Look at ME!

Investigating Intel ME Firmware

Daniel Maslowski

Disclaimer

This is not about whether we should trust Intel or any (chip) vendor.

Many details about the ME are not public or scattered across the web.

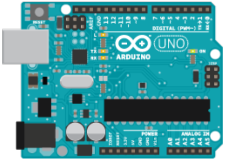
I probably have errors in some places; please report them to me.

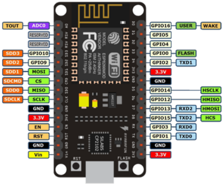
Agenda

- Introduction
- Open Source Firmware
- Intel x86 Hardware
- Motivation
- Firmware Analysis
- Conclusion

Introduction

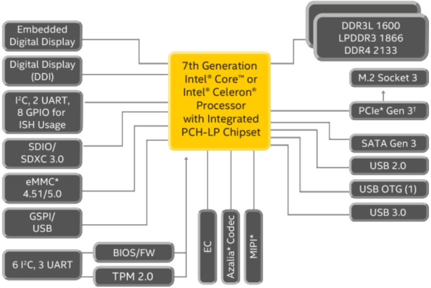
Microcontrollers and fun





Microcontrollers and SoCs on your x86 mainboard

- Chipset (southbridge)
- Gigabit Ethernet (Gbe)
- USB controller
- PCI(e)
- SATA
- GPU
- HD Audio
- Bluetooth module
- Wi-Fi module
- …



Kaby Lake U Mobile block diagram adapted from Intel specifications

Critical Controllers

- Trusted Platform Module (TPM)
- Embedded Controller (EC)
- Baseboard Management Controller (BMC)

Open Source Firmware

Open Source Firmware projects

Host (CPU, main SoC, chipset)

- coreboot
- LinuxBoot
  - Heads
  - u-root

Embedded Controller (EC)

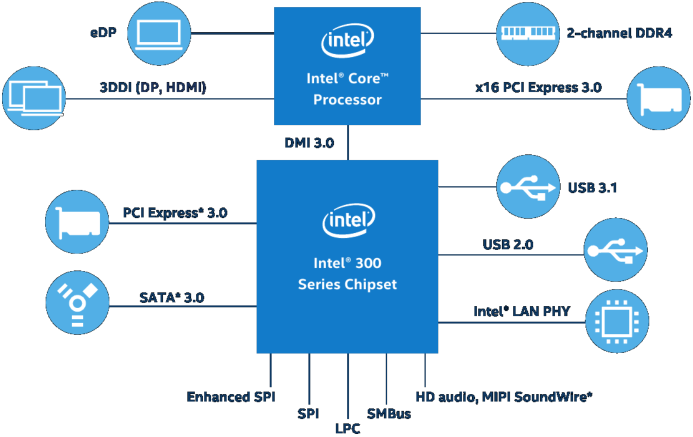
- Chromium OS EC
- System76 EC

Baseboard Management Controller (BMC)

- OpenBMC
- u-bmc

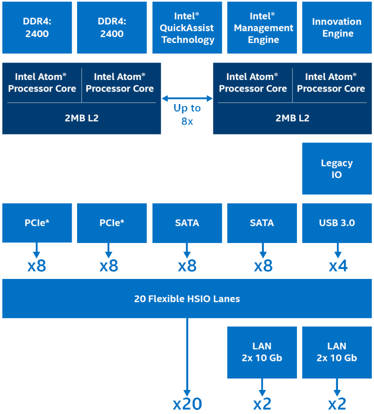
Intel x86 Hardware

Intel chipsets



A closer look: Denverton platform

see Intel website and WikiChip



So what is this...?

- Management Engine
- Innovation Engine

Innovation Engine

> *Enables next-generation systems to customize solution* firmware *to drive greater operational efficiency, security, and predictive maintenance.*

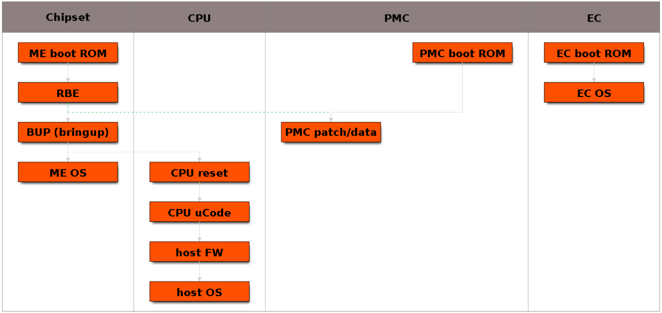
HP Enterprise is using it, I have been told.

It’s very much just a copy of the ME MCU, I have been told.

Intel Management Engine (today)

- Microcontroller unit (MCU)
- part of chipset or System on Chip (SoC)
- connected to SPI flash, CPU, GbE
- started from Active Management Technology (AMT)
- may offer runtime services
- can verify host firmware

Intel platform boot sequence



AMT, MEI and ISH

Active Management Technology

- available through MEI driver
  - hardware monitoring
  - power control
  - OS updates
  - storage
  - proxy for KVM (keyboard, video, mouse)

Management Engine Interface

- implemented in Linux kernel

Integrated Sensor Hub

- dedicated low power co-processor
- implemented in Linux Kernel

MEBX

Management Engine BIOS Extensions

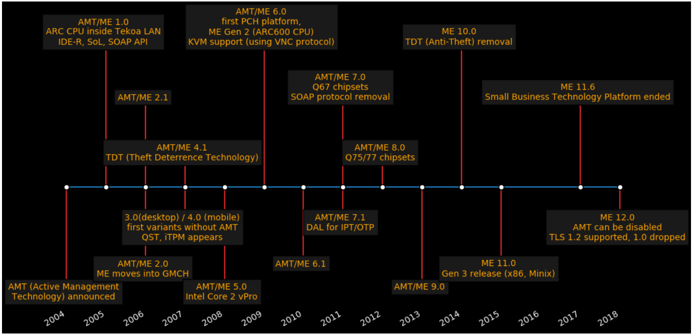
- configuration interface in host firmware
- Ctrl + P or F6
- default password is `admin`

vPro

What is this vPro thing?

- umbrella marketing term for a set of technologies
- as per ARK, for some chips, there is no “eligibility”

Once upon a time…



adapted from Igor Skochinksy - Intel ME Myths and Reality,

Wikipedia and Intel

Intel ME Version 12.0

- release notes are public
- supports TLS 1.2, dropped 1.0
- `CIM_Battery` class
- AMT can be disabled
- category of “super_critical” events

ME Firmware Variants

CON(S)	Consumer
COR(P)	Corporate
SLM(?)	Slim
SPS	Server Platform Services
IGN(?)	Ignition

Motivation

First public release of a redistributable ME firmware binary

EDK II non-osi mailing list

> *Ignition Firmware is a variant of ME firmware that is intended to provide lightweight chipset initialization. It does not contain all the features of the Intel® Server Platform Services (SPS) ME firmware. Ignition Firmware is consequently much smaller than Intel® SPS Firmware (~0.5 MB vs. ~3 MB).*

Build and distribute full firmware images with binaries

- Firmware Support Package (FSP) for host firmware
- Ignition ME firmware for Cascade Lake / Purley

Follow the yellow brick road…

ME Ignition Firmware License

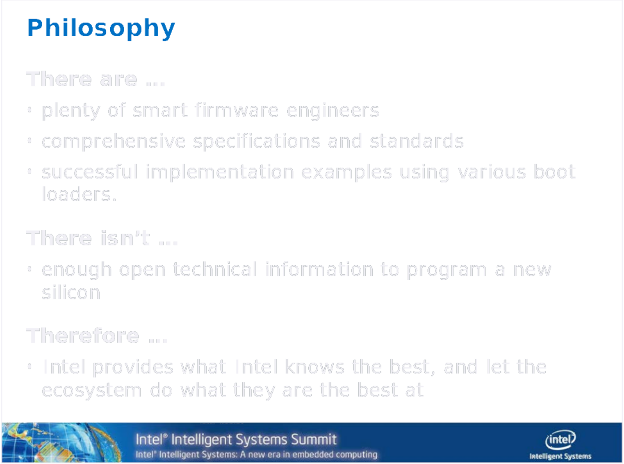
Redistribution and use in binary form, without modification, are permitted, provided that the following conditions are met:

1. *Redistributions must reproduce the above copyright notice and the following disclaimer in the documentation and/or other materials provided with the distribution.*
2. *Neither the name of Intel Corporation nor the names of its suppliers may be used to endorse or promote products derived from this software without specific prior written permission.*
3. *No reverse engineering, decompilation, or disassembly of this software is permitted.*

Pay no attention to that man behind the curtain!

Philosophy

training for FSP by Intel



Philosophy

There are …

- plenty of smart firmware engineers
- comprehensive specifications and standards
- successful implementation examples using various boot loaders.

There isn't …

- enough open technical information to program a new silicon

Therefore …

- Intel provides what Intel knows the best, and let the ecosystem do what they are the best at

Intel® Intelligent Systems Summit

Intel® Intelligent Systems: A new era in embedded computing

intel

Intelligent Systems

Vendor perspective

> *Intel is working towards releasing as much source code as possible going forward. A binary component is still the best way to encapsulate the complex solution that developers may not necessarily need to bother about as long as the binary component does its job right.*

source: FSP whitepaper

Dexter’s Law

Only proprietary software vendors want proprietary software.

Spotting the issue

Attackers do not play by the rules

First steps

Previous work / existing resources

Analysis

- `me_cleaner` and its wiki
- Heads docs on ME cleaner
- MEAnalyzer

Reverse engineering

- ROMP module reverse engineering effort by Youness Alaoui
- Huffman decoders
- tools by Positive Research

More information

- talks by Igor Skochinsky
- Win-Raid Forum
- talk by Intel at Black Hat USA 2019
- Peter Bosch’ talk at 36C3

Plundervolt

We build on the reverse engineering efforts of [64, 49, 57] that revealed the existence of an undocumented MSR to adjust operating voltage on Intel Core CPUs. To ensure reproducibil- ity of our findings, we document this concealed interface in detail. All results were experimentally confirmed on our test platforms (cf. Table I).

Trust

Trust is complicated and hard to define.

Blind trust

- security by obscurity
- consumers “don’t care”

Established trust

- full insight
- personal relationship

Why do I have to disclose if a cookie may contain traces of nuts, but not what hardware actually contains or when software may have flaws?

BootGuard

https://u-root.slack.com/archives/CCVC8PJA0/p1579903778021700

https://u-root.slack.com/archives/CCWLQKEHG/p1579946453042500

SGX

https://cacheoutattack.com/

Security Issues

Security has many dimensions.

- physical: voltages, hardware accessibility
  - see Plundervolt
- computational: constant-time for crypto ops
  - see TPM Fail
- logical: programmatic flaws

CVEs happen, which closed models make worse.

Lots of highly severe CVEs regarding (CS)ME were disclosed lately.

More issues were announced.

Security Perspectives

Hardware and firmware have to be considered in combination.

Intel researchers agree.

PTT is a TPM 2.0 implementation.

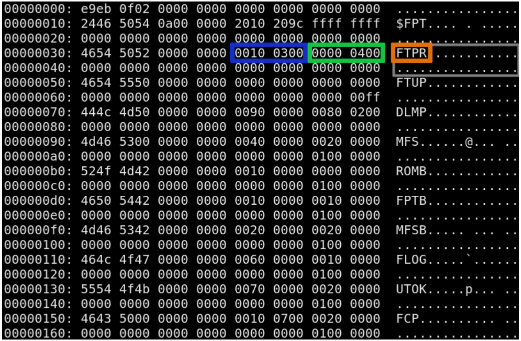
Auditability is a requirement, fulfilled by open source.

Theorem

no audit => no trust

Firmware Analysis

Firmware Partition Table



```
00000000: e9eb 0f02 0000 0000 0000 0000 0000 0000  ................
00000010: 2446 5054 0a00 0000 2010 209c ffff ffff  $FPT.... . .....
00000020: 0000 0000 0000 0000 0000 0000 0000 0000  ................
00000030: 4654 5052 0000 0000 0010 0300 0000 0400  FTPR............
00000040: 0000 0000 0000 0000 0000 0000 0000 0000  ................
00000050: 4654 5550 0000 0000 0000 0000 0000 0000  FTUP............
00000060: 0000 0000 0000 0000 0000 0000 0000 00ff  ................
00000070: 444c 4d50 0000 0000 0090 0000 0080 0200  DLMP............
00000080: 0000 0000 0000 0000 0000 0000 0000 0000  ................
00000090: 4d46 5300 0000 0000 0040 0000 0020 0000  MFS.....@... ..
000000a0: 0000 0000 0000 0000 0000 0000 0100 0000  ................
000000b0: 524f 4d42 0000 0000 0010 0000 0000 0000  ROMB............
000000c0: 0000 0000 0000 0000 0000 0000 0100 0000  ................
000000d0: 4650 5442 0000 0000 0010 0000 0010 0000  FPTB............
000000e0: 0000 0000 0000 0000 0000 0000 0100 0000  ................
000000f0: 4d46 5342 0000 0000 0020 0000 0020 0000  MFSB.... ... ..
00000100: 0000 0000 0000 0000 0000 0000 0100 0000  ................
00000110: 464c 4f47 0000 0000 0060 0000 0010 0000  FLOG....`.......
00000120: 0000 0000 0000 0000 0000 0000 0100 0000  ................
00000130: 5554 4f4b 0000 0000 0070 0000 0020 0000  UTOK....p... ..
00000140: 0000 0000 0000 0000 0000 0000 0100 0000  ................
00000150: 4643 5000 0000 0000 0010 0700 0020 0000  FCP.......... ..
00000160: 0000 0000 0000 0000 0000 0000 0100 0000  ................
```

- partition FTPR
- offset 0x31000
- size 0x40000

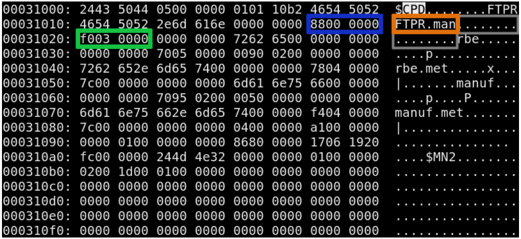
Code Partition Directory

Each CPD entry can be either:

- partition manifest (“.man”), “old” generation 2 manifest
- module metadata (“.met”), also contains the module hash
- module

CPD data structure

see Win-Raid Forum



```
00031000: 2443 5044 0500 0000 0101 10b2 4654 5052  $CPD........FTPR
00031010: 4654 5052 2e6d 616e 0000 0000 8800 0000  FTPR.man........
00031020: f003 0000 0000 0000 7262 6500 0000 0000  ........rbe.....
00031030: 0000 0000 7005 0000 0090 0200 0000 0000  ....p...........
00031040: 7262 652e 6d65 7400 0000 0000 7804 0000  rbe.met.....x...
00031050: 7c00 0000 0000 0000 6d61 6e75 6600 0000  |.......manuf...
00031060: 0000 0000 7095 0200 0050 0000 0000 0000  ....p....P......
00031070: 6d61 6e75 662e 6d65 7400 0000 f404 0000  manuf.met.......
00031080: 7c00 0000 0000 0000 0400 0000 a100 0000  |...............
00031090: 0000 0100 0000 0000 8680 0000 1706 1920  ................
000310a0: fc00 0000 244d 4e32 0000 0000 0100 0000  ....$MN2........
000310b0: 0200 1d00 0100 0000 0000 0000 0000 0000  ................
000310c0: 0000 0000 0000 0000 0000 0000 0000 0000  ................
000310d0: 0000 0000 0000 0000 0000 0000 0000 0000  ................
000310e0: 0000 0000 0000 0000 0000 0000 0000 0000  ................
000310f0: 0000 0000 0000 0000 0000 0000 0000 0000  ................
```

- file
  `FTPR.man`
- offset
  `0x0088`
- size
  `0x03f0`

FTPR

- meaning unknown; could refer to *factory*, *partition*, *reset*

files

- `FTPR.man` - FTPR manifest
- `rbe`
- `rbe.met`
- `manuf`
- `manuf.met`

FTPR manifest

- seems to consist of three parts (lots of `0000` and `ffff` may be separators)
- header includes architecture (`8086`) and date (`2019-06-17`)
  - followed by the tag `$MN2`
- more metadata? (`FTPR` itself, `rbe`, `manuf`)
- `0x7c`, `0x200200`?

Trailer?

```
rbe

7262 6500 0000 0000 0000 0000 0000 ffff 7c00 0000

b5da a898 d17c c016 4c04 3b2c f141 c26b
756a de87 dc2c 59b0 995a f551 ac0d e839

manuf

6d61 6e75 6600 0000 0000 0000 0000 ffff 7c00 0000

9064 981d 6cf7 c15d 9a4a 64aa f081 58cc
2619 a3ae 71ae 6230 8bdb 3694 a7cb 1b83

FTPR

0f00 0000 9c00 0000 4654 5052
```

And almost the same thing again

`rbe`

```
7262 6500 0000 0000 0000 0000 0002 2000 7c00 0000
```

```
b5da a898 d17c c016 4c04 3b2c f141 c26b
756a de87 dc2c 59b0 995a f551 ac0d e839
```

`manuf`

```
6d61 6e75 6600 0000 0000 0000 0002 2000 7c00 0000
```

```
9064 981d 6cf7 c15d 9a4a 64aa f081 58cc
2619 a3ae 71ae 6230 8bdb 3694 a7cb 1b83
```

`RCHA` - what is that?

```
3200 0000 1000 0000 5243 4841 0000 0000
```

manuf

consists of three parts

- bootpart
- boot_fpt
- ftpr.mft

x86 Instructions

```
manuf

00000000: 0fa0 66b8 3000 8ee0 b904 0000 0064 8b09  ..f.0..
00000010: b800 0000 0064 8b00 ba04 0000 0064 8b12  .....d.
```

```
PUSH FS ; segment register
MOV  AX,  0x0030
MOV  FS,  AX
MOV  ECX,  0x000004
MOV ECX,DWORD PTR FS:[ECX]
MOV  EAX,  0x000000
```

References

- push onto stack
- 16-bit and 8-bit registers
- single byte or small x86 opcodes
- x86 assembler in 256 LOC

PMC

- included twice, 65584 bytes - 64KB + 48B (3 * 16B)

Last three lines

```
00010000: 706d 635f 6677 5f6c 6267 5f62 302d 3138  pmc_fw_
00010010: 7777 3334 6100 0000 0000 0000 0000 0137  ww34a..
00010020: 0000 0100 0000 0000 0000 0000 0000 0000  .......
```

- probably upper 64KB are actual image and last three lines are meta information
- `pmc_fw_lbg_b0-18ww34a` looks like a version string

Obtaining ME firmware images

- Lenovo
  - download update, e.g., `https://support.lenovo.com/us/de/downloads/ds503998`
  - run `innoextract [file]` => app/ directory with files
  - one for consumer and one for corporate version, `Me_xx.x_Coxx.bin` :)
- HP
  - download update, e.g., `h30318.www3.hp.com/pub/softpaq/sp99501-100000/sp998`
  - run `7z x [file]` (in a new directory) => many files, we want `Q72_xxxxxx.bin`
  - `xxd Q72_xxxxxx.bin | grep "\$FPT"` (extract line with FPT tag)
  - note down address at beginning without `0` at the end, minus 1
  - `dd if=Q72_xxxxxx.bin bs=16 skip=0x[beginning] count=0x1000 of=me.bin`
  - run `MEA.py` over it: `MEA.py me.bin`
  - check expected length, try higher `count` for `dd` in case of error

Conclusion

Run Linux everywhere?

Prerequisite: Code execution possible, preferably early, e.g., in mask ROM.

Constraint: Need capable hardware around. Sorry, not on Arduino! ;)

On x86: LinuxBoot

On BMCs: OpenBMC, u-bmc

On routers: OpenWrt

On iPhones? http://iokit.racing/oneweirdtrick.pdf

In AMD PSP?

In the ME?

Security

All firmware has to be fully open source.

Abbreviations and Acronyms

PMC	Power Management Controller
MSR(1)	Model-Specific Register
MSR(2)	Machine Status Register
PCR	Platform Configuration Register
FIT(C)	Flash Image Tool
FPT	Firmware Partition Table
CPD	Code Partition Directory
RBE	ROM Boot Extension
DAL	Dynamic Application Loader
PTT	Platform Trust Technology
FPF	Field Programmable Fuse

Related work

Talks from Black Hat USA 2019

- Firmware Cartography: Charting the Course for Modern Server Compromise
- Behind the scenes of iOS and Mac Security
- Inside the Apple T2
- Breaking Through Another Side: Bypassing Firmware Security Boundaries from Embedded Controller
- Breaking Samsung’s ARM TrustZone

Talks by Alexander Ermolov

- Safeguarding rootkits: Intel BootGuard

Kudos

CHAOSPOTT
ESSEN

Chaosdorf

LABOR.

CHAOS WEST

coreboot

LinuxBoot

Thanks!

Questions?

https://github.com/orangecms/look-at-me

https://metaspora.org/look-at-me.pdf