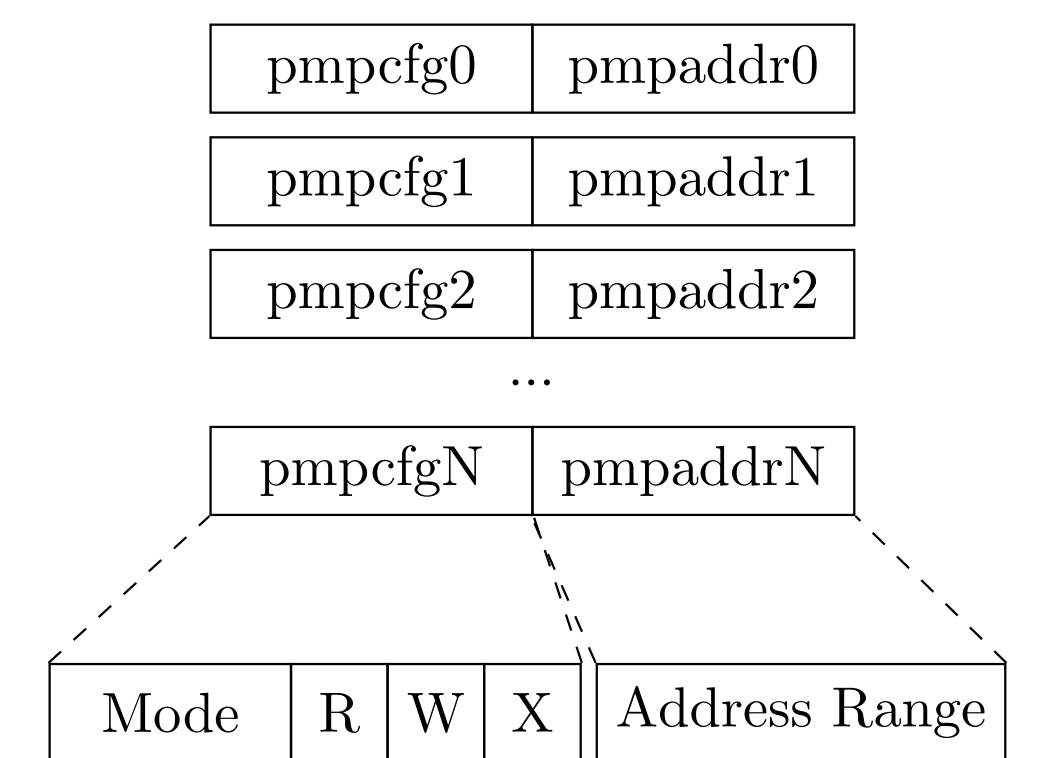


Figure 2: Clock Glitch principles parameters

## CVA6 PMP

- **PMP** secures up to 16 memory regions with access permissions.
- Each region uses **two Control Status Registers (CSRs)**.
- In the CVA6 core, PMP configuration is handled in the **CSR Write** module of the **Commit** stage.



## Effects of FIA on PMP configuration

**5,561 injections** modified PMP configuration, enabling write access to protected memory. Figure 3 shows a **correlation** between fault effects and injection parameters, *Width* and *External Offset*.

- **Sensitive** zones can be further divided into sub-zones with specific effects.
- **Single bit-flip effects** mainly occur at zone boundaries.
- **Specific effects** can be targeted by an attacker.

Different impact of pmpcfg0 & pmpaddr0 combinations :

- **G1** gathers faults that lead to *complex* effects.
- **G2** gathers faults that impact either pmpcfg0 or pmpaddr0.
- **G3** gathers faults that impact both pmpcfg0 & pmpaddr0.

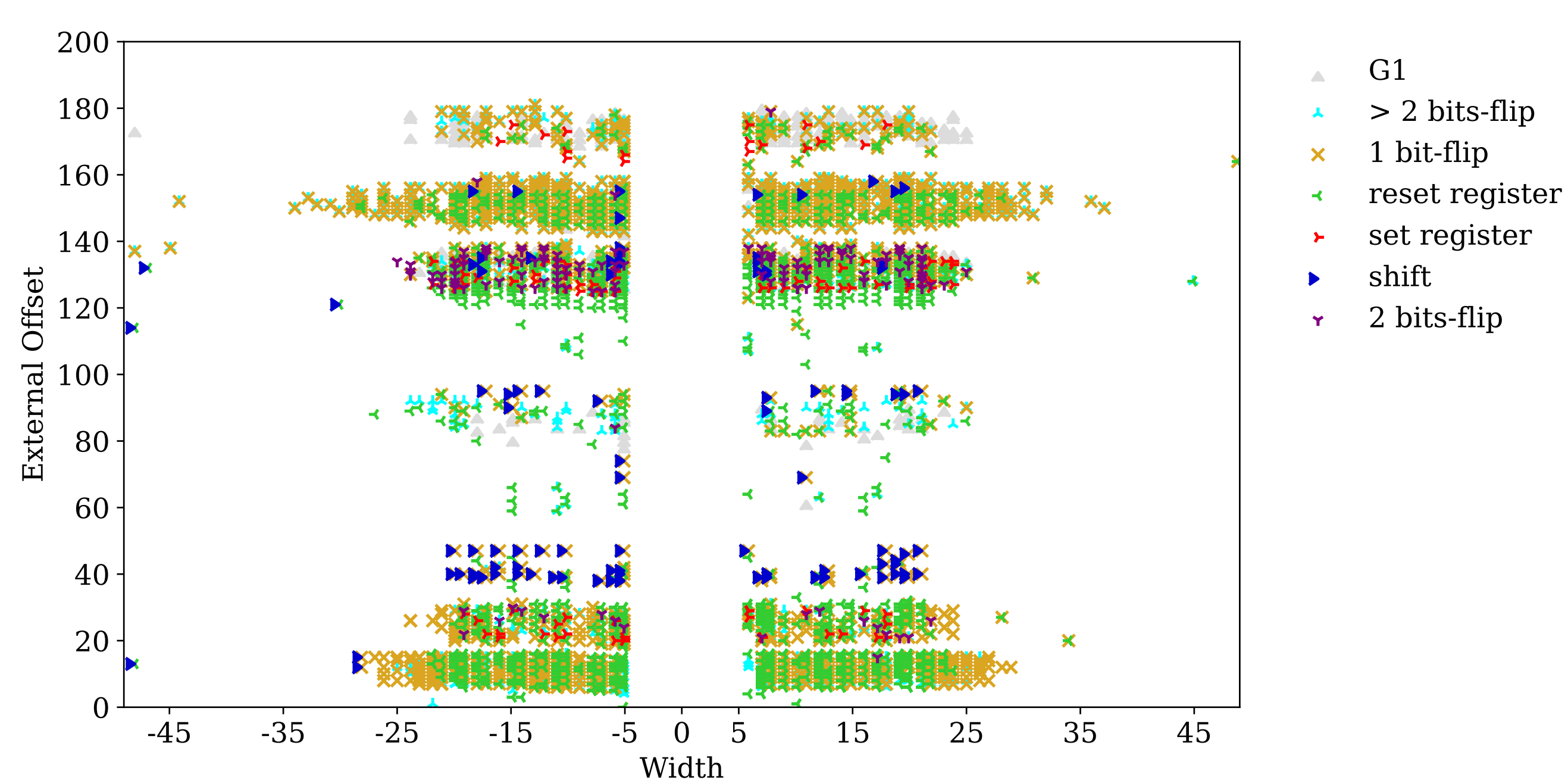


Figure 3: Fault effects about injection parameters

## Filters along the PMP configuration flow

- Figure 4 shows **Hamming Code-based filters** that correct **single bit-flips** in PMP registers.
- Table 1 quantifies fault effects for the baseline and **CVA6 core extended with the proposed filters** in the *ID* stage:
- Figure 5 quantifies **the impact of pmpcfg0 & pmpaddr0 combinations** in both core versions.

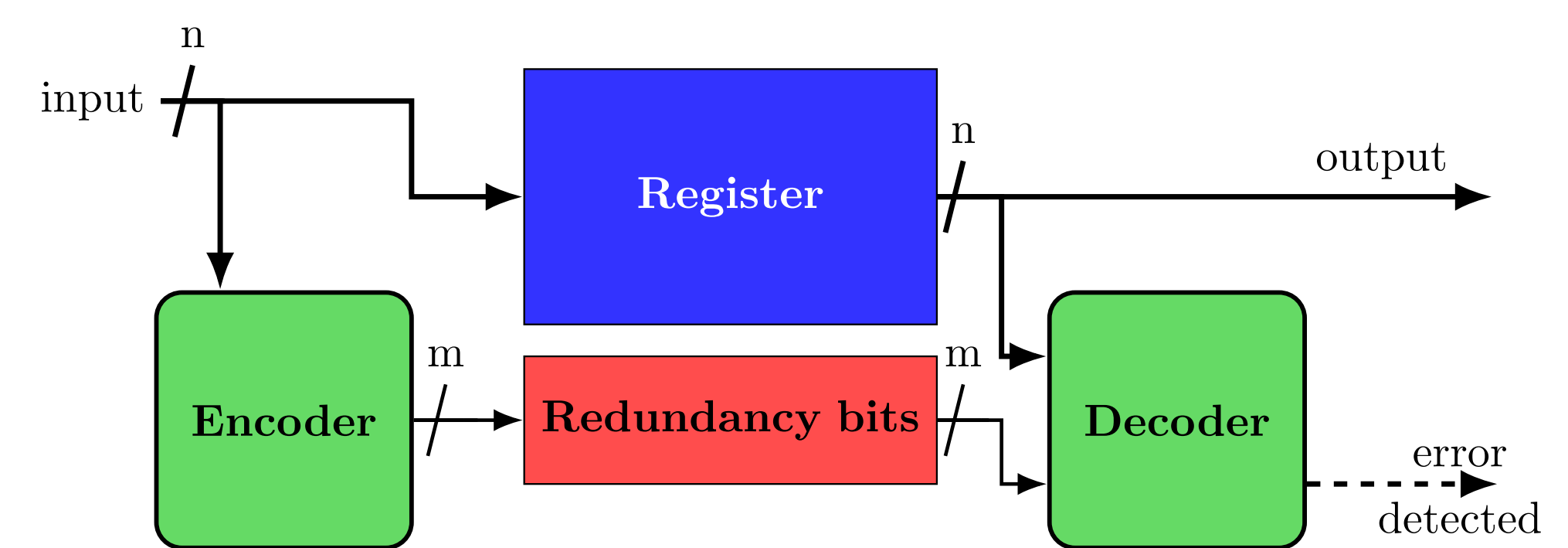


Figure 4: Hamming Code - Filter

Table 1: Results comparison between baseline and filtered

CVA6	Crash	Silent	Faults			Total
			G1	G2	G3	
Baseline	50,146	1,914,294	1,165	2,091	2,305	5,561
ID Filter	122,047	1,846,171	248	487	1,048	1,783

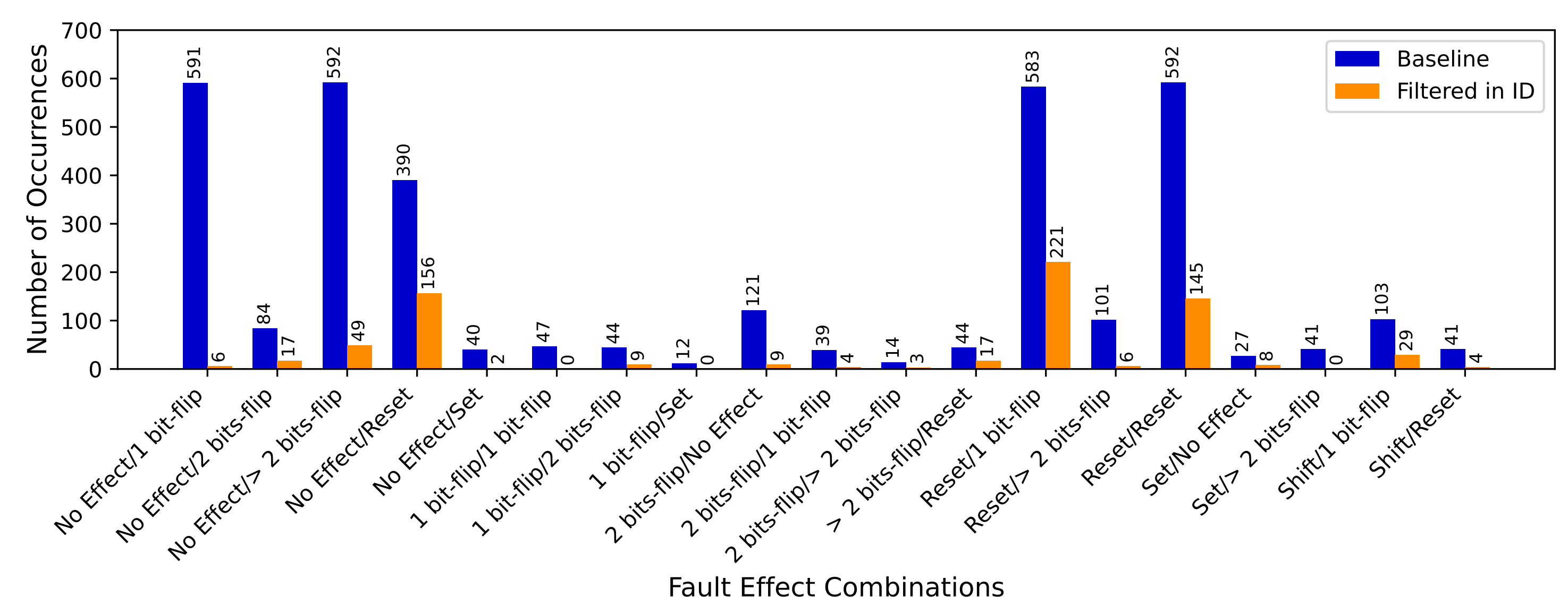


Figure 5: Effects on PMP registers - group G2 & G3 with Hamming Code-based filters in *ID* stage

## Conclusion & perspectives

- Shows clock glitch FIA on CVA6 PMP configuration, **identifying exploitable effects**.
- Attackers can adjust injection parameters for **desired effects** with high success.
- Filter helps in **characterizing multiple fault effects**.
- Approach can be applied to **other pipeline stages**.
- Consider **different processor** cores and implementations.

## Bibliography

- [1] H. Bar-El et al., "The sorcerer's apprentice guide to fault attacks," *Proceedings of the IEEE*, 2006.
- [2] S. Nashimoto et al., "Bypassing Isolated Execution on RISC-V using Side-Channel-Assisted Fault-Injection and Its Countermeasure," *IACR Transactions on Cryptographic Hardware and Embedded Systems (TCHES)*, 2021.
- [3] K. Quénehervé et al., "Exploring Fault Injection Attacks on CVA6 PMP Configuration Flow," in *27th Euromicro Conference Series on Digital System Design (DSD)*, 2024.