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BRIEFINGS

# PMFault: Voltage Fault Injection on Server Platforms Through the PMBus

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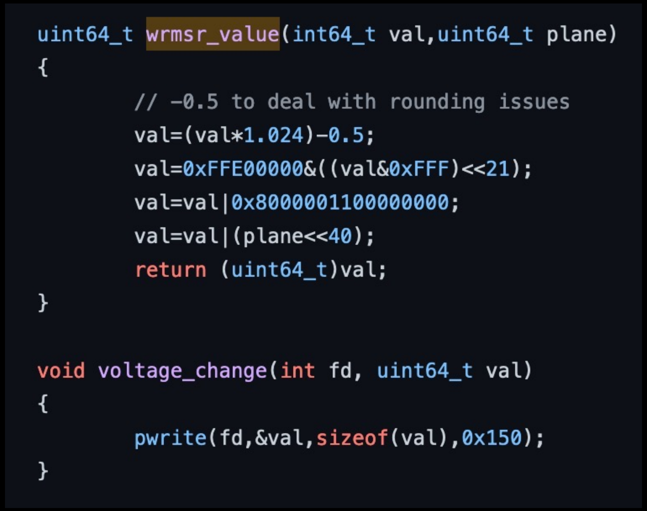
PM Fault

# Evolution of fault injection on Intel systems

## Software-based (MSR 0x150)

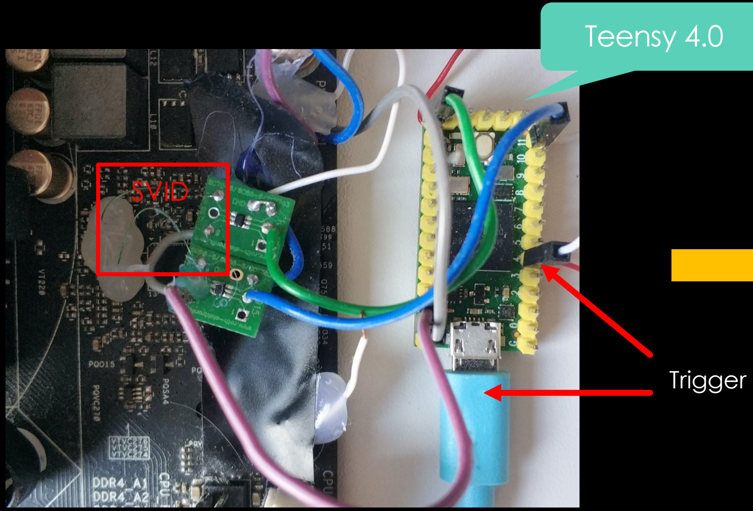


```
uint64_t wrmsr_value(int64_t val,uint64_t plane)
{
        // -0.5 to deal with rounding issues
        val=(val*1.024)-0.5;
        val=0xFFE00000&((val&0xFFF)<<21);
        val=val|0x8000001100000000;
        val=val|(plane<<40);
        return (uint64_t)val;
}

void voltage_change(int fd, uint64_t val)
{
        pwrite(fd,&val,sizeof(val),0x150);
}
```

Ref: Plundervolt [1] GitHub

## Hardware-based (SVID Bus)



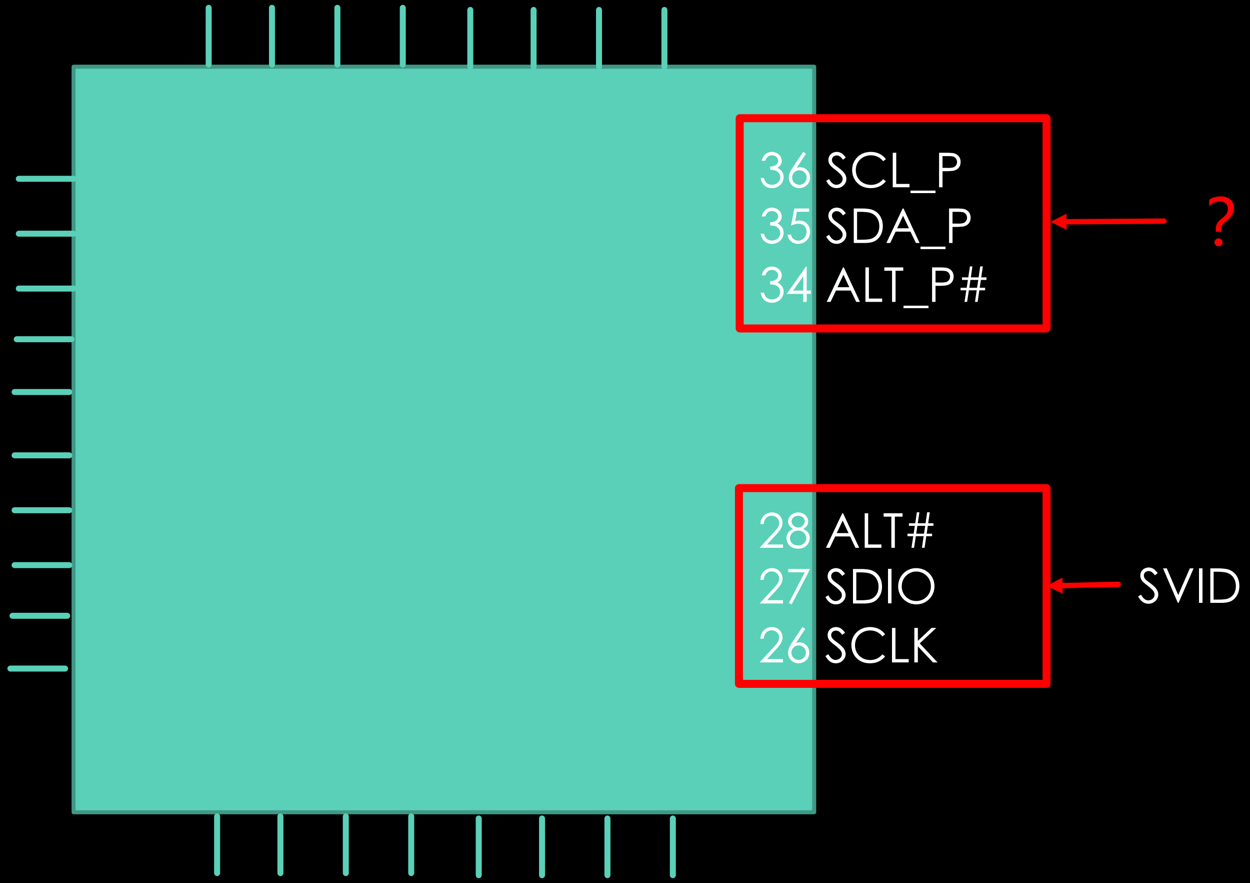
Ref: Voltpillager [2] Talk

?

Supermicro
X11SSL-CF

[1] Kit Murdock et al. Plundervolt: Software-based Fault Injection Attacks against Intel SGX
[2] Zitai Chen et al. VoltPillager: Hardware-based fault injection attacks against Intel SGX Enclaves using the SVID voltage scaling interface

# What is PMBus?

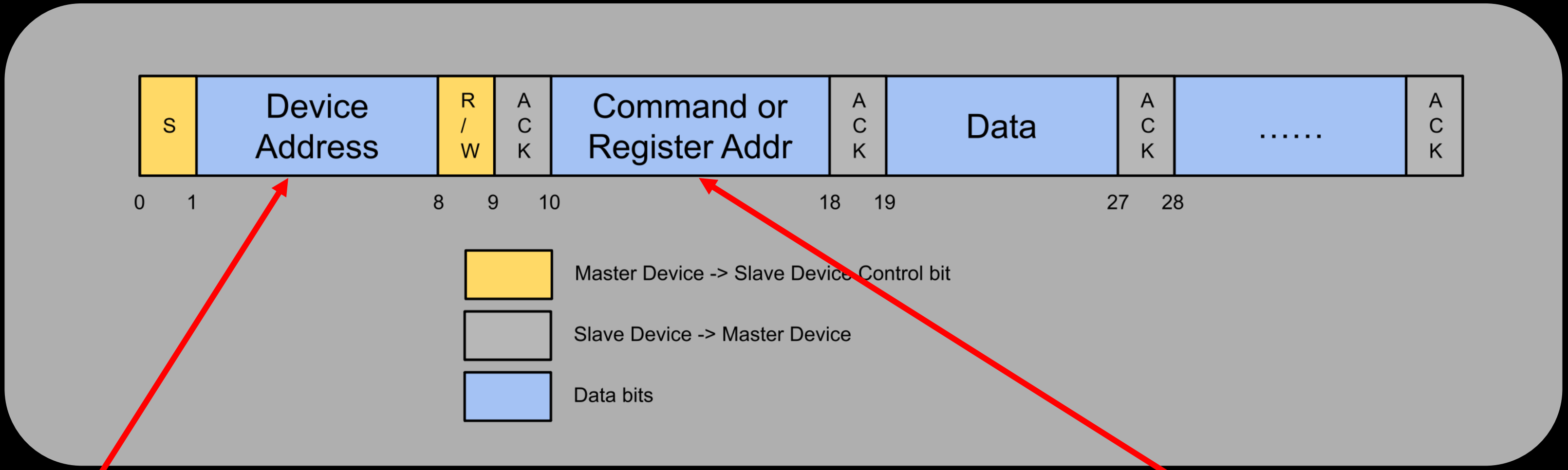


SDA_P: PMBUS Data
SCL_P: PMBus Clock

- I2C based
- Semi-standardized protocol
  - Standard commands
  - + Manufacturer-defined commands

Ref: MP2965 DataSheet (Supermicro X11SSL-CF server motherboard uses MP2955)

# Packet structure



| S | Device Address | R / W | A C K | Command or Register Addr | A C K | Data | A C K | …… | A C K |
|---|---|---|---|---|---|---|---|---|---|

0
1
8
9
10
18
19
27
28
🟨 Master Device -> Slave Device Control bit
⬜ Slave Device -> Master Device
🟦 Data bits

Each device is assigned a 7-bit address
What is the address for VRM?

From **PMBus Spec**
and **MP2965** VRM datasheet

# Attempt 0: From CPU? What is the VRM address?

```
~$ sudo modprobe i2c_i801
~$ sudo i2cdetect 0
         0  1  2  3  4  5  6  7  8  9  a  b  c  d  e  f
[00-20]: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
30:     -- -- -- -- -- -- -- 37 -- -- -- -- -- -- -- --
40:     -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
50:     50 -- -- -- -- -- -- -- 58 -- -- -- -- -- -- --
60:     -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
70:     -- -- -- -- -- -- -- --

~$ sudo i2cdetect 1
     0  1  2  3  4  5  6  7  8  9  a  b  c  d  e  f
00:          -- -- -- -- -- 08 -- -- -- -- -- -- --
10: 10 -- -- -- -- -- -- -- -- 19 -- -- -- -- -- --
20: 20 -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
30: 30 -- -- -- -- 35 36 -- -- -- -- -- -- -- -- --
40: -- -- -- -- 44 -- -- -- -- -- -- -- -- -- -- --
50: -- 51 -- -- -- -- -- -- -- -- -- -- -- -- -- --
60: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
70: -- -- -- -- -- -- -- --
```

- 12 devices - Which one looks like VRM?
  - Response to common PMBus commands
  - The value returned make sense

```
READ_VOUT() < 0.55V
&& MFR_ADDR_PMBUS == ADDR
```

→ 0x20

- Next: Change the voltage!

# Attempt 0: From CPU? Undervolt it!

With libi2c – library for sending commands on I2C bus

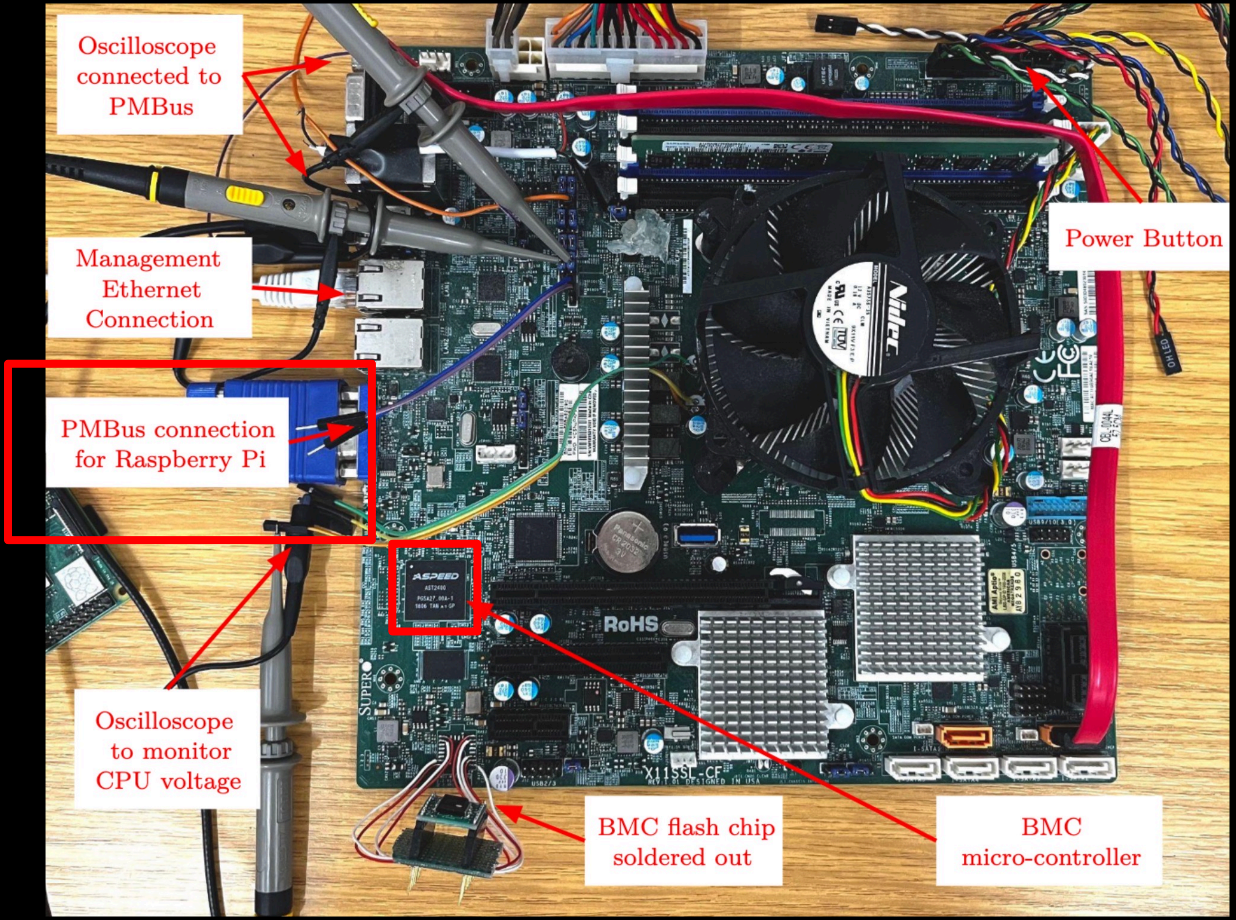
1. PMBus Override Mode -> REG_VOUT_OPERATION
2. Target Voltage -> REG_VOUT_COMMAND
3. SVID_OVERCLK2_EN (Bit 3) -> REG_MFR_VR_CONFIG

→ **Stall...🫠**

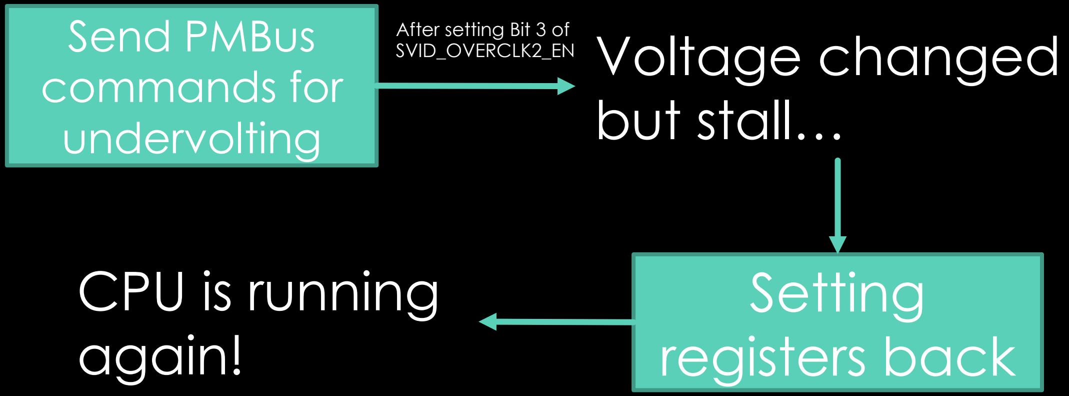
At least… we know the address of the VRM now.

🤔 CPU crashed or recoverable?

# Attempt 0.1: Try with "EXPENSIVE" equipment – Raspberry Pi


Oscilloscope connected to PMBus
Management Ethernet Connection
PMBus connection for Raspberry Pi
Oscilloscope to monitor CPU voltage
BMC flash chip soldered out
BMC micro-controller
Power Button

Luckily, we can use libi2c on RPi.
No changes in code needed.


Send PMBus commands for undervolting

After setting Bit 3 of SVID_OVERCLK2_EN

Voltage changed but stall…

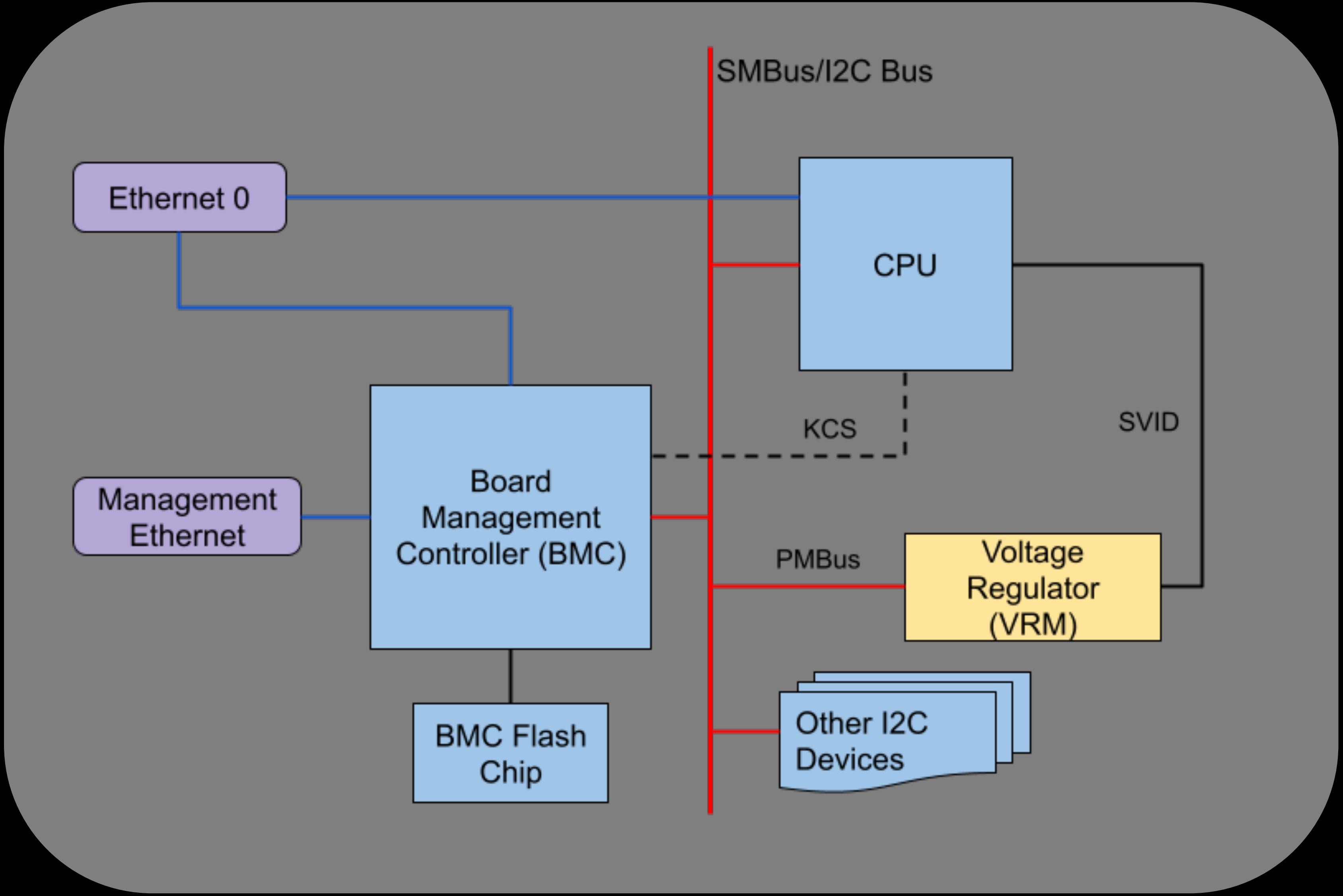
Setting registers back

CPU is running again!

Fault injection on CRT-RSA? Success!

Why 0.1 ?
-- Requires "Opening the box"

# How to access PMBus?

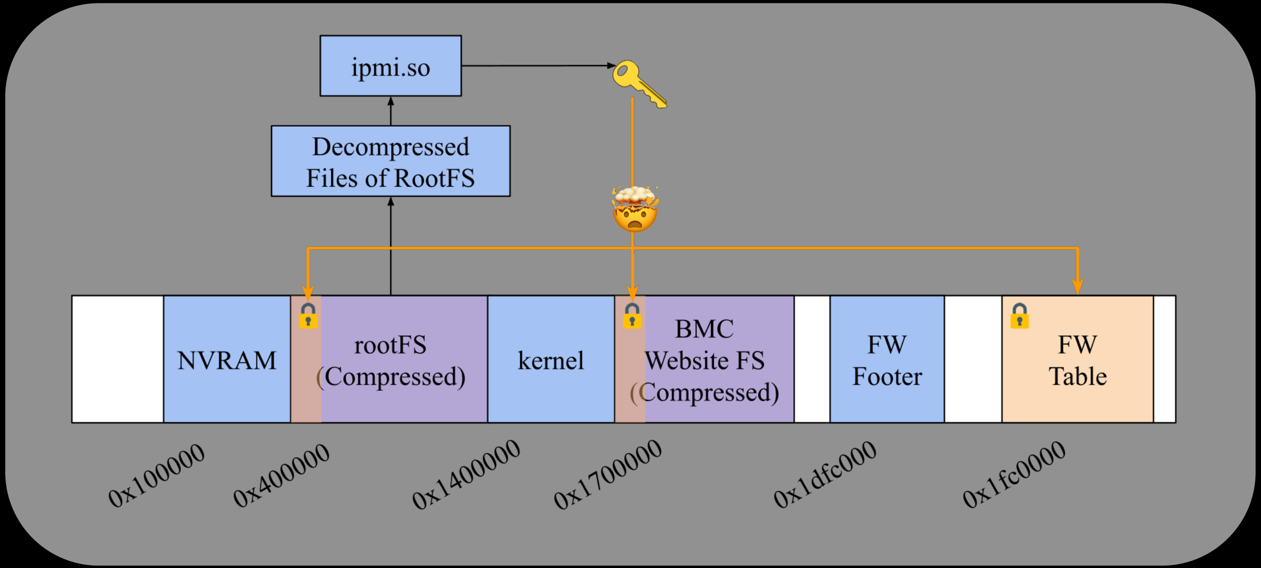


# Attempt 1: BMC

- How to run custom code on it or get SHELL?
  - 22 (SSH) -> gives “ATEN SMASH-CLP SystemManagement Shell”
    - `shell sh? [1] ->` not working
  - Firmware reflashing?
    - Web Interface – 🔒 BMC password, diversified in Supermicro Servers.
    - `AlUpdate` – 🔥 No password required.
  - Firmware package is “encrypted” 🔐

[1] **Exploiting the Supermicro Onboard IPMI Controller,** Available at: https://www.rapid7.com/blog/post/2013/11/15/exploiting-the-supermicro-onboard-ipmi-controller/

# BMC Vulnerability – Firmware Upgrade



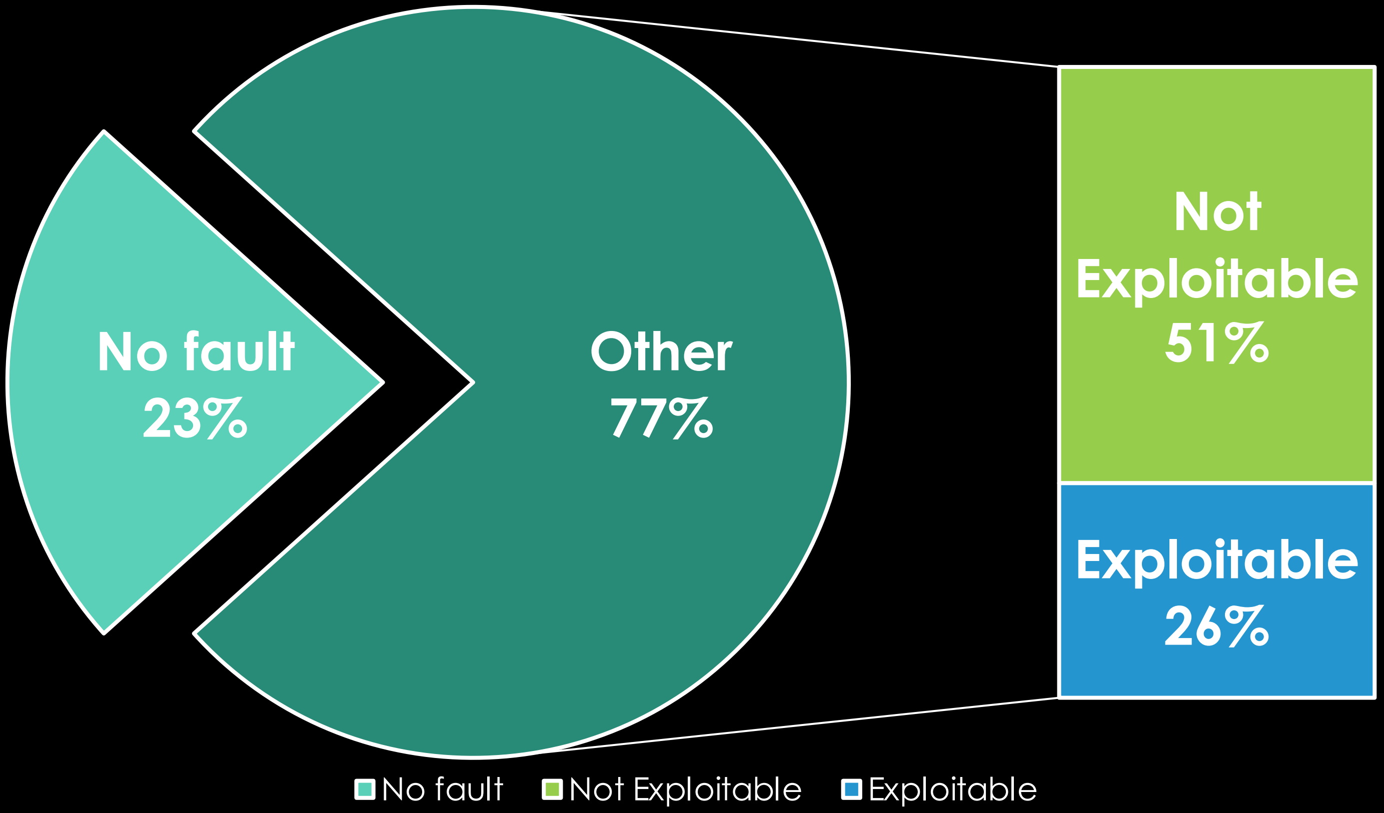
Firmware layout is mostly the same as described by Eclypsium![1]

- Write tool to decrypt, modify and repack firmware, based on
  - smcbmc [2] tool and ipmi_firmware_tools [3]
- Reverse-engineered the firmware
  - `/SMASH/msh` provides the shell
  - Replace it with shell script with content `/bin/sh`
- Re-flash via KCS with `AlUpdate`
- SSH and successfully get root shell !!!
  - PMBus - Implement libi2c by hand

[1] **Insecure Firmware Updates in Server Management Systems**, Available at: https://eclypsium.com/2018/09/06/insecure-firmware-updates-in-server-management-systems/
[2] https://github.com/c0d3z3r0/smcbmc
[3] https://github.com/devicenull/ipmi_firmware_tools

# Attack 1: Undervolting

- Fault injection on SGX WITHOUT physical access – Plundervolt revived! 🎉
- Stability test with CRT-RSA fault injection (in SGX):



**253 tests in 545 mins, on average 9 mins for a useful fault**

# Things happen – server is broken

One day at 3:00AM 🌛

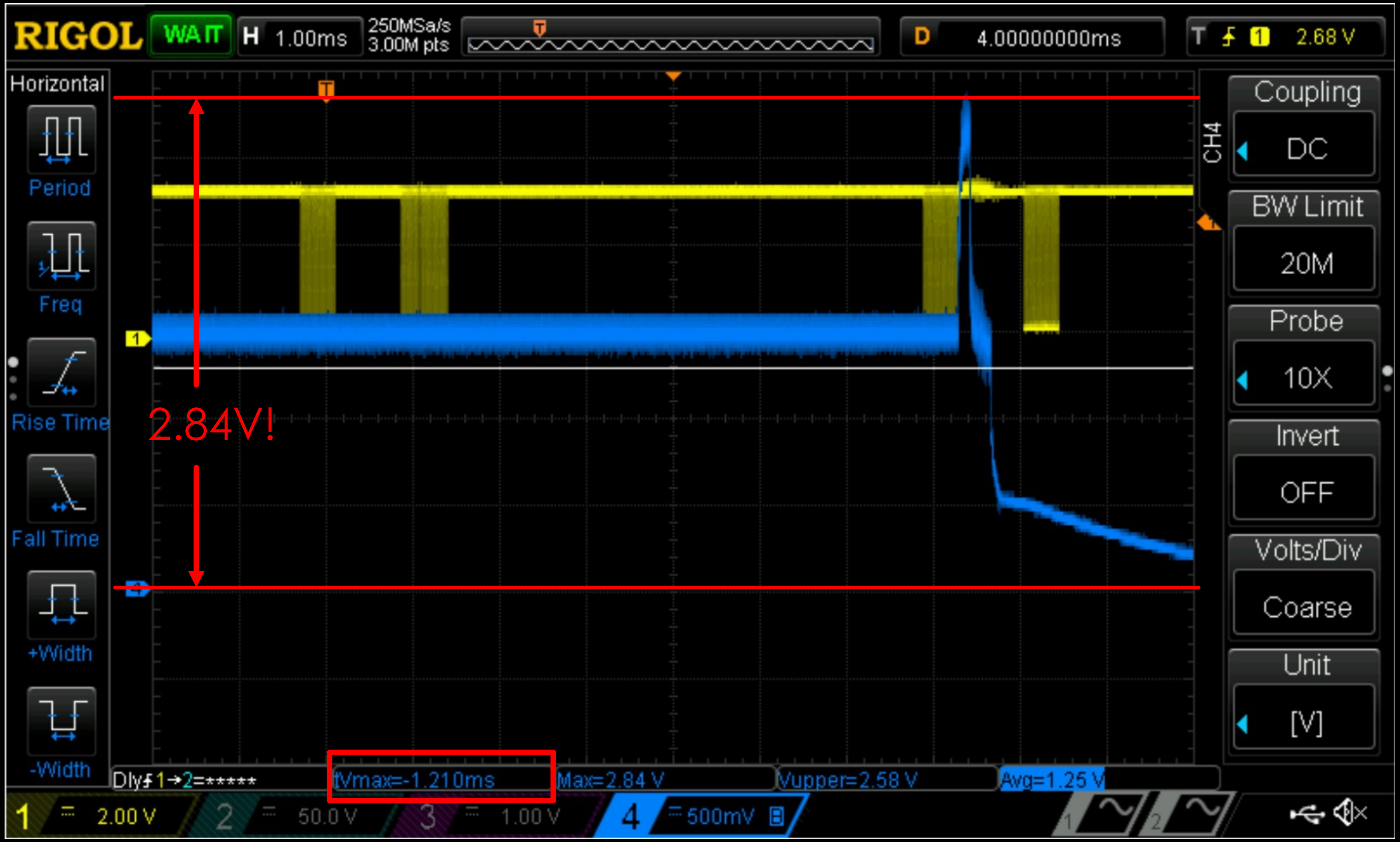
Why is my undervolting code not working!

( 😴 Dream coding 😴 )

VID_STEP_SEL MFR_VR_CONFIG? VR_CONFIG!!

Reset it to 0x00 try again™!!

# Attack 2: Overvolting



Coupling DC
BW Limit 20M
Probe 10X
Invert OFF
Volts/Div Coarse
Unit [V]

Dly 1→2=*****
tVmax=-1.210ms
Max=2.84 V
Vupper=2.58 V
Avg=1.25 V

2.84V!

https://youtu.be/hXuidPexanM?t=88

# Attack 2: Overvolting

VID_STEP_SEL MFR_VR_CONFIG
(p104 of MP2965 Datasheet)

Bit 8: VID_STEP_SEL
1’b0: 10mV per VID step
1’b1: 5mV per VID step

With 10mV per VID step
Vcpu can be up to 3V!!! (CPU spec: 1.52V max)

# We have BMC, maybe use ipmitool?

- `ipmitool i2c`
  - directly interact with I2C buses on the BMC
  - Via KCS: same, not need to login to BMC.
  - Via Ethernet: login required (password can be cleared with `ipmitool` via KCS)

No need to reflash the firmware anymore, instead:

```
sudo ipmitool user set name
sudo ipmitool user set password
sudo ipmitool channel setaccess

ipmitool i2c (Via Ethernet)
```

# I think this attack is nicer than the VoltPillager

Less messy

# Tested on

- Supermicro X11SSL-CF - Vulnerable
- Supermicro X11SPG-TF and X11SSE-F
  - VRM reachable with default config, undervolting crashed the server
  - Didn’t try overvolting as it was kindly provided by a friend
- Supermicro X12DPi-NT - NOT Vulnerable
- Responsible disclosed to Supermicro, see security advisory

# Black Hat Sound Bytes

- Think of a server as an embedded system
  - Vulnerability/functionality in one component --> rest of the system
  - Software + hardware
- SGX security
  - SGX attestation cannot measure BMC firmware
- Improper jumper configuration can cause security issues
  - LPC, SMBus, SPI, I2C, PCIE…

# PMBusDetect Tool

```
$ sudo modprobe i2c_i801
$ sudo ./pmbusdetect -d /dev/i2c-1
Device 0x20              READ_TEMPERATURE success: 0019
!!!!!!!!!!! Detected! Device addr: 20 !!!!!!!!!!!
Device 0x20              SVID_VENDOR_PRODUCT_ID success,
data: 2555 This device is likely to be a MPS VRM
# Save the page
Device 0x20 : 00         READ_PAGE success

Page: 00
Device 0x20 : 00         WRITE_PAGE success
Device 0x20 : 00         READ_VOUT success: 00D8

Page: 01
Device 0x20 : 01         WRITE_PAGE success
Device 0x20 : 01         READ_VOUT success: 0001
# Restore the page
Device 0x20 : 00         WRITE_PAGE success
```

Currently only tested with ISL68137 and MP2955.
Contributions are welcome.

https://github.com/zt-chen/PMFault

# Acknowledgements

- This research is partially funded by the Engineering and Physical Sciences Research Council (EPSRC) under grants EP/R012598/1, EP/R008000/1, and EP/V000454/1.  The results feed into DsbDtech.
- We would also like to thank Supermicro for providing a X12DPi-NT6 server for further investigation of the issue.

# Thank You!

GitHub Repo

PMFault Website