black hat USA 2017

TREATS OR TRETAS!
V5.0

14ª EDITION 2017
H2HC
HACKERS TO HACKERS CONFERENCE

ZERO NIGHTS

BETRAYING THE BIOS:

WHERE THE GUARDIANS OF THE BIOS ARE FAILING

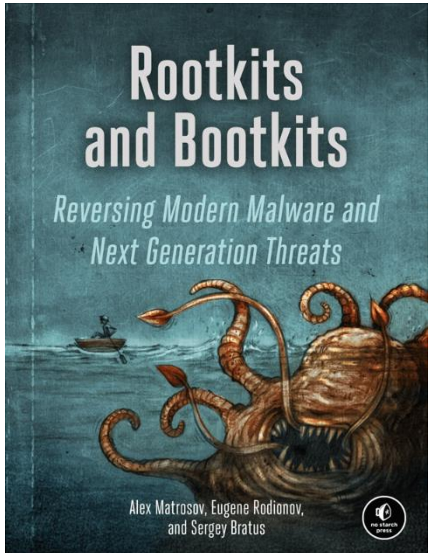
Alex Matrosov
@matrosov

Have a lot of fun with UEFI Security and RE

Former Security Researcher @Intel

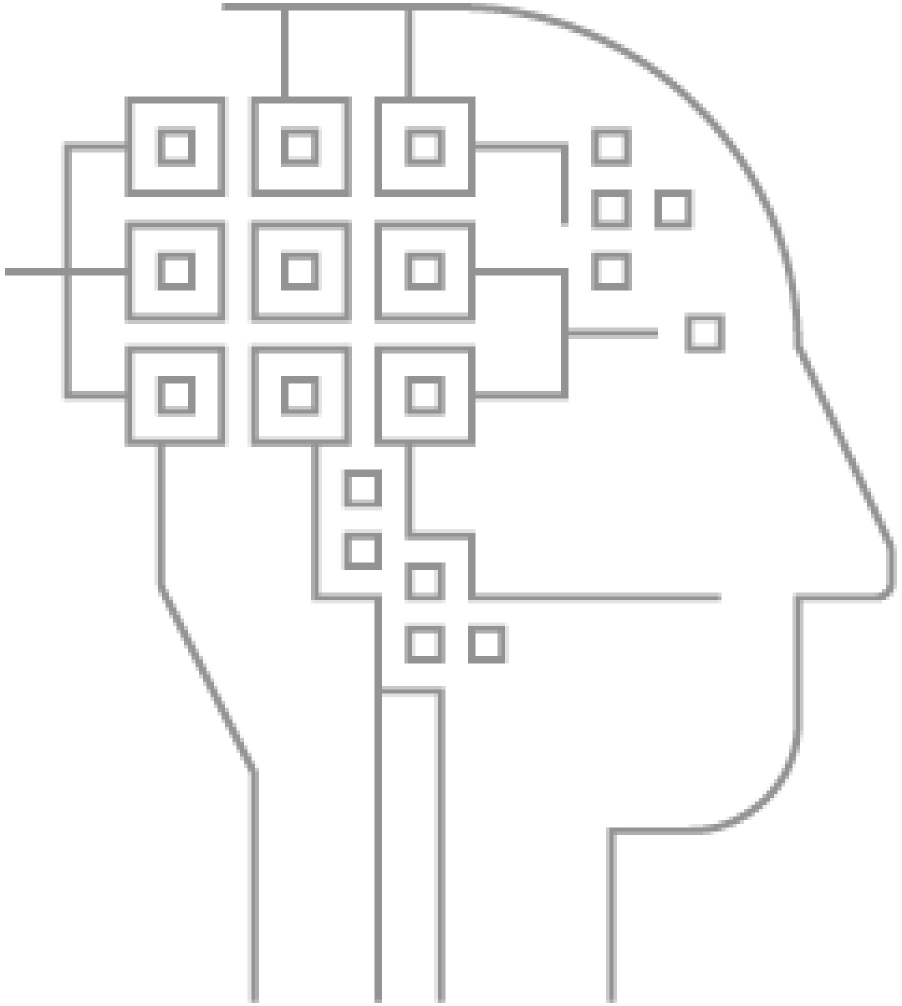
Reverse Engineering since 1997

Book co-author nostarch.com/rootkits

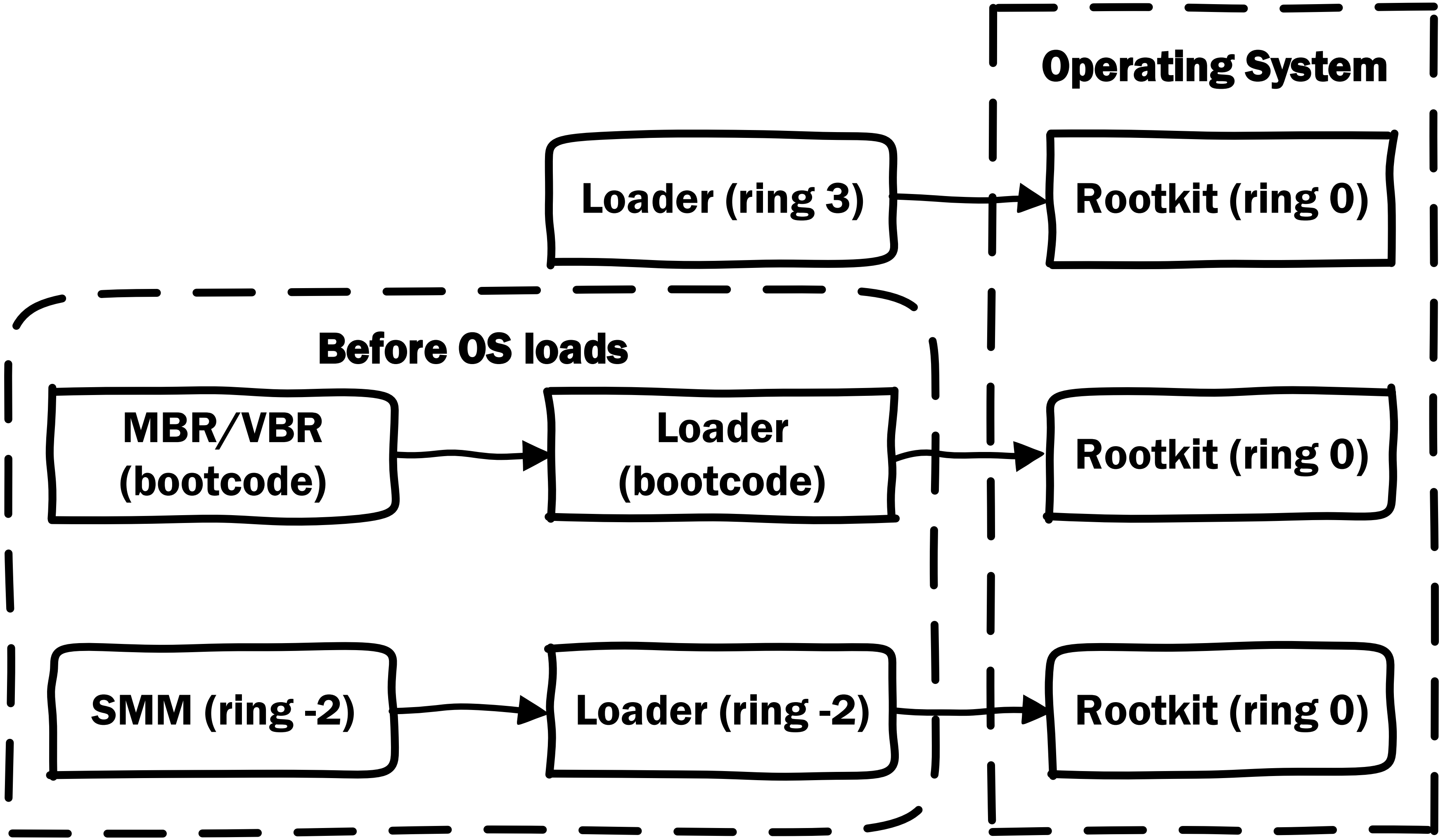

Rootkits and Bootkits
Reversing Modern Malware and Next Generation Threats
Alex Matrosov, Eugene Rodionov, and Sergey Bratus

@matrosov

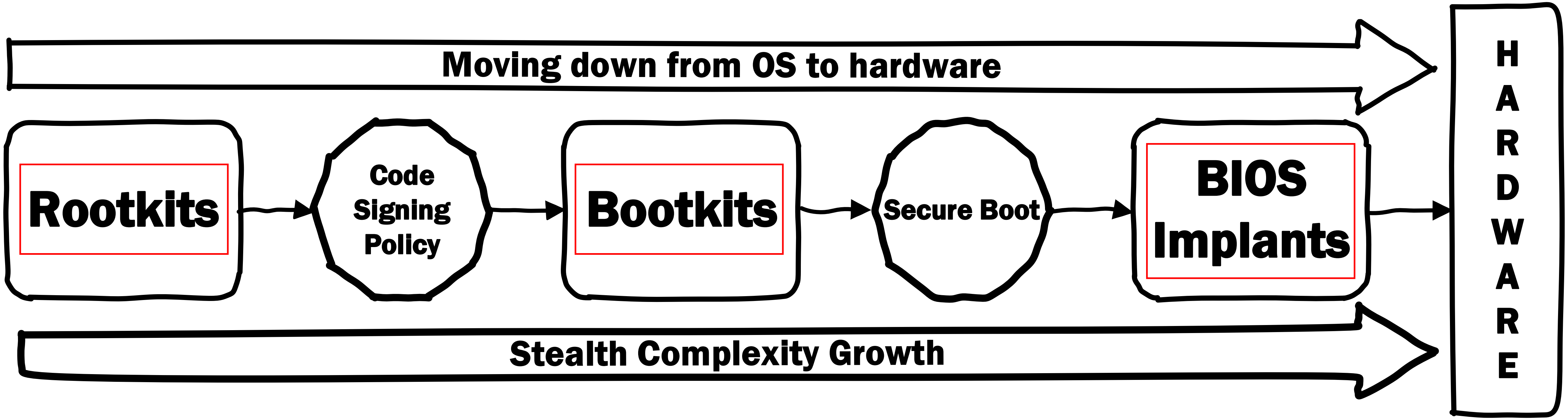
- Intro
- Attacks on BIOS Updates
  - ✓ Unsigned Updates
  - ✓ BIOS protection bits
  - ✓ SmiFlash and SecSmiFlash
- Intel Boot Guard
  - ✓ AMI implementation details
  - ✓ Discover ACM secrets
  - ✓ Vulns
  - ✓ Boot Guard Bypass!
- Intel BIOS Guard
  - ✓ AMI implementation details



All rootkits want to get into Ring 0



More mitigations, more rootkits complexity



Moving down from OS to hardware

Rootkits

Code Signing Policy

Bootkits

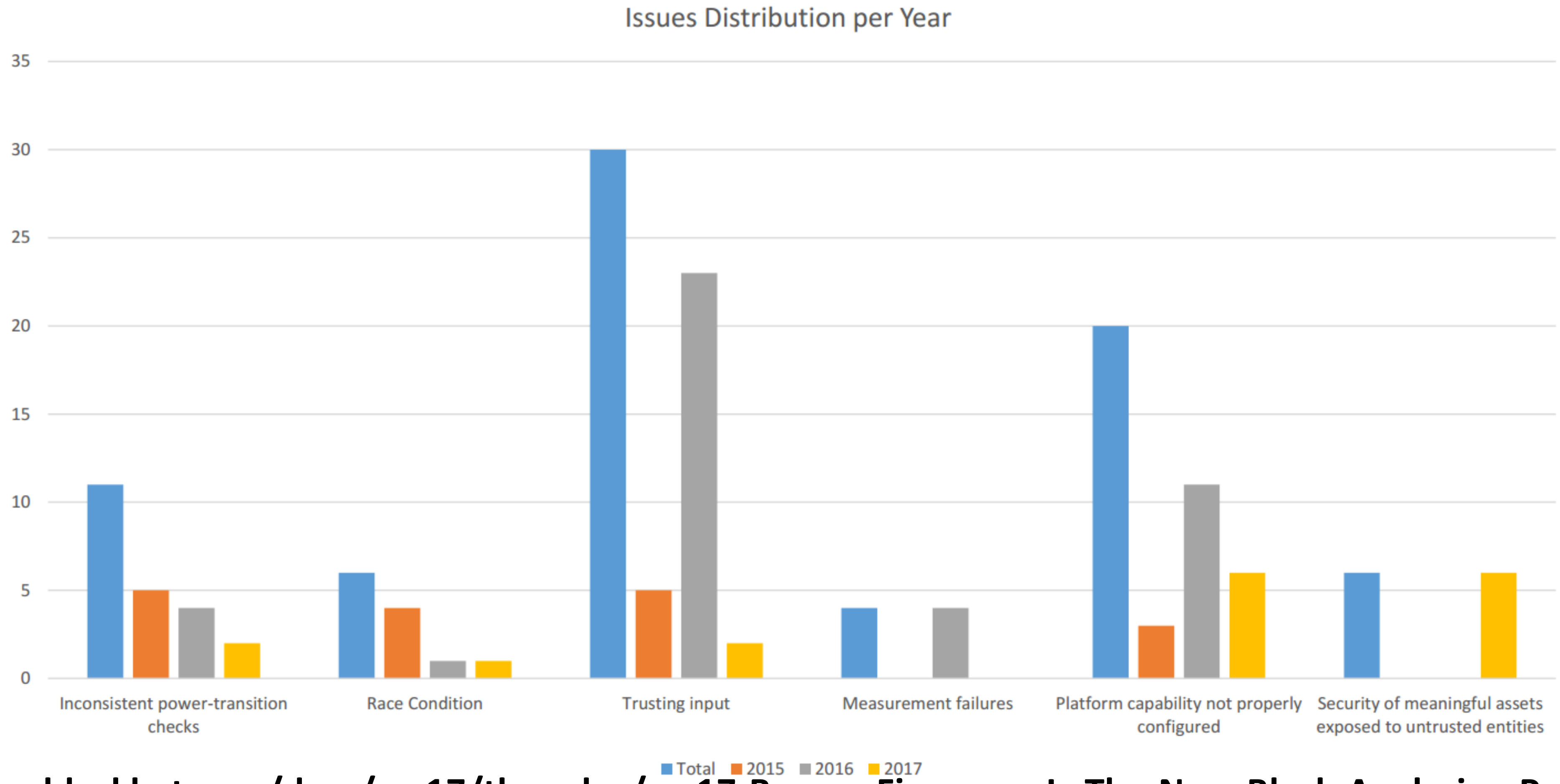
Secure Boot

BIOS Implants

HARDWARE

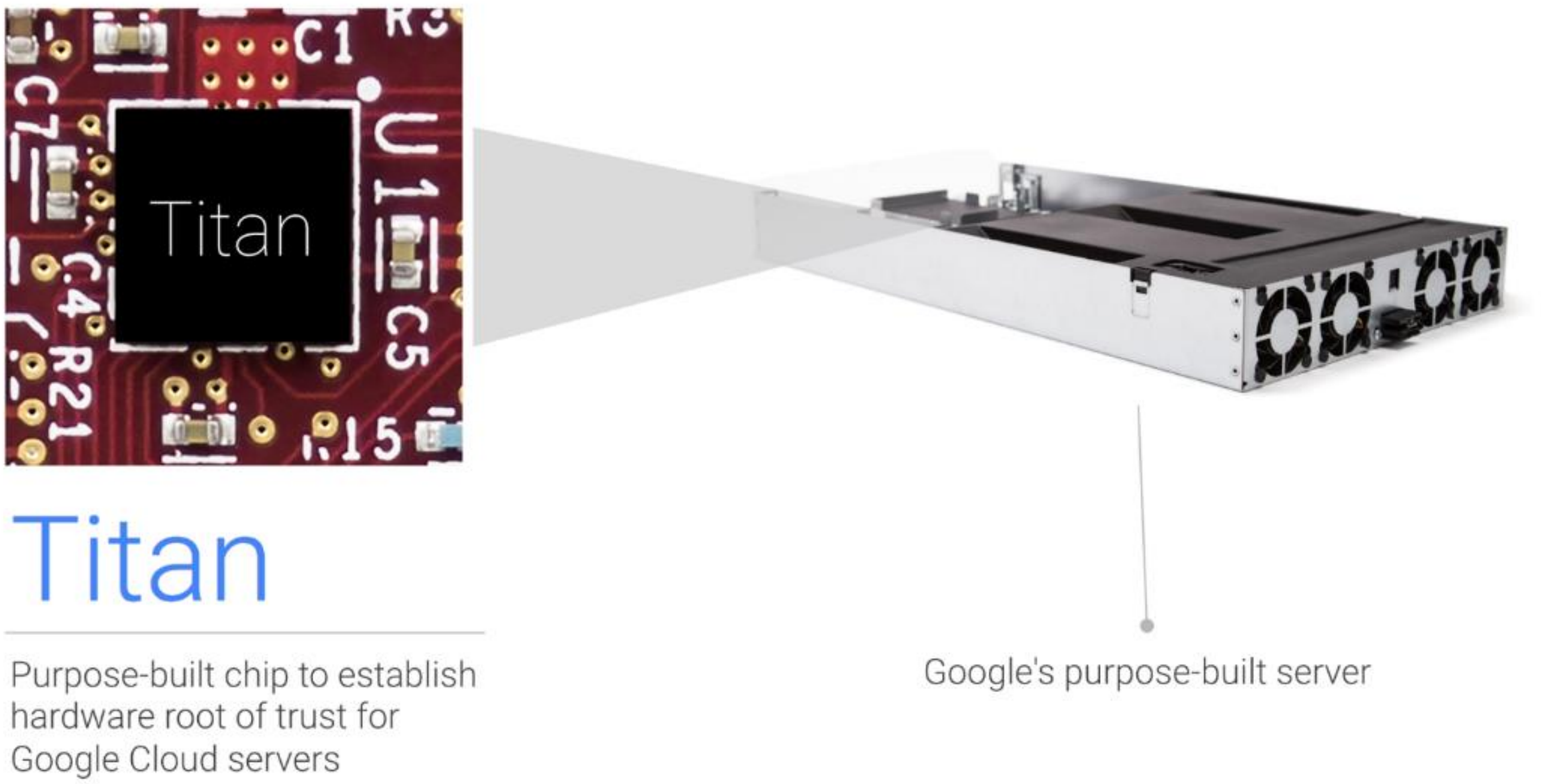
Stealth Complexity Growth

Growths of configuration based vulnerabilities



https://www.blackhat.com/docs/us-17/thursday/us-17-Branco-Firmware-Is-The-New-Black-Analyzing-Past-Three-Years-Of-BIOS-UEFI-Security-Vulnerabilities.pdf

Google Titan Chip



Titan

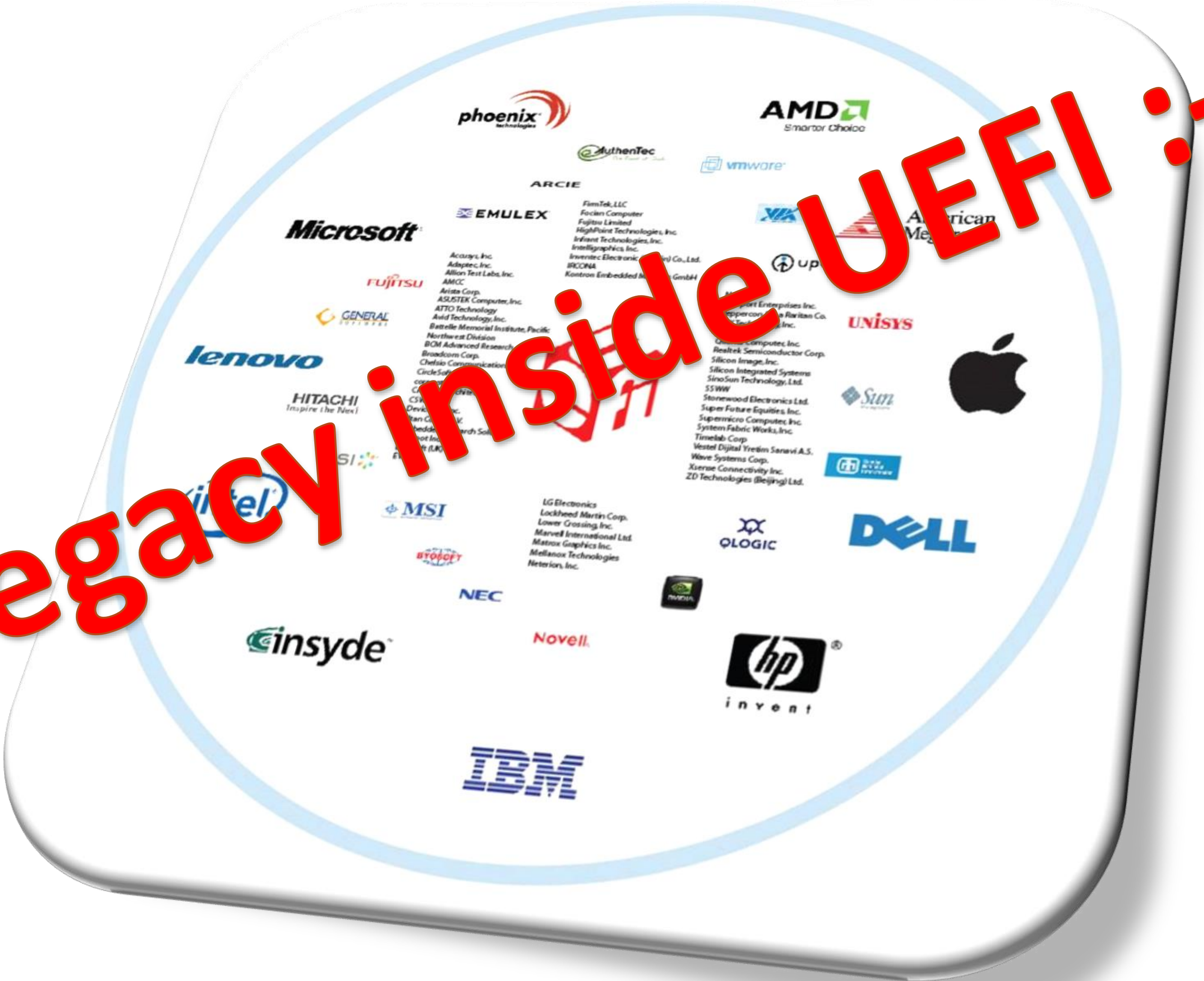
Purpose-built chip to establish hardware root of trust for Google Cloud servers

Google's purpose-built server

https://cloudplatform.googleblog.com/2017/08/Titan-in-depth-security-in-plaintext.html

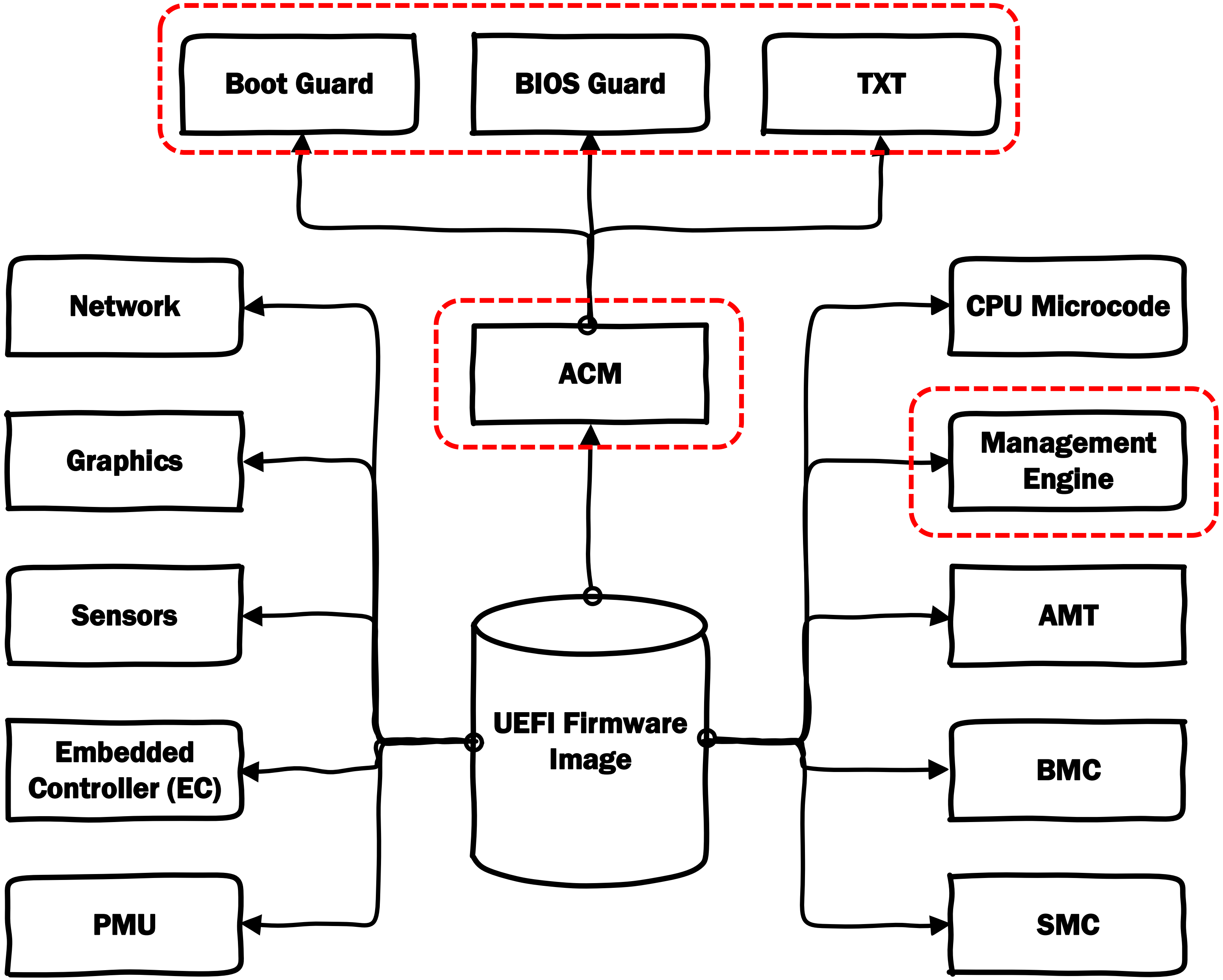
BIOS Update Issues

No more legacy! UEFI is everywhere!!



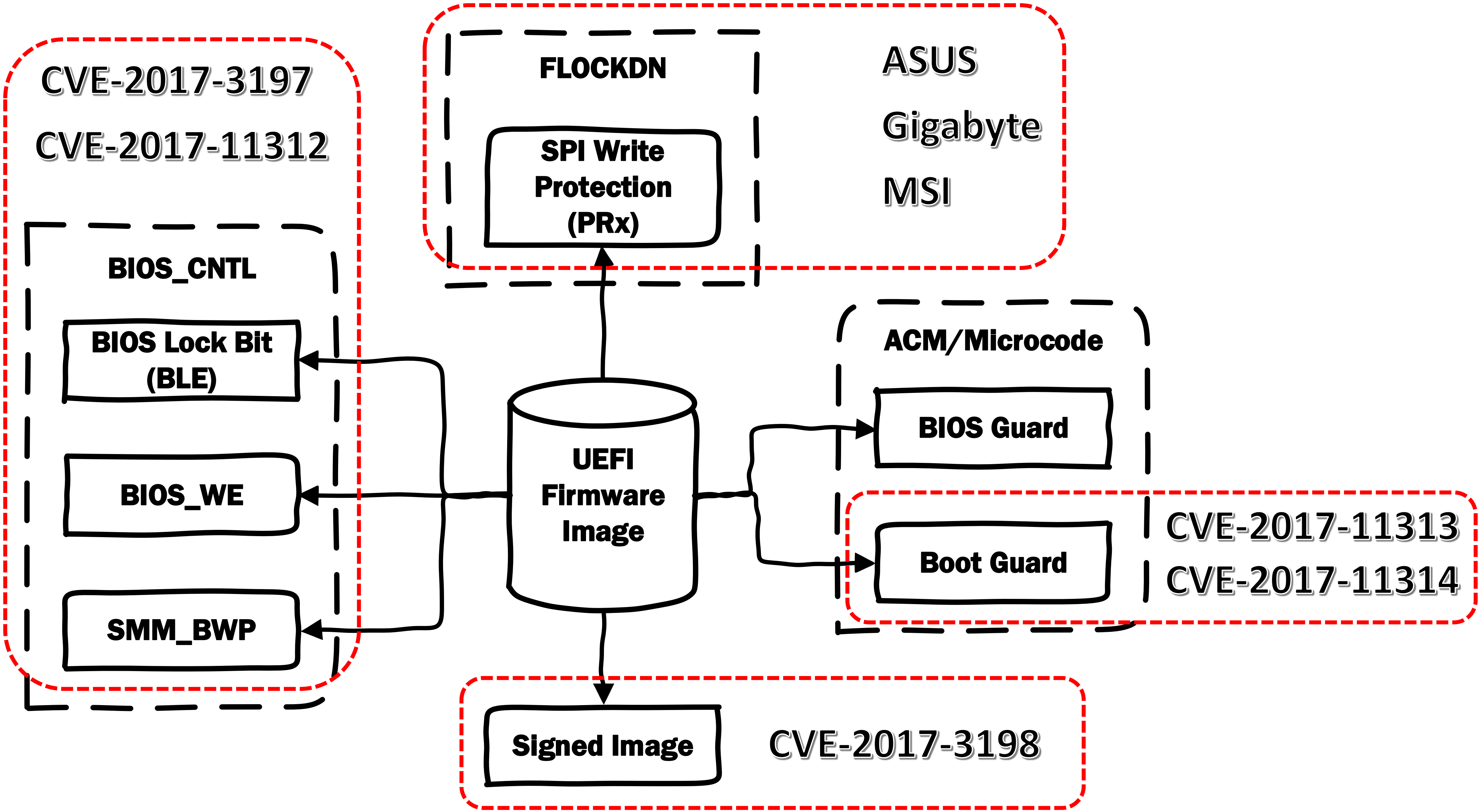
Now the legacy inside UEFI :-)

How many different firmware's inside BIOS update?



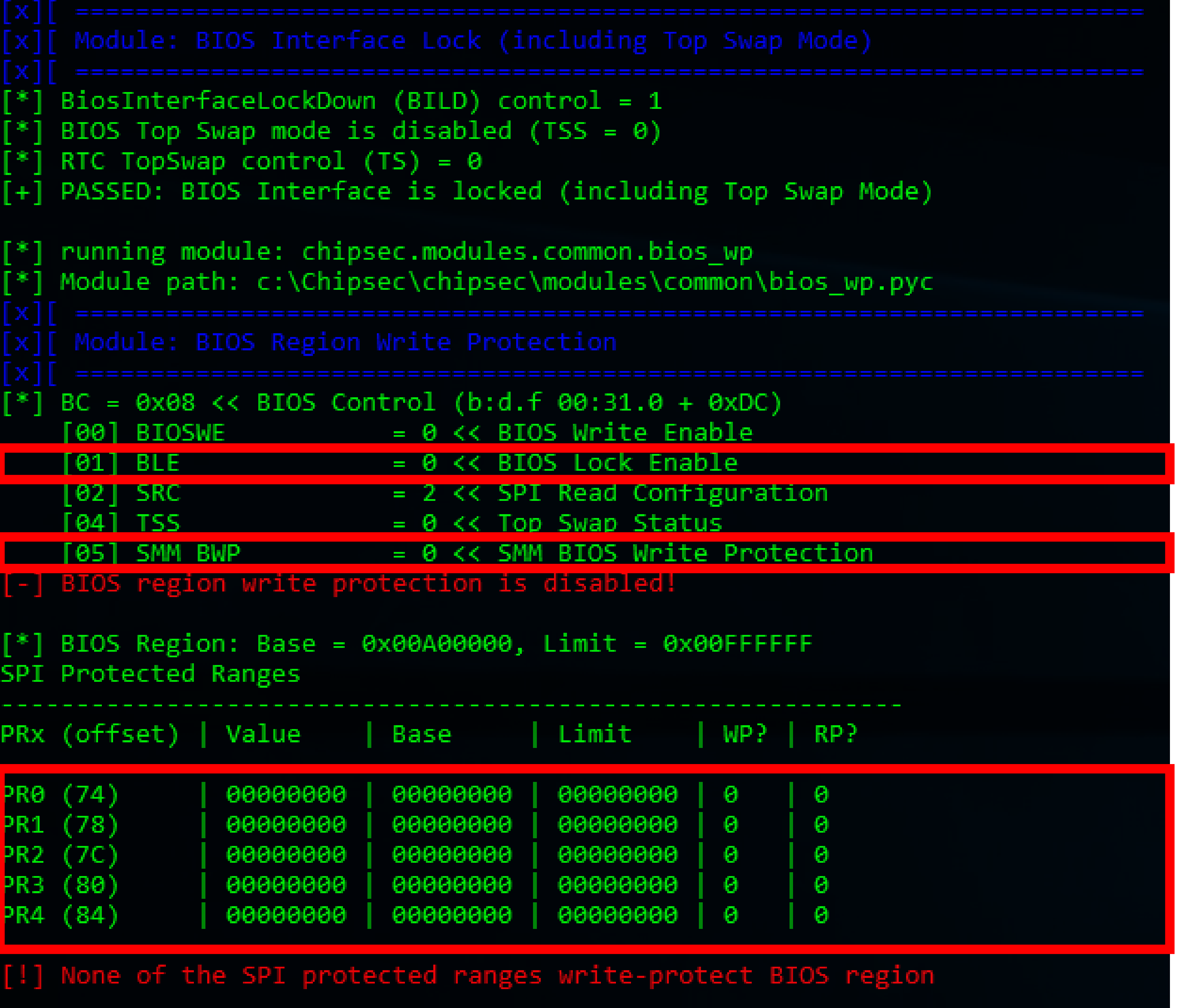
All the vulnerabilities mention in this research found inside AMI-based UEFI firmware’s

All Guardians of the BIOS on one slide



How different vendors care about security?

Vendor Name	BLE	SMM_BWP	PRx	Authenticated Update
ASUS	+	+	-	-
MSI	-	-	-	-
Gigabyte	+	+	-	-
Dell	+	+	-+	+
Lenovo	+	+	RP	+
HP	+	+	RP/WP	+
Intel	+	+	-	+
Apple	-	-	WP	+



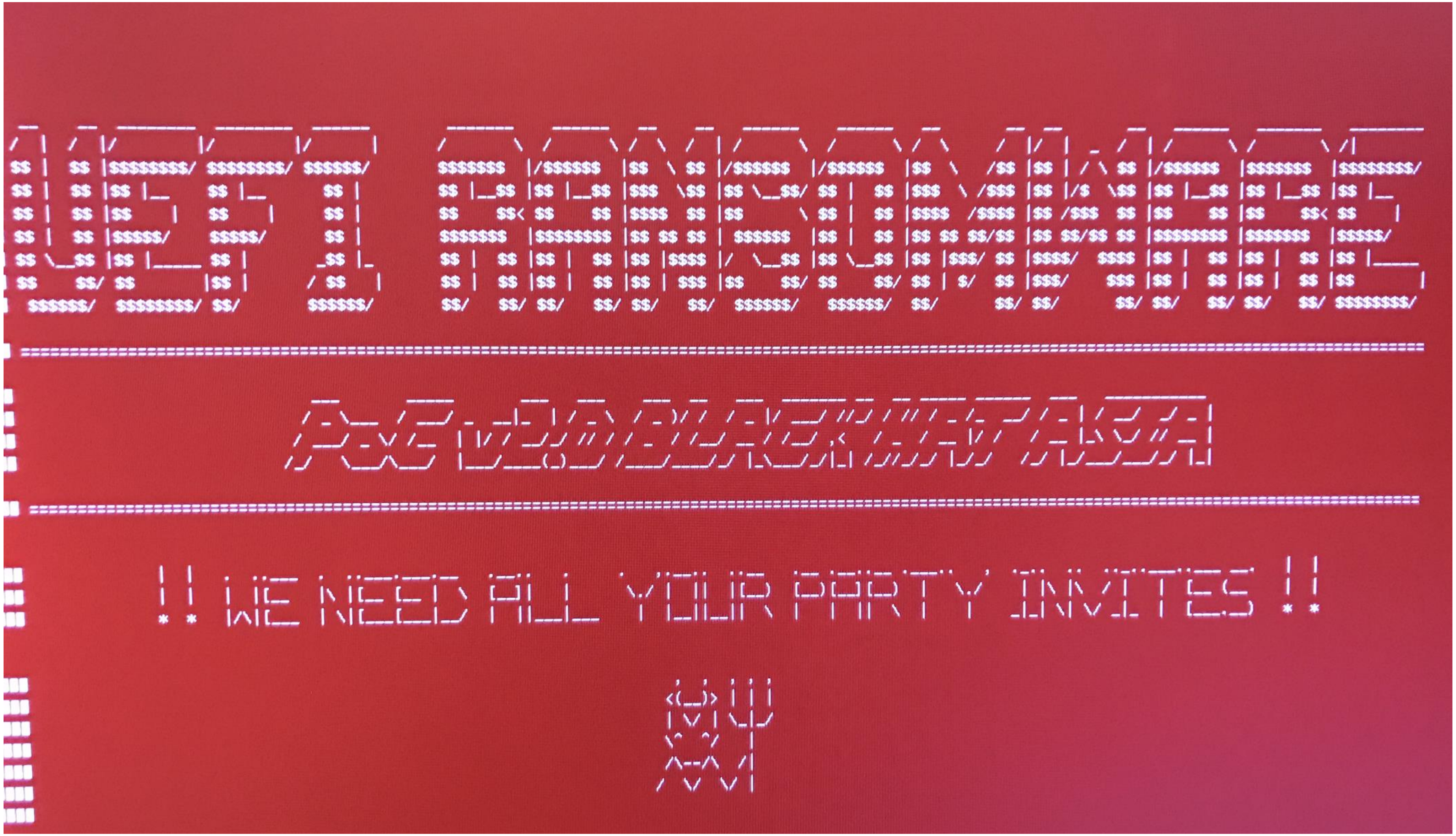
```
[x][ =======================================================================
[x][ Module: BIOS Interface Lock (including Top Swap Mode)
[x][ =======================================================================
[*] BiosInterfaceLockDown (BILD) control = 1
[*] BIOS Top Swap mode is disabled (TSS = 0)
[*] RTC TopSwap control (TS) = 0
[+] PASSED: BIOS Interface is locked (including Top Swap Mode)

[*] running module: chipsec.modules.common.bios_wp
[*] Module path: c:\Chipsec\chipsec\modules\common\bios_wp.pyc
[x][ =======================================================================
[x][ Module: BIOS Region Write Protection
[x][ =======================================================================
[*] BC = 0x08 << BIOS Control (b:d.f 00:31.0 + 0xDC)
    [00] BIOSWE           = 0 << BIOS Write Enable
    [01] BLE              = 0 << BIOS Lock Enable
    [02] SRC              = 2 << SPI Read Configuration
    [04] TSS              = 0 << Top Swap Status
    [05] SMM_BWP          = 0 << SMM BIOS Write Protection
[-] BIOS region write protection is disabled!

[*] BIOS Region: Base = 0x00A00000, Limit = 0x00FFFFFF
SPI Protected Ranges
------------------------------------------------------------
PRx (offset) | Value    | Base     | Limit    | WP? | RP?

PR0 (74)     | 00000000 | 00000000 | 00000000 | 0   | 0
PR1 (78)     | 00000000 | 00000000 | 00000000 | 0   | 0
PR2 (7C)     | 00000000 | 00000000 | 00000000 | 0   | 0
PR3 (80)     | 00000000 | 00000000 | 00000000 | 0   | 0
PR4 (84)     | 00000000 | 00000000 | 00000000 | 0   | 0

[!] None of the SPI protected ranges write-protect BIOS region
```



UEFI RANSOMWARE

PoC v0.0 BLACKHAT ASIA

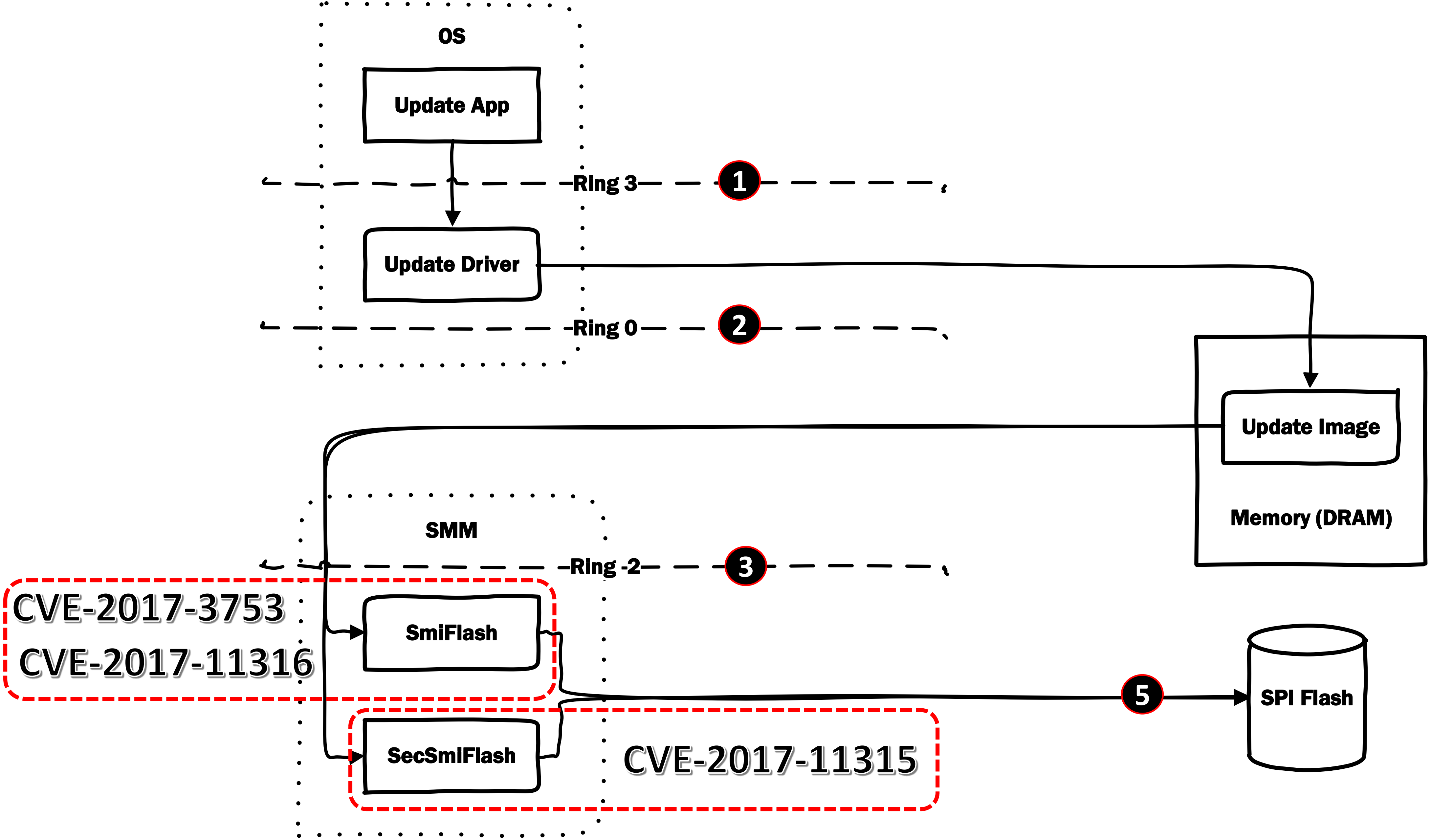
!! WE NEED ALL YOUR PARTY INVITES !!

blackhat.com/docs/asia-17/materials/asia-17-Matrosov-The-UEFI-Firmware-Rootkits-Myths-And-Reality.pdf

Why so vulnerable?

- ➢ BIOS LOCK (BLE) not enabled (CLVA-2016-12-001/CVE-2017-3197)
  - ✓ Attacker is able to modify BIOSWE bit
  - ✓ Attacker can arbitrary write to SPI flash from OS
- ➢ FW update process don’t verify signature
  - ✓ Attacker is able to abuse BIOS updater with signed driver
- ➢ SmiFlash Handler multiple vulns (CLVA-2016-12-002/CVE-2017-3198)
  - ✓ Attacker can elevate privileges to SMM (ring -2)

How BIOS Update Guardians Fail?



SMIFlash Handler Issues: Gigabyte, Lenovo, MSI

- SmiFlash HANDLERS (SMiFlash.efi)→ CVE-2017-3753, CVE-2017-11316

  [BC327DBD-B982-4f55-9F79-056AD7E987C5]

✓ ENABLE	0x20
✓ READ	0x21
✓ ERASE	0x22
✓ WRITE	0x23
✓ DISABLE	0x24
✓ GET_INFO	0x25

- No checks for the input pointers

  SmmIsBufferOutsideSmmValid()

SecSMIFlash Handler Issues: ASUS

- SecSmiFlash HANDLERS (SecSMiFlash.efi) → CVE-2017-11315

  [3370A4BD-8C23-4565-A2A2-065FEEDE6080]

✓ LOAD_IMAGE	0x1d
✓ GET_POLICY	0x1e
✓ SET_POLICY	0x1f

- No checks for the input pointers

  SmmIsBufferOutsideSmmValid()

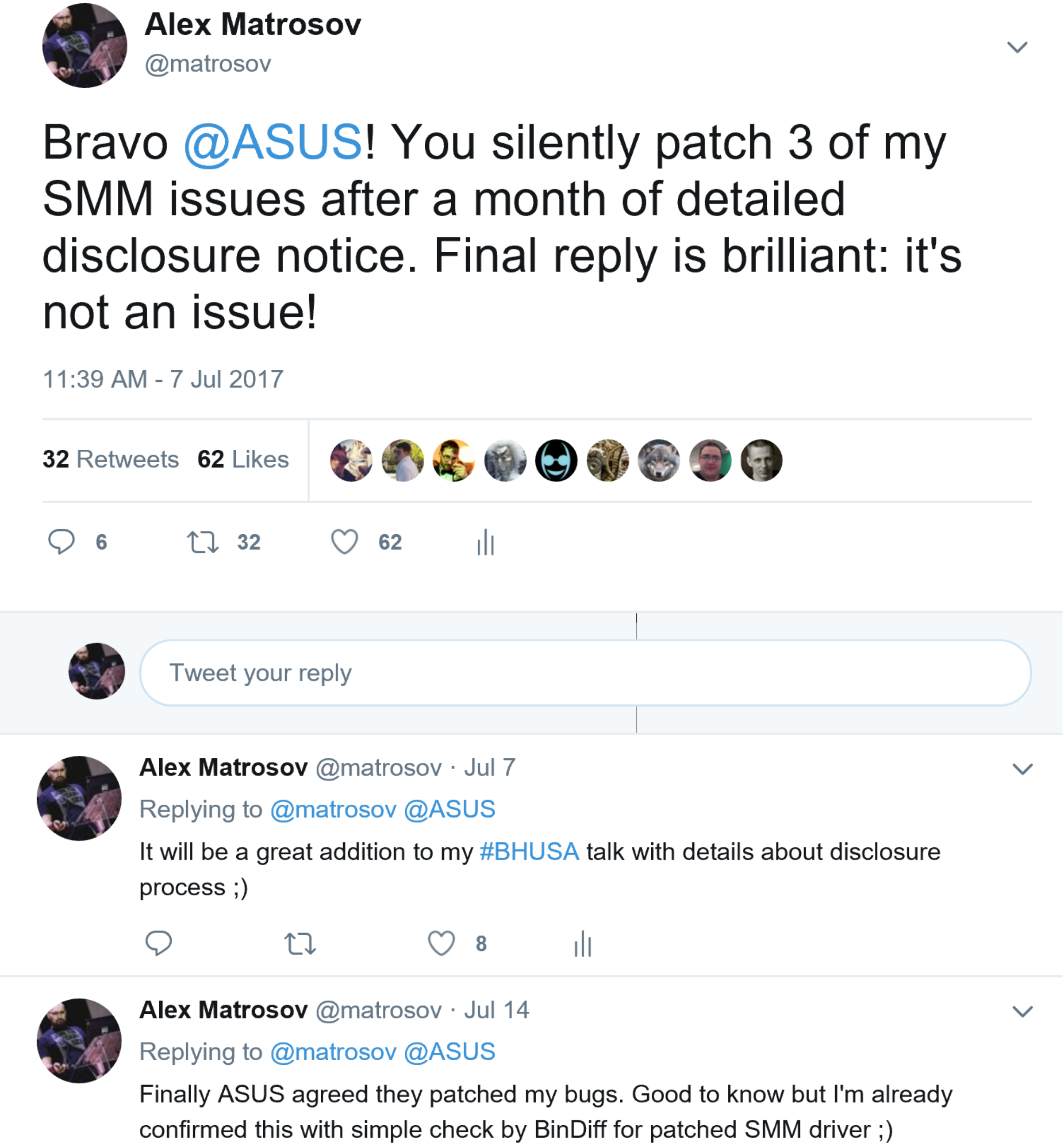
That’s why BIOS Guard created

Responsible Disclosure Fun

- ✓ Discovery Date: 2017-04-20
- ✓ Intel PSIRT Notified: 2017-05-22
- ✓ All the Vendors Notified: 2017-05-26
- ✓ Disclosure Notification Date: 2017-05-30
- ✓ Lenovo Released a Patch: 2017-07-11
- ✓ ASUS Released a Patch: 2017-06-23
- ✓ MITRE Assign 6 CVE’s: 2017-07-13
- ✓ Gigabyte Released a Patch: 2017-07-25
- ✓ Public Disclosure Date: 2017-07-27

https://github.com/CylanceVulnResearch/disclosures

ASUS Responsible Disclosure Fun



Alex Matrosov
@matrosov

Bravo @ASUS! You silently patch 3 of my SMM issues after a month of detailed disclosure notice. Final reply is brilliant: it's not an issue!

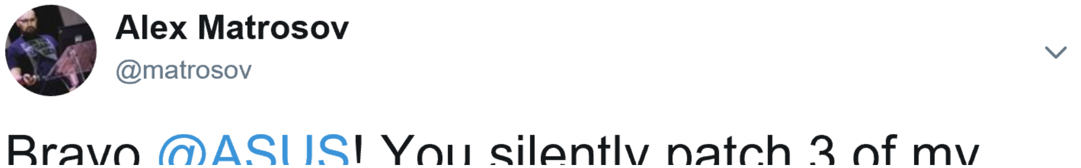
11:39 AM - 7 Jul 2017

32 Retweets **62** Likes

Alex Matrosov @matrosov · Jul 7
Replying to @matrosov @ASUS
It will be a great addition to my #BHUSA talk with details about disclosure process ;)

Alex Matrosov @matrosov · Jul 14
Replying to @matrosov @ASUS
Finally ASUS agreed they patched my bugs. Good to know but I'm already confirmed this with simple check by BinDiff for patched SMM driver ;)

ASUS Responsible Disclosure Fun



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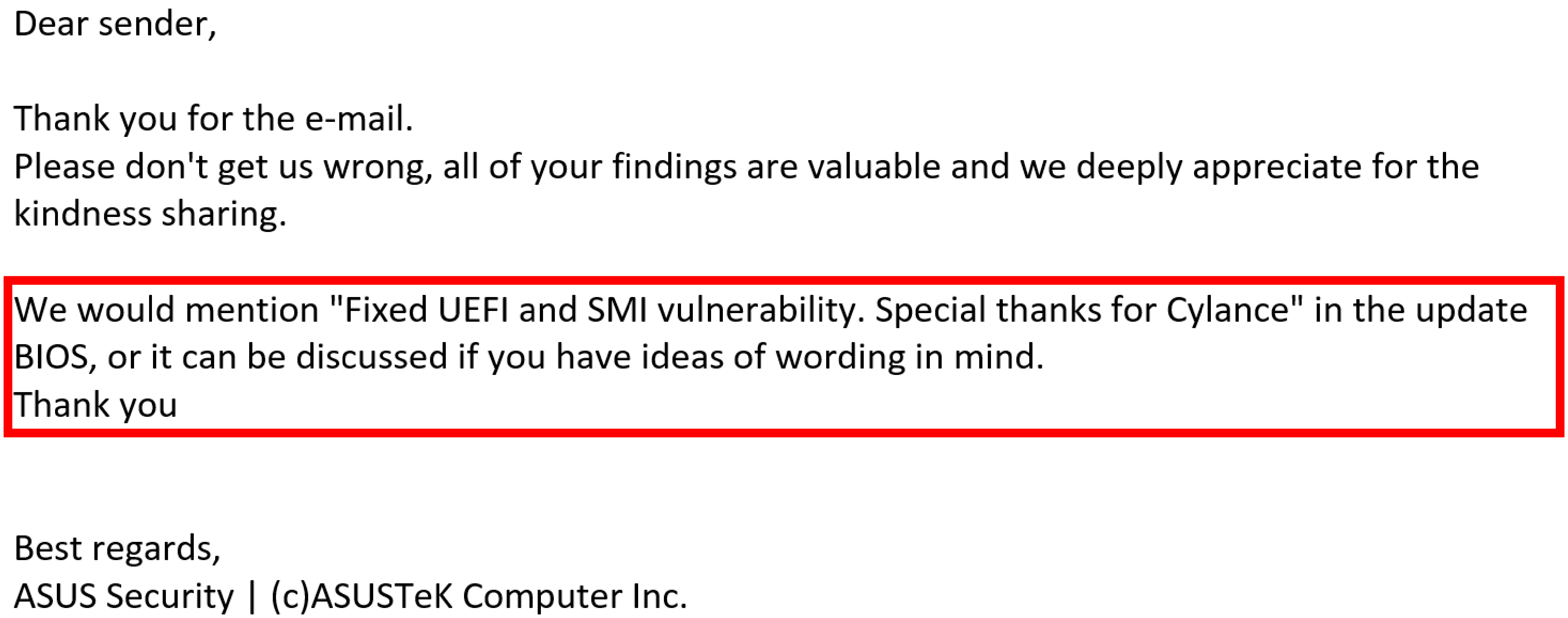
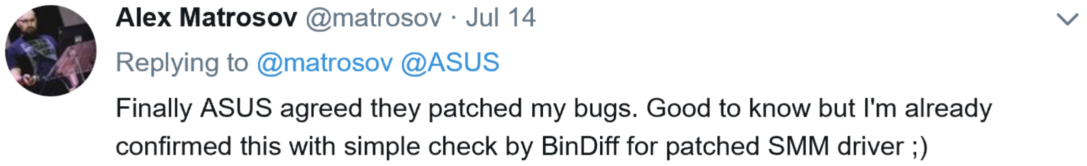


Dear sender,

Thank you for the e-mail.
Please don't get us wrong, all of your findings are valuable and we deeply appreciate for the kindness sharing.

We would mention "Fixed UEFI and SMI vulnerability. Special thanks for Cylance" in the update BIOS, or it can be discussed if you have ideas of wording in mind.
Thank you

Best regards,
ASUS Security | (c)ASUSTeK Computer Inc.



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Intel Boot Guard

Different shades of Secure Boot

- ➢ **Secure Boot -> since 2012**
  - ✓ Root of Trust = Firmware -> BIOS
  - ✓ Attack Surface = Firmware

- ➢ **Measured Boot (Boot Guard) -> since 2013**
  - ✓ Root of Trust = Hardware -> Trusted Platform Module (TPM)
  - ✓ Attack Surface = Firmware

- ➢ **Verified Boot (Boot Guard) -> since 2013**
  - ✓ Root of Trust = Hardware -> Field Programming Fuse (FPF)->Locked
  - ✓ Attack Surface = Firmware + Hardware

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  - ✓ Attack Surface = Firmware + Hardware

First bypass today?!

Why Boot Guard has been created?

- **Secure Boot** starts from DXE phase and impacted with any SMM issues/implants

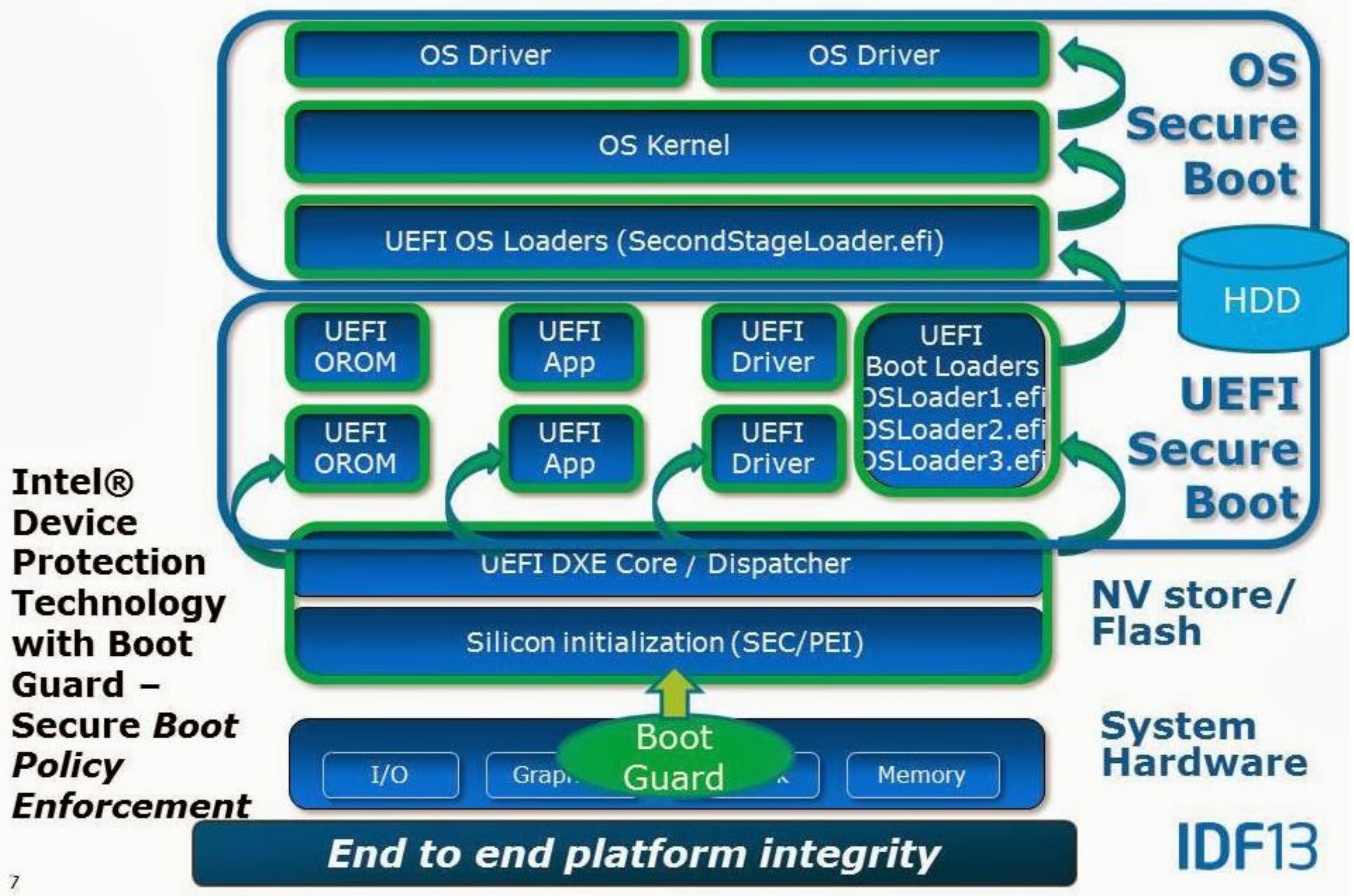
- No verification on early boot for SEC/PEI boot phases

- **Measured Boot** starts before PEI phase but also impacted with any SMM issues/implants

- The Root of Trust must be locked by hardware (**Verified Boot**)

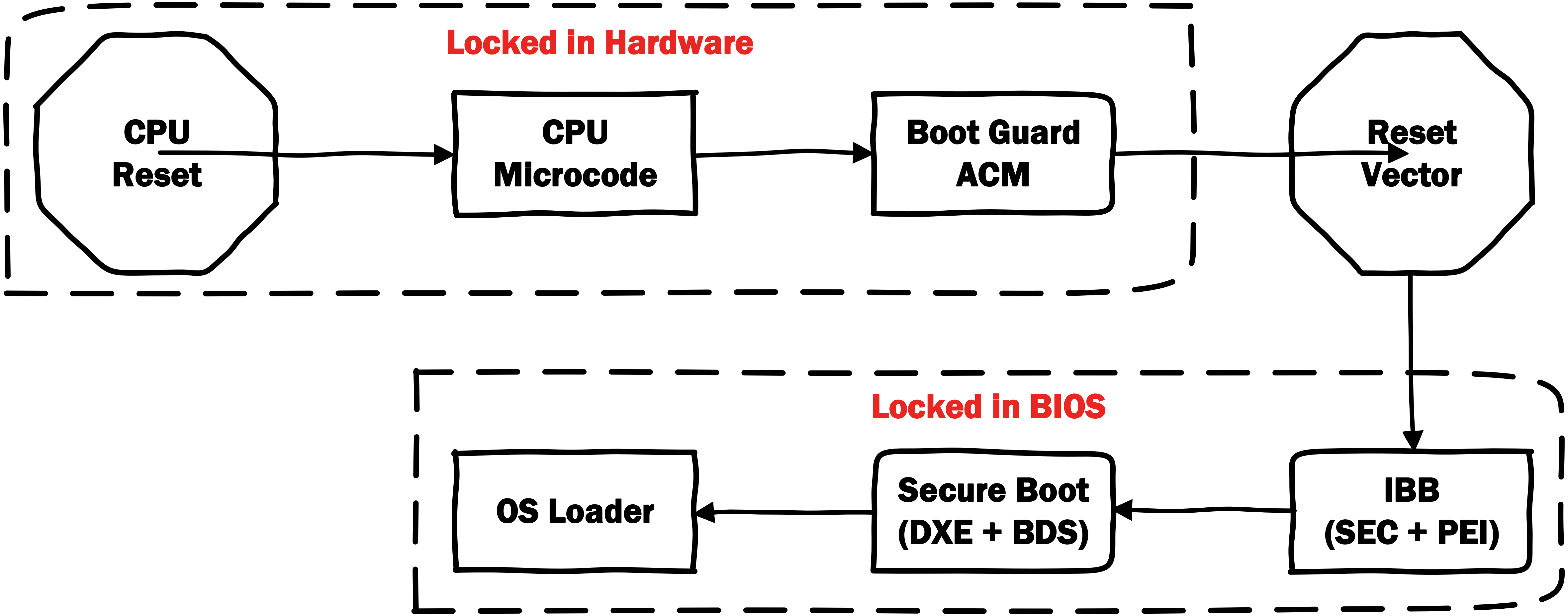
- The first step of verification should rely on microcode authentication

Intel Boot Guard Technology


OS Driver
OS Driver
OS Kernel
UEFI OS Loaders (SecondStageLoader.efi)
OS Secure Boot
HDD
UEFI OROM
UEFI App
UEFI Driver
UEFI Boot Loaders OSLoader1.efi OSLoader2.efi OSLoader3.efi
UEFI OROM
UEFI App
UEFI Driver
UEFI Secure Boot
Intel® Device Protection Technology with Boot Guard – Secure *Boot Policy Enforcement*
UEFI DXE Core / Dispatcher
Silicon initialization (SEC/PEI)
NV store/ Flash
Boot Guard
I/O
Grap...
Memory
System Hardware
End to end platform integrity
IDF13
7

http://vzimmer.blogspot.com/2013/09/where-do-i-sign-up.html

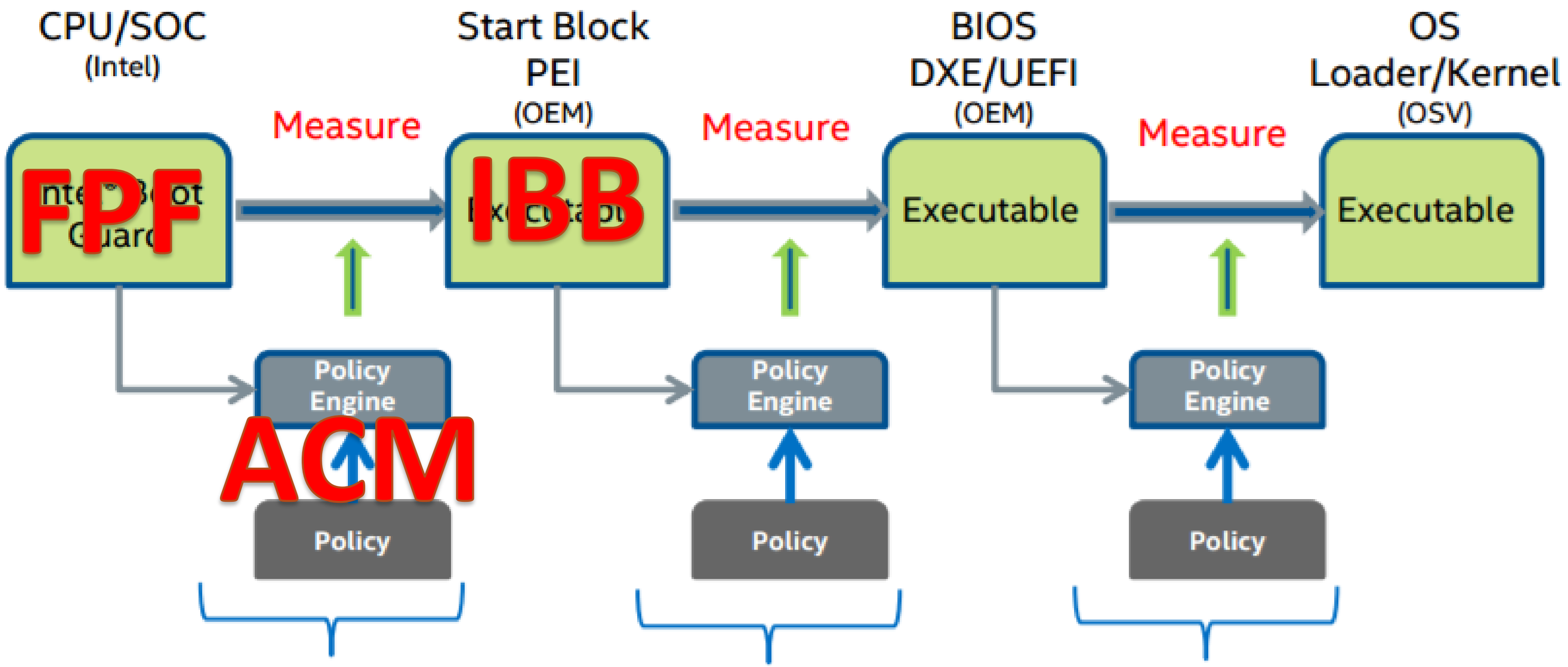
Boot Guard: Boot Flow



Intel Boot Guard operating modes

- Not Enabled
- Measured Boot (root of trust = TPM)
- Verified Boot (root of trust = FPF)
- Measured + Verified Boot (root of trust = FPF + TPM)

Demystifying Intel Boot Guard



Intel® Device Protection Technology with Boot Guard

http://www.intel.com/content/dam/www/public/us/en/documents/product-briefs/4th-gen-core-family-mobile-brief.pdf

OEM PI Verification Using PI Signed Firmware Volumes

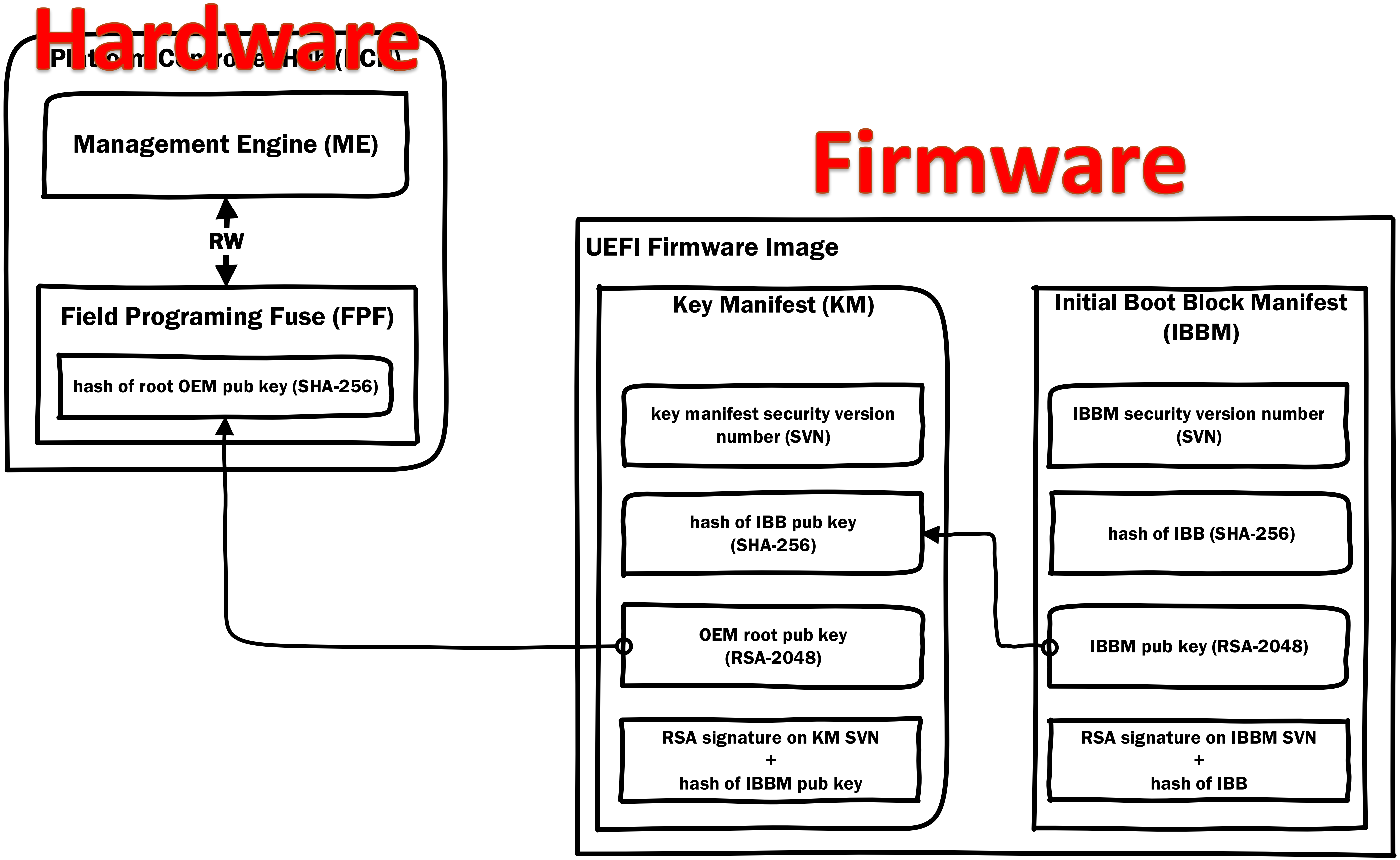
Vol 3, section 3.2.1.1 of PI 1.3 Specification

OEM UEFI 2.4 Secure Boot

Chapter 27.2 of The UEFI 2.4 Specification

https://firmware.intel.com/sites/default/files/STTS003%20-%20SF15_STTS003_100f.pdf

Boot Guard: Chain of Trust



Hardware

Platform Controller Hub (PCH)

Management Engine (ME)

RW

Field Programing Fuse (FPF)

hash of root OEM pub key (SHA-256)

Firmware

UEFI Firmware Image

Key Manifest (KM)

key manifest security version number (SVN)

hash of IBB pub key (SHA-256)

OEM root pub key (RSA-2048)

RSA signature on KM SVN + hash of IBBM pub key

Initial Boot Block Manifest (IBBM)

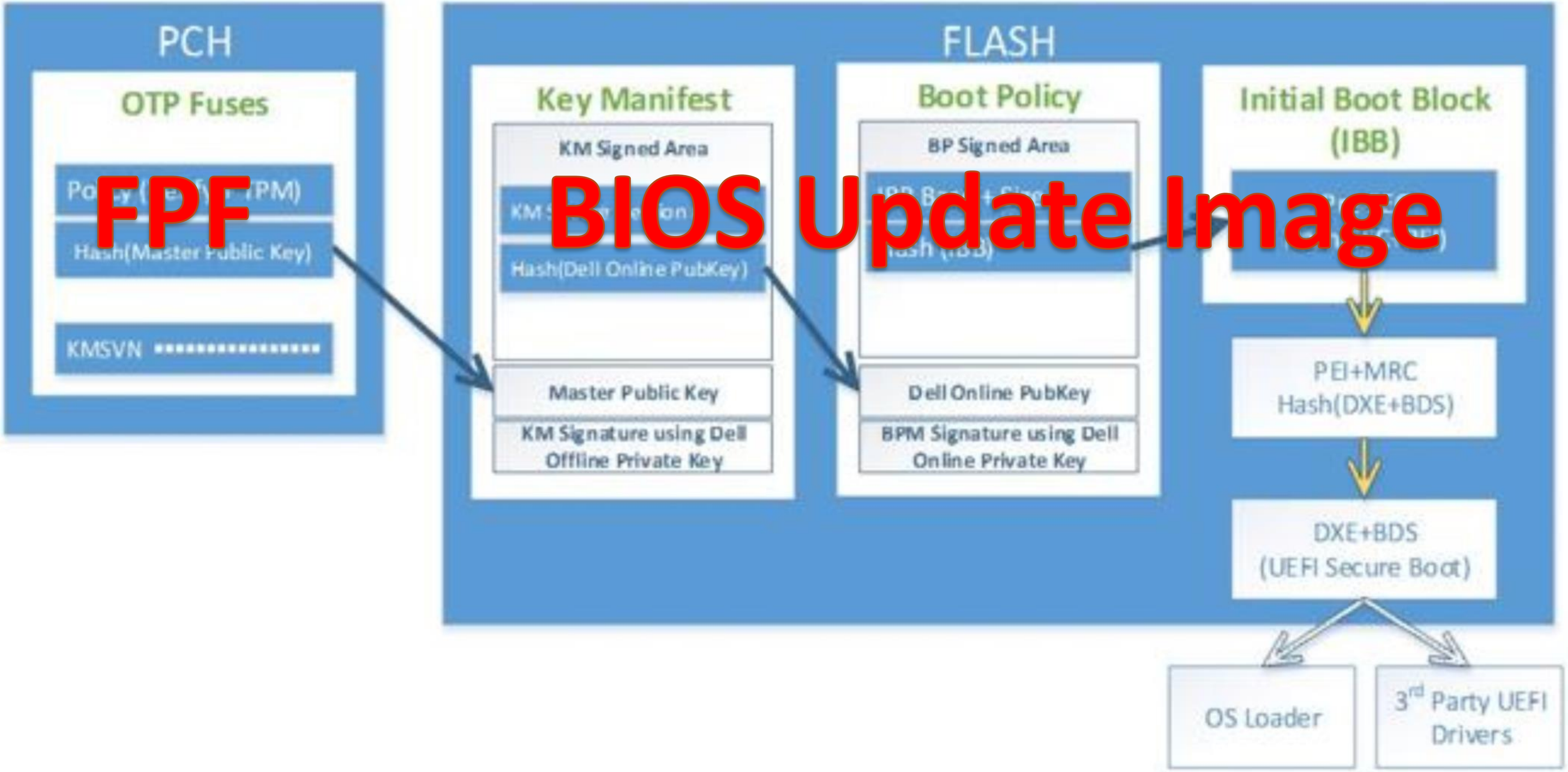
IBBM security version number (SVN)

hash of IBB (SHA-256)

IBBM pub key (RSA-2048)

RSA signature on IBBM SVN + hash of IBB

Demystifying Intel Boot Guard



http://en.community.dell.com/techcenter/extras/m/white_papers/20444061

Guard’s Configuration of Tested Hardware

Vendor Name	ME Access	EC Access	CPU Debugging (DCI)	Boot Guard	Forced Boot Guard ACM	Boot Guard FPF	BIOS Guard
ASUS VivoMini	Disabled	Disabled	Enabled	Disabled	Disabled	Disabled	Disabled
MSI Cubi2	Disabled	Disabled	Enabled	Disabled	Disabled	Disabled	Disabled
Gigabyte Brix	Read/Write Enabled	Read/Write Enabled	Enabled	Measured Verified	Enabled (FPF not set)	Not Set	Disabled
Dell	Disabled	Disabled	Enabled	Measured Verified	Enabled	Enabled	Enabled
Lenovo ThinkCentre	Disabled	Disabled	Enabled	Disabled	Disabled	Disabled	Disabled
HP Elitedesk	Disabled	Disabled	Enabled	Disabled	Disabled	Disabled	Disabled
Intel NUC	Disabled	Disabled	Enabled	Disabled	Disabled	Disabled	Disabled
Apple	Read Enabled	Disabled	Disabled	Not Supported	Not Supported	Not Supported	Not Supported

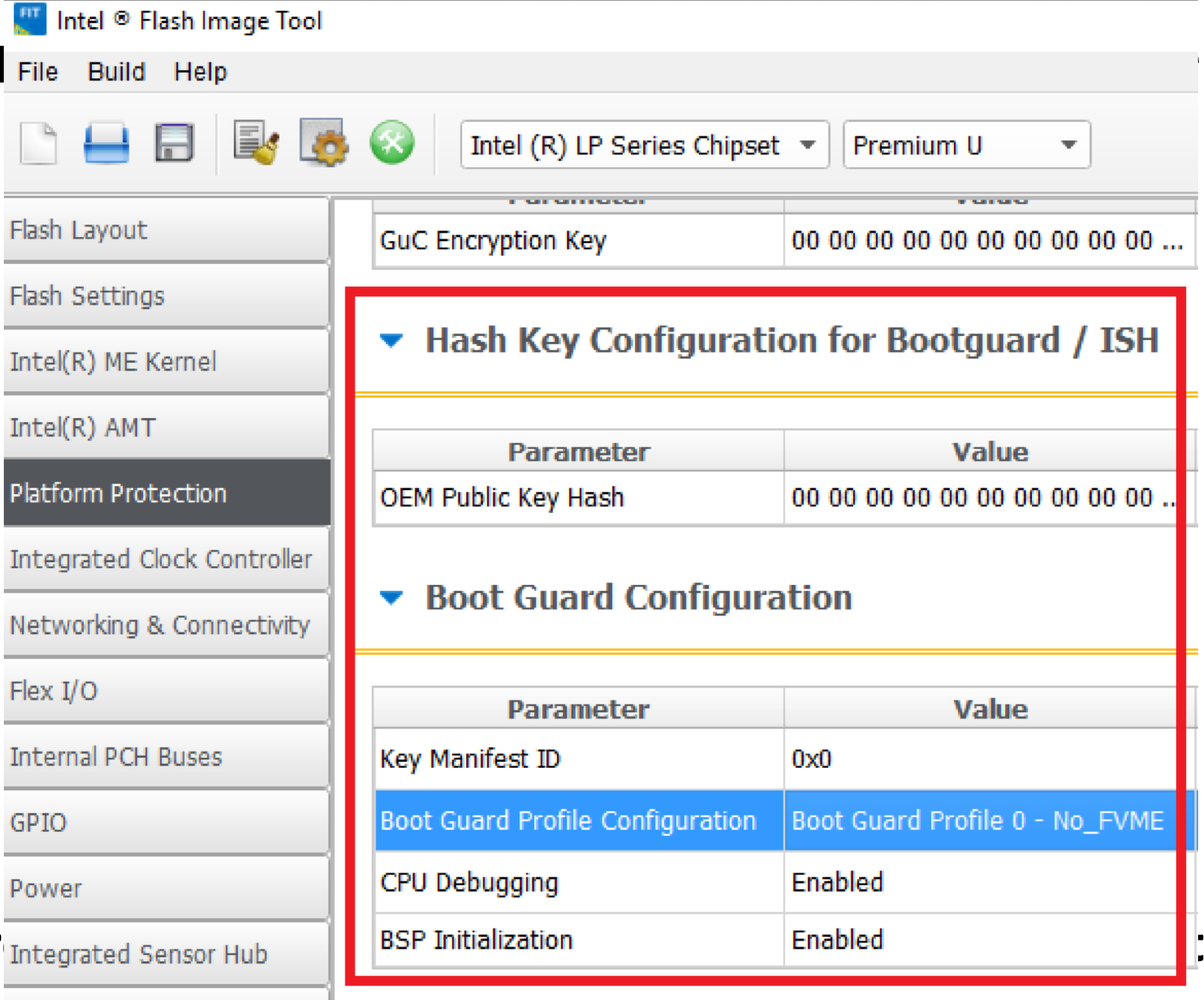
TRUST
NO
ONE

Safeguarding Rootkits: Intel BootGuard

by Alex Ermolov

2016.zeronights.ru/wp-content/uploads/2017/03/Intel-BootGuard.pdf

Safegu d



Parameter	Value
GuC Encryption Key	00 00 00 00 00 00 00 00 00 00 ...

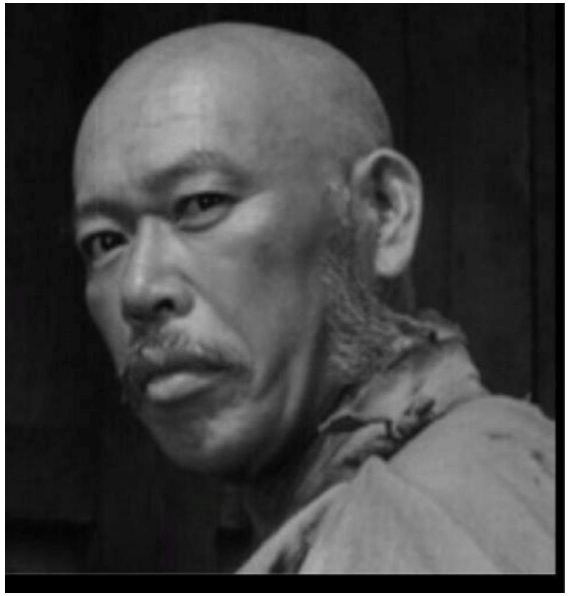
Hash Key Configuration for Bootguard / ISH

Parameter	Value
OEM Public Key Hash	00 00 00 00 00 00 00 00 00 00 ..

Boot Guard Configuration

Parameter	Value
Key Manifest ID	0x0
Boot Guard Profile Configuration	Boot Guard Profile 0 - No_FVME
CPU Debugging	Enabled
BSP Initialization	Enabled

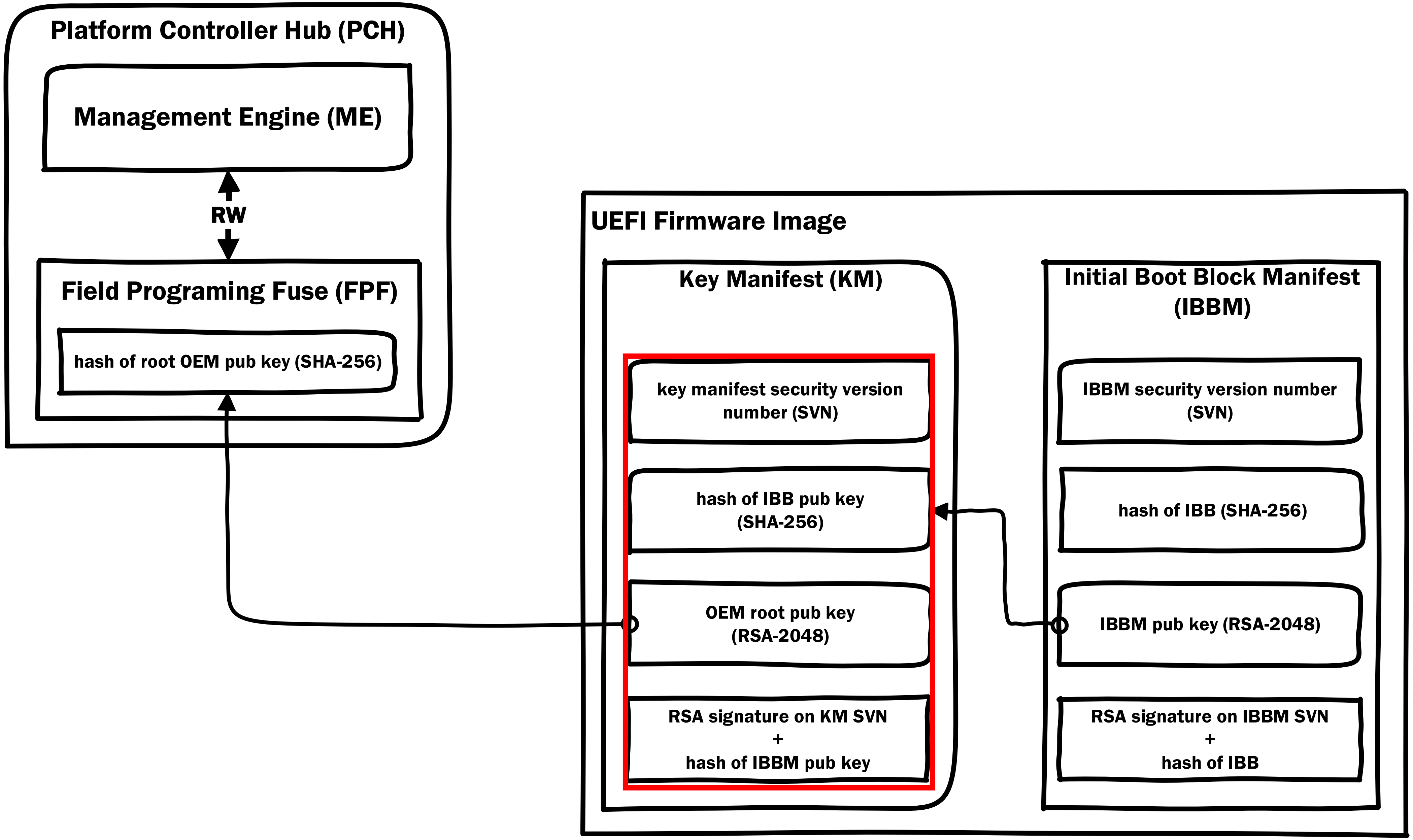
2016.zer :Guard.pdf



**You never attack
the standard, you attack
the implementation, including the process**

Grugq

Boot Guard: Chain of Trust



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hash of root OEM pub key (SHA-256)

UEFI Firmware Image

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key manifest security version number (SVN)

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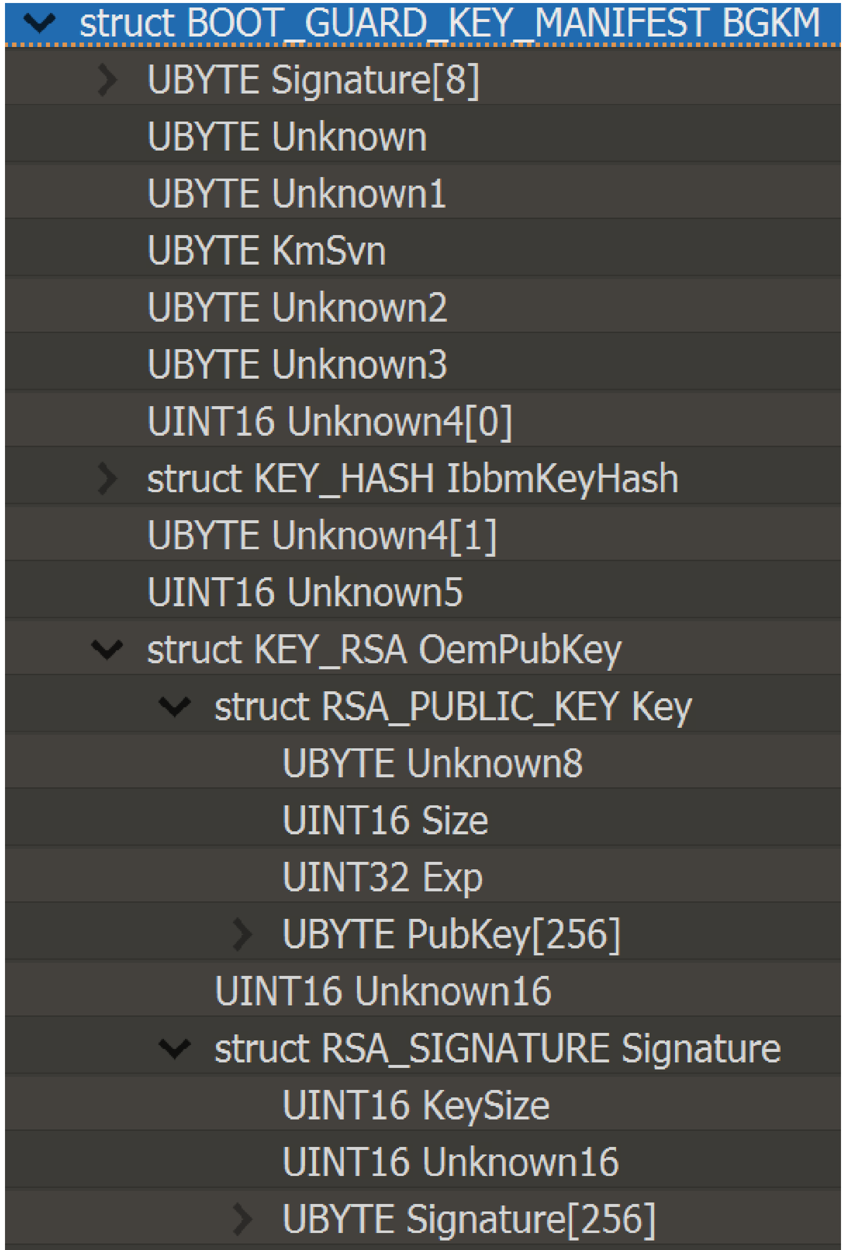
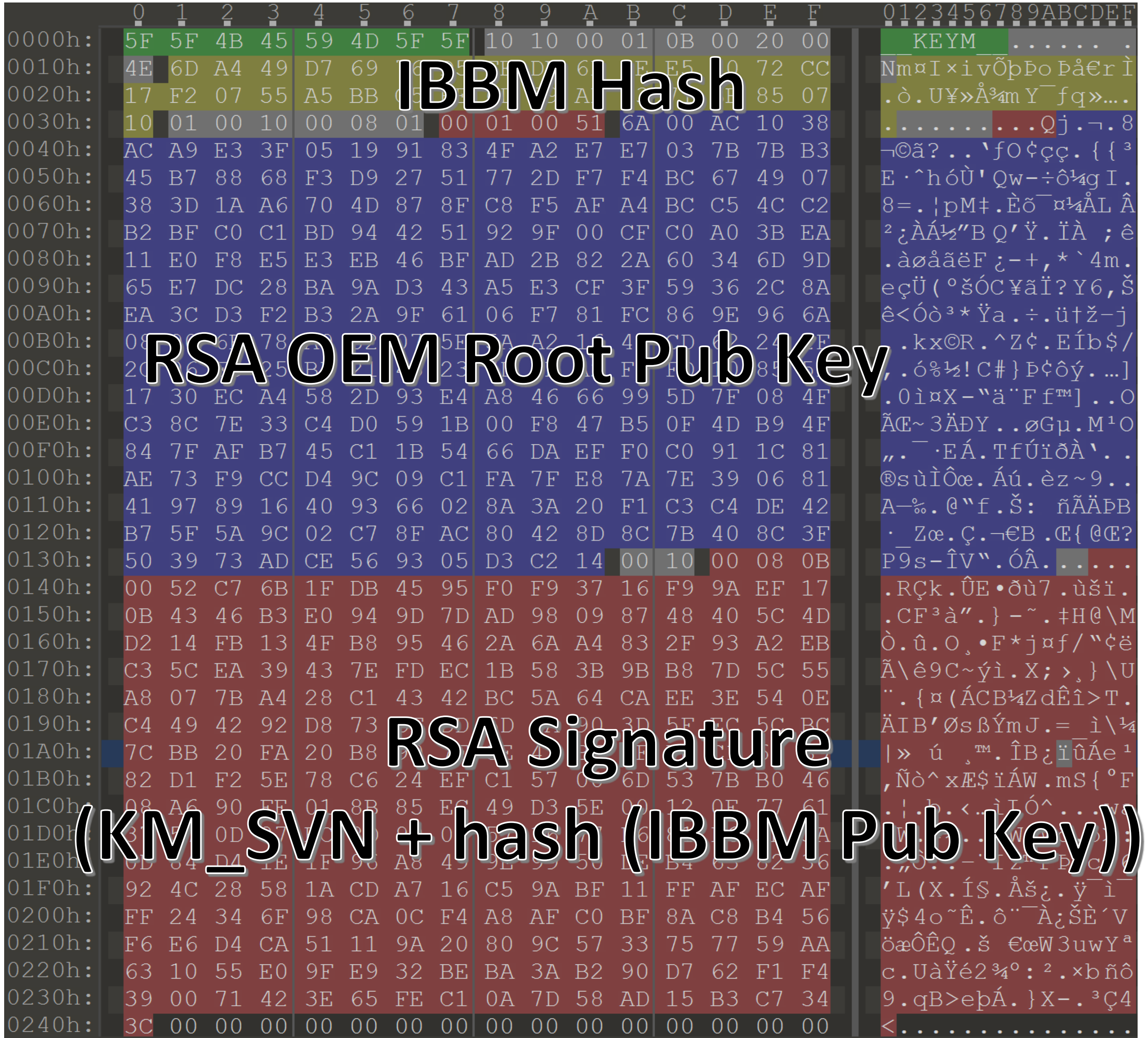
Boot Guard: Key Manifest (KM)

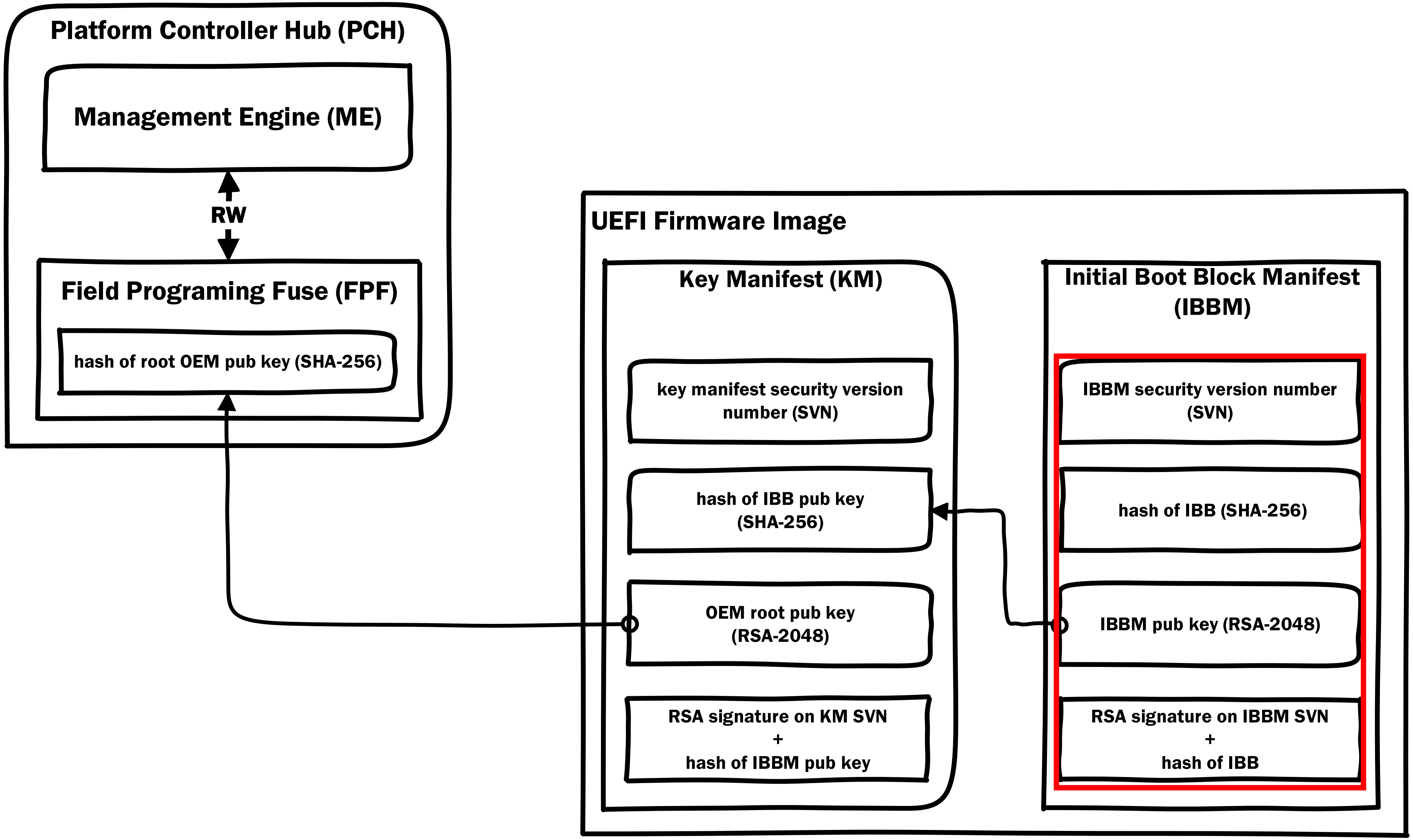


```
struct BOOT_GUARD_KEY_MANIFEST BGKM
    UBYTE Signature[8]
    UBYTE Unknown
    UBYTE Unknown1
    UBYTE KmSvn
    UBYTE Unknown2
    UBYTE Unknown3
    UINT16 Unknown4[0]
    struct KEY_HASH IbbmKeyHash
    UBYTE Unknown4[1]
    UINT16 Unknown5
    struct KEY_RSA OemPubKey
        struct RSA_PUBLIC_KEY Key
            UBYTE Unknown8
            UINT16 Size
            UINT32 Exp
            UBYTE PubKey[256]
        UINT16 Unknown16
        struct RSA_SIGNATURE Signature
            UINT16 KeySize
            UINT16 Unknown16
            UBYTE Signature[256]
```



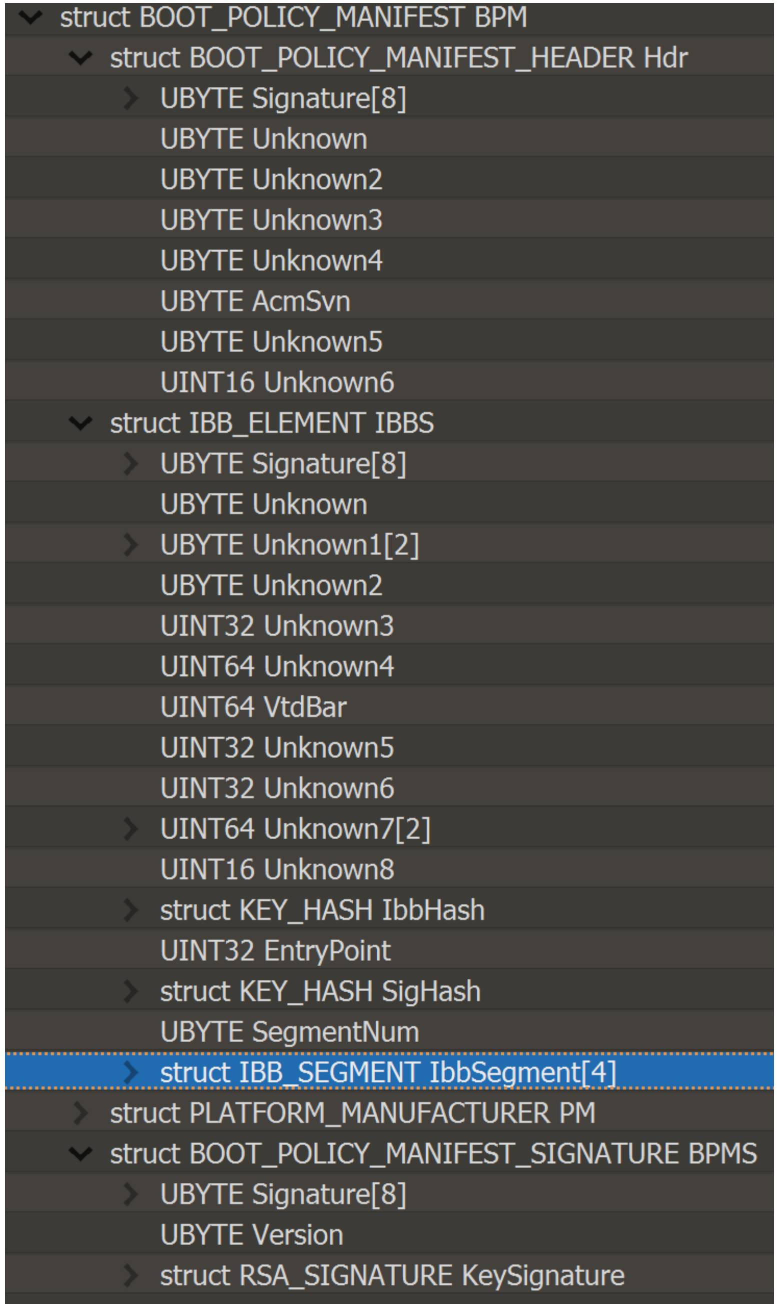
```
        0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F   0123456789ABCDEF
0000h: 5F 5F 4B 45 59 4D 5F 5F 10 10 00 01 0B 00 20 00   __KEYM__........
0010h: 4E 6D A4 49 D7 69 [illegible] 72 CC   Nm¤I×ivÕþÞoÞå€rÌ
0020h: 17 F2 07 55 A5 BB [illegible] 85 07   .ò.U¥»Å¾mY¯fq»…
0030h: 10 01 00 10 00 08 01 00 01 00 51 6A 00 AC 10 38   ..........Qj.¬.8
0040h: AC A9 E3 3F 05 19 91 83 4F A2 E7 E7 03 7B 7B B3   ¬©ã?..'ƒO¢çç.{{³
0050h: 45 B7 88 68 F3 D9 27 51 77 2D F7 F4 BC 67 49 07   E·ˆhóÙ'Qw-÷ô¼gI.
0060h: 38 3D 1A A6 70 4D 87 8F C8 F5 AF A4 BC C5 4C C2   8=.¦pM‡.Èõ¯¤¼ÅLÂ
0070h: B2 BF C0 C1 BD 94 42 51 92 9F 00 CF C0 A0 3B EA   ²¿ÀÁ½"BQ'Ÿ.ÏÀ ;ê
0080h: 11 E0 F8 E5 E3 EB 46 BF AD 2B 82 2A 60 34 6D 9D   .àøåãëF¿-+,*`4m.
0090h: 65 E7 DC 28 BA 9A D3 43 A5 E3 CF 3F 59 36 2C 8A   eçÜ(ºšÓC¥ãÏ?Y6,Š
00A0h: EA 3C D3 F2 B3 2A 9F 61 06 F7 81 FC 86 9E 96 6A   ê<Óò³*Ÿa.÷.ü†ž–j
00B0h: 08 [illegible] 78 [illegible] 5E [illegible] A2 [illegible] 24 [illegible]   .kx©R.^Z¢.EÍb$/
00C0h: 20 [illegible] 25 [illegible] 23 [illegible] 85 [illegible]   ,.ó%½!C#}Þ¢ôý.…]
00D0h: 17 30 EC A4 58 2D 93 E4 A8 46 66 99 5D 7F 08 4F   .0ì¤X-"ä¨Ff™]..O
00E0h: C3 8C 7E 33 C4 D0 59 1B 00 F8 47 B5 0F 4D B9 4F   ÃŒ~3ÄÐY..øGµ.M¹O
00F0h: 84 7F AF B7 45 C1 1B 54 66 DA EF F0 C0 91 1C 81   „.¯·EÁ.TfÚïðÀ'..
0100h: AE 73 F9 CC D4 9C 09 C1 FA 7F E8 7A 7E 39 06 81   ®sùÌÔœ.Áú.èz~9..
0110h: 41 97 89 16 40 93 66 02 8A 3A 20 F1 C3 C4 DE 42   A—‰.@"f.Š: ñÃÄÞB
0120h: B7 5F 5A 9C 02 C7 8F AC 80 42 8D 8C 7B 40 8C 3F   ·_Zœ.Ç.¬€B.Œ{@Œ?
0130h: 50 39 73 AD CE 56 93 05 D3 C2 14 00 10 00 08 0B   P9s-ÎV".ÓÂ......
0140h: 00 52 C7 6B 1F DB 45 95 F0 F9 37 16 F9 9A EF 17   .RÇk.ÛE•ðù7.ùšï.
0150h: 0B 43 46 B3 E0 94 9D 7D AD 98 09 87 48 40 5C 4D   .CF³à".}-˜.‡H@\M
0160h: D2 14 FB 13 4F B8 95 46 2A 6A A4 83 2F 93 A2 EB   Ò.û.O¸•F*j¤ƒ/"¢ë
0170h: C3 5C EA 39 43 7E FD EC 1B 58 3B 9B B8 7D 5C 55   Ã\ê9C~ýì.X;›¸}\U
0180h: A8 07 7B A4 28 C1 43 42 BC 5A 64 CA EE 3E 54 0E   ¨.{¤(ÁCB¼ZdÊî>T.
0190h: C4 49 42 92 D8 73 [illegible]   ÄIB'ØsßÝmJ.=_ì\¼
01A0h: 7C BB 20 FA 20 B8 [illegible]   |» ú ¸™.ÎB¿ïûÁe¹
01B0h: 82 D1 F2 5E 78 C6 24 EF C1 57 00 6D 53 7B B0 46   ,Ñò^xÆ$ïÁW.mS{°F
01C0h: [illegible]
01D0h: [illegible]
01E0h: [illegible]
01F0h: 92 4C 28 58 1A CD A7 16 C5 9A BF 11 FF AF EC AF   'L(X.Í§.Åš¿.ÿ¯ì¯
0200h: FF 24 34 6F 98 CA 0C F4 A8 AF C0 BF 8A C8 B4 56   ÿ$4o˜Ê.ô¨¯À¿ŠÈ´V
0210h: F6 E6 D4 CA 51 11 9A 20 80 9C 57 33 75 77 59 AA   öæÔÊQ.š €œW3uwYª
0220h: 63 10 55 E0 9F E9 32 BE BA 3A B2 90 D7 62 F1 F4   c.UàŸé2¾º:².×bñô
0230h: 39 00 71 42 3E 65 FE C1 0A 7D 58 AD 15 B3 C7 34   9.qB>eþÁ.}X-.³Ç4
0240h: 3C 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   <...............
```

Boot Guard: Chain of Trust

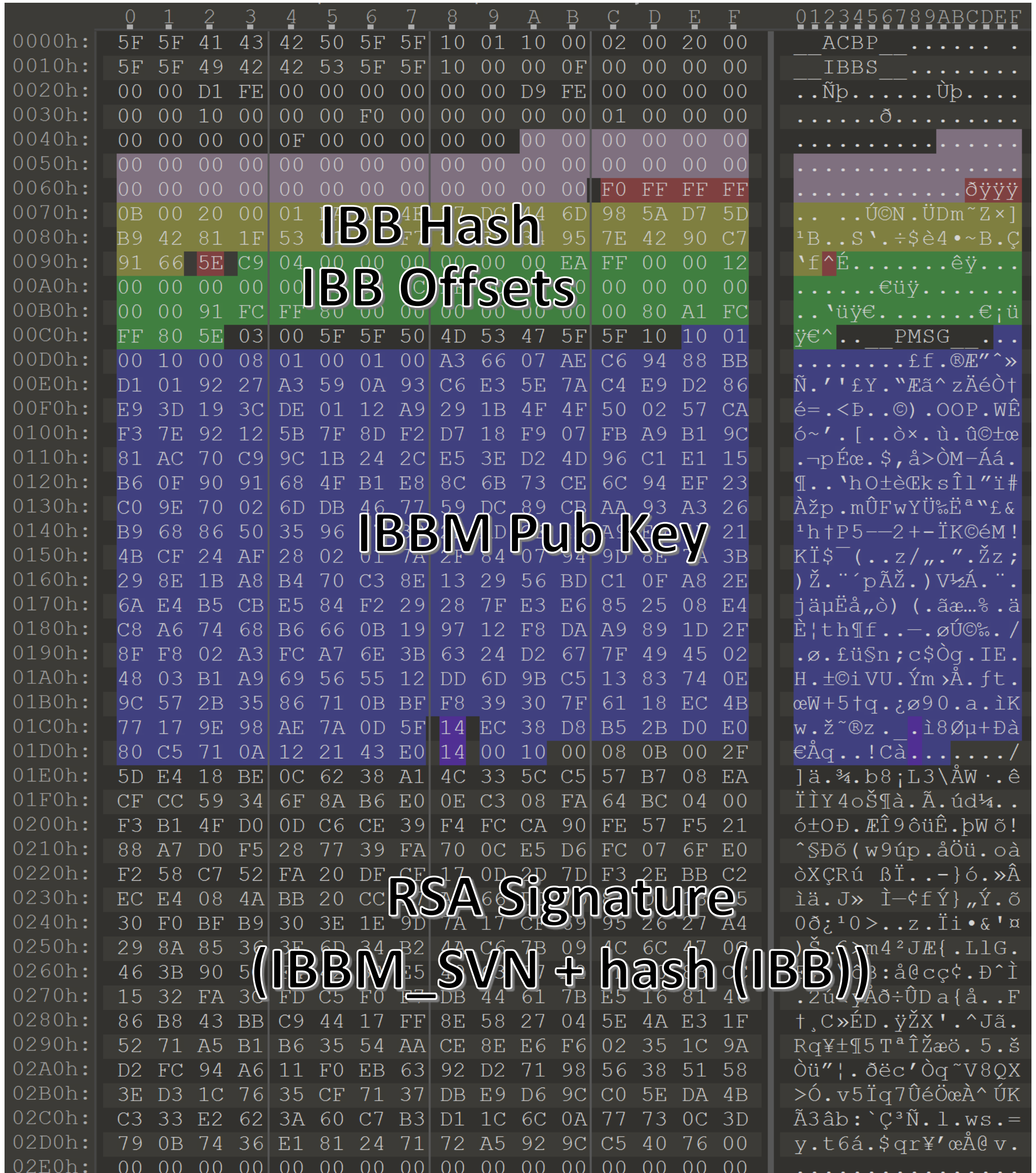


Platform Controller Hub (PCH)
Management Engine (ME)
RW
Field Programing Fuse (FPF)
hash of root OEM pub key (SHA-256)
UEFI Firmware Image
Key Manifest (KM)
key manifest security version number (SVN)
hash of IBB pub key (SHA-256)
OEM root pub key (RSA-2048)
RSA signature on KM SVN + hash of IBBM pub key
Initial Boot Block Manifest (IBBM)
IBBM security version number (SVN)
hash of IBB (SHA-256)
IBBM pub key (RSA-2048)
RSA signature on IBBM SVN + hash of IBB

Boot Guard: Boot Policy Manifest (BPM)



```
struct BOOT_POLICY_MANIFEST BPM
    struct BOOT_POLICY_MANIFEST_HEADER Hdr
        UBYTE Signature[8]
        UBYTE Unknown
        UBYTE Unknown2
        UBYTE Unknown3
        UBYTE Unknown4
        UBYTE AcmSvn
        UBYTE Unknown5
        UINT16 Unknown6
    struct IBB_ELEMENT IBBS
        UBYTE Signature[8]
        UBYTE Unknown
        UBYTE Unknown1[2]
        UBYTE Unknown2
        UINT32 Unknown3
        UINT64 Unknown4
        UINT64 VtdBar
        UINT32 Unknown5
        UINT32 Unknown6
        UINT64 Unknown7[2]
        UINT16 Unknown8
        struct KEY_HASH IbbHash
        UINT32 EntryPoint
        struct KEY_HASH SigHash
        UBYTE SegmentNum
        struct IBB_SEGMENT IbbSegment[4]
    struct PLATFORM_MANUFACTURER PM
    struct BOOT_POLICY_MANIFEST_SIGNATURE BPMS
        UBYTE Signature[8]
        UBYTE Version
        struct RSA_SIGNATURE KeySignature
```



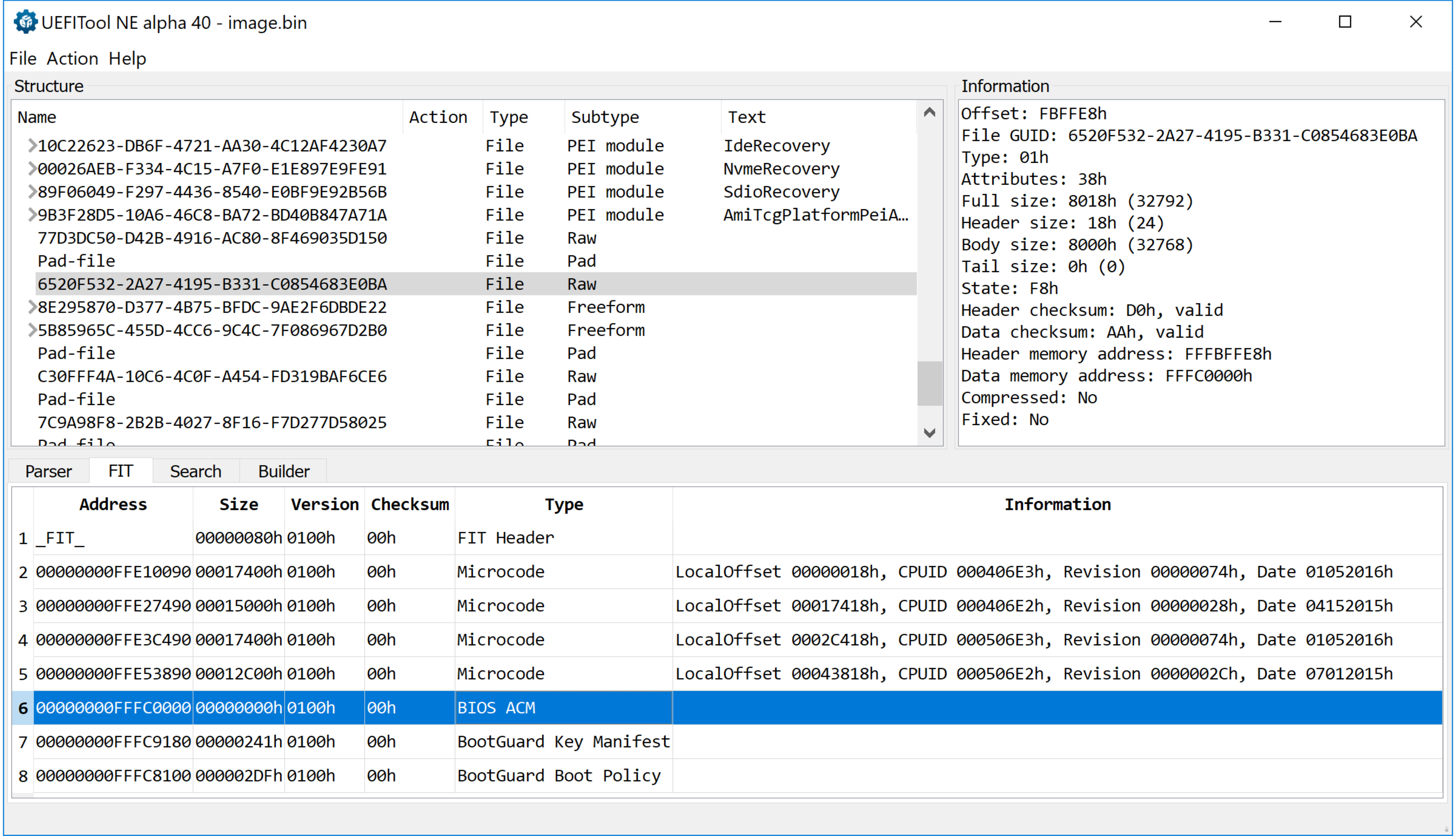
```
        0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F   0123456789ABCDEF
0000h: 5F 5F 41 43 42 50 5F 5F 10 01 10 00 02 00 20 00   __ACBP__...... .
0010h: 5F 5F 49 42 42 53 5F 5F 10 00 00 0F 00 00 00 00   __IBBS__........
0020h: 00 00 D1 FE 00 00 00 00 00 00 D9 FE 00 00 00 00   ..Ñþ......Ùþ....
0030h: 00 00 10 00 00 00 F0 00 00 00 00 00 01 00 00 00   ......ð.........
0040h: 00 00 00 00 0F 00 00 00 00 00 00 00 00 00 00 00   ................
0050h: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
0060h: 00 00 00 00 00 00 00 00 00 00 00 00 F0 FF FF FF   ............ðÿÿÿ
0070h: 0B 00 20 00 01 DA A9 4E [illegible] DC 44 6D 98 5A D7 5D   .. ..Ú©N.ÜDm˜Z×]
0080h: B9 42 81 1F 53 91 [illegible] F7 24 E8 34 95 7E 42 90 C7   ¹B..S'.÷$è4•~B.Ç
0090h: 91 66 5E C9 04 00 00 00 00 00 00 EA FF 00 00 12   'f^É.......êÿ...
00A0h: 00 00 00 00 00 [illegible] 80 FC FF [illegible] [illegible] [illegible] 00 00 00 00   ......€üÿ.......
00B0h: 00 00 91 FC FF 80 00 00 00 00 00 00 00 80 A1 FC   ..'üÿ€.......€¡ü
00C0h: FF 80 5E 03 00 5F 5F 50 4D 53 47 5F 5F 10 10 01   ÿ€^..__PMSG__...
00D0h: 00 10 00 08 01 00 01 00 A3 66 07 AE C6 94 88 BB   ........£f.®Æ"ˆ»
00E0h: D1 01 92 27 A3 59 0A 93 C6 E3 5E 7A C4 E9 D2 86   Ñ.''£Y."Æã^zÄéÒ†
00F0h: E9 3D 19 3C DE 01 12 A9 29 1B 4F 4F 50 02 57 CA   é=.<Þ..©).OOP.WÊ
0100h: F3 7E 92 12 5B 7F 8D F2 D7 18 F9 07 FB A9 B1 9C   ó~'.[..ò×.ù.û©±œ
0110h: 81 AC 70 C9 9C 1B 24 2C E5 3E D2 4D 96 C1 E1 15   .¬pÉœ.$,å>ÒM–Áá.
0120h: B6 0F 90 91 68 4F B1 E8 8C 6B 73 CE 6C 94 EF 23   ¶..'hO±èŒksÎl"ï#
0130h: C0 9E 70 02 6D DB 46 77 59 DC 89 CB AA 93 A3 26   Àžp.mÛFwYÜ‰Ëª"£&
0140h: B9 68 86 50 35 96 97 32 2B AD CF 4B A9 E9 4D 21   ¹h†P5–—2+-ÏK©éM!
0150h: 4B CF 24 AF 28 02 01 7A 2F 84 07 94 9D 8E 7A 3B   KÏ$¯(..z/„.".Žz;
0160h: 29 8E 1B A8 B4 70 C3 8E 13 29 56 BD C1 0F A8 2E   )Ž.¨´pÃŽ.)V½Á.¨.
0170h: 6A E4 B5 CB E5 84 F2 29 28 7F E3 E6 85 25 08 E4   jäµËå„ò)(.ãæ…%.ä
0180h: C8 A6 74 68 B6 66 0B 19 97 12 F8 DA A9 89 1D 2F   È¦th¶f..—.øÚ©‰./
0190h: 8F F8 02 A3 FC A7 6E 3B 63 24 D2 67 7F 49 45 02   .ø.£ü§n;c$Òg.IE.
01A0h: 48 03 B1 A9 69 56 55 12 DD 6D 9B C5 13 83 74 0E   H.±©iVU.Ým›Å.ƒt.
01B0h: 9C 57 2B 35 86 71 0B BF F8 39 30 7F 61 18 EC 4B   œW+5†q.¿ø90.a.ìK
01C0h: 77 17 9E 98 AE 7A 0D 5F 14 EC 38 D8 B5 2B D0 E0   w.ž˜®z._.ì8Øµ+Ðà
01D0h: 80 C5 71 0A 12 21 43 E0 14 00 10 00 08 0B 00 2F   €Åq..!Cà......./
01E0h: 5D E4 18 BE 0C 62 38 A1 4C 33 5C C5 57 B7 08 EA   ]ä.¾.b8¡L3\ÅW·.ê
01F0h: CF CC 59 34 6F 8A B6 E0 0E C3 08 FA 64 BC 04 00   ÏÌY4oŠ¶à.Ã.úd¼..
0200h: F3 B1 4F D0 0D C6 CE 39 F4 FC CA 90 FE 57 F5 21   ó±OÐ.ÆÎ9ôüÊ.þWõ!
0210h: 88 A7 D0 F5 28 77 39 FA 70 0C E5 D6 FC 07 6F E0   ˆ§Ðõ(w9úp.åÖü.oà
0220h: F2 58 C7 52 FA 20 DF CF 17 0D 2D 7D F3 2E BB C2   òXÇRú ßÏ..-}ó.»Â
0230h: EC E4 08 4A BB 20 CC 97 A2 66 DD 7D 84 DD [illegible] F5   ìä.J» Ì—¢fÝ}„Ý.õ
0240h: 30 F0 BF B9 30 3E 1E 9D 7A 17 CF 69 95 26 27 A4   0ð¿¹0>..z.Ïi•&'¤
0250h: 29 8A 85 36 3E 6D 34 B2 4A C6 7B 09 4C 6C 47 [illegible]   )Š…6>m4²JÆ{.LlG.
0260h: 46 3B 90 [illegible] [illegible] [illegible] 3A E5 40 63 E7 A2 [illegible] D0 5E CC   F;.[illegible]:å@cç¢.Ð^Ì
0270h: 15 32 FA 30 FD C5 F0 F7 DB 44 61 7B E5 16 81 46   .2ú0ýÅð÷ÛDa{å..F
0280h: 86 B8 43 BB C9 44 17 FF 8E 58 27 04 5E 4A E3 1F   †¸C»ÉD.ÿŽX'.^Jã.
0290h: 52 71 A5 B1 B6 35 54 AA CE 8E E6 F6 02 35 1C 9A   Rq¥±¶5TªÎŽæö.5.š
02A0h: D2 FC 94 A6 11 F0 EB 63 92 D2 71 98 56 38 51 58   Òü"¦.ðëc'Òq˜V8QX
02B0h: 3E D3 1C 76 35 CF 71 37 DB E9 D6 9C C0 5E DA 4B   >Ó.v5Ïq7ÛéÖœÀ^ÚK
02C0h: C3 33 E2 62 3A 60 C7 B3 D1 1C 6C 0A 77 73 0C 3D   Ã3âb:`Ç³Ñ.l.ws.=
02D0h: 79 0B 74 36 E1 81 24 71 72 A5 92 9C C5 40 76 00   y.t6á.$qr¥'œÅ@v.
02E0h: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
```

IBB Hash

IBB Offsets

IBBM Pub Key

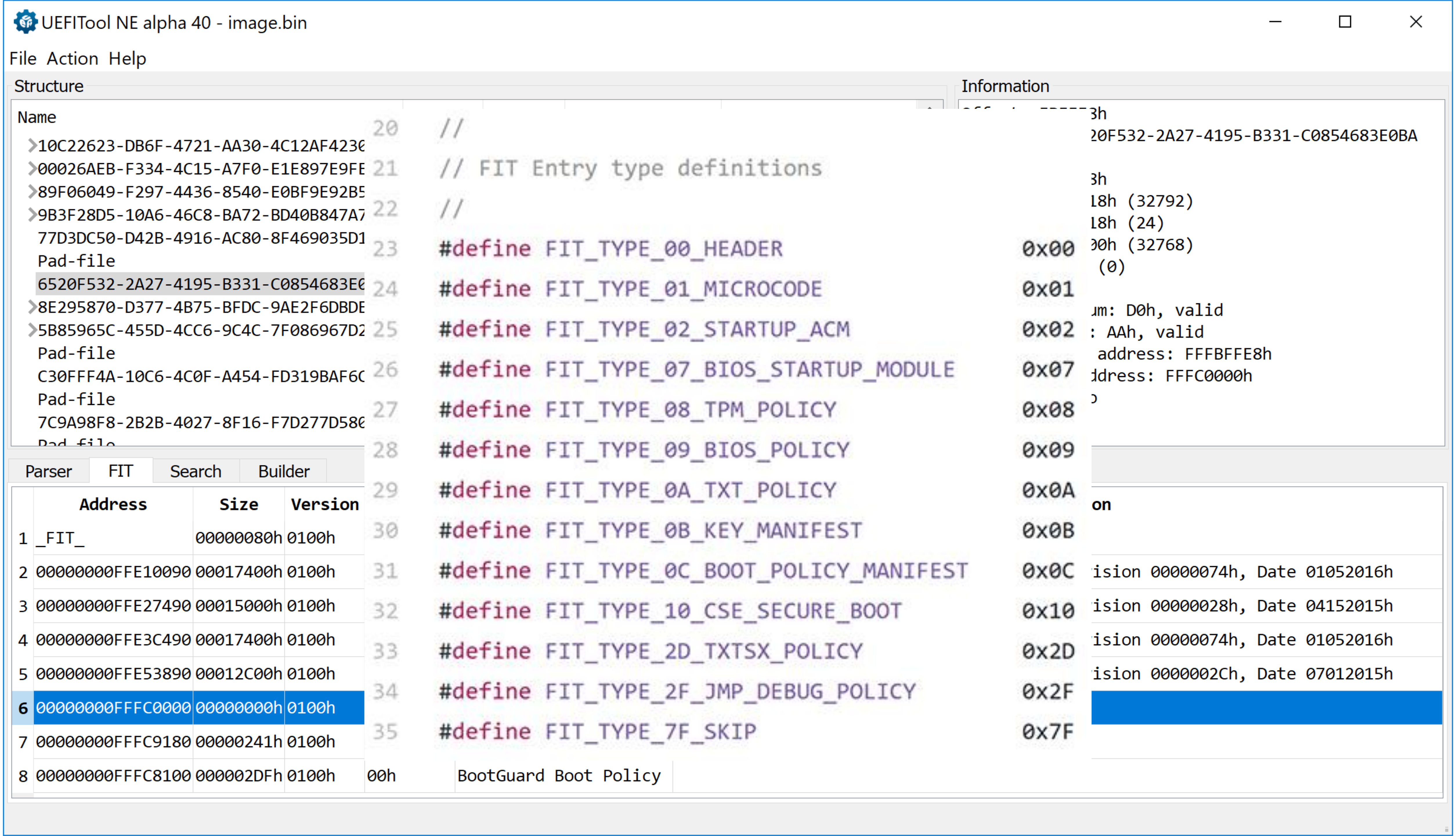
RSA Signature (IBBM_SVN + hash (IBB))



Name	Action	Type	Subtype	Text
10C22623-DB6F-4721-AA30-4C12AF4230A7		File	PEI module	IdeRecovery
00026AEB-F334-4C15-A7F0-E1E897E9FE91		File	PEI module	NvmeRecovery
89F06049-F297-4436-8540-E0BF9E92B56B		File	PEI module	SdioRecovery
9B3F28D5-10A6-46C8-BA72-BD40B847A71A		File	PEI module	AmiTcgPlatformPeiA…
77D3DC50-D42B-4916-AC80-8F469035D150		File	Raw	
Pad-file		File	Pad	
6520F532-2A27-4195-B331-C0854683E0BA		File	Raw	
8E295870-D377-4B75-BFDC-9AE2F6DBDE22		File	Freeform	
5B85965C-455D-4CC6-9C4C-7F086967D2B0		File	Freeform	
Pad-file		File	Pad	
C30FFF4A-10C6-4C0F-A454-FD319BAF6CE6		File	Raw	
Pad-file		File	Pad	
7C9A98F8-2B2B-4027-8F16-F7D277D58025		File	Raw	
Pad-file		File	Pad	

```
Offset: FBFFE8h
File GUID: 6520F532-2A27-4195-B331-C0854683E0BA
Type: 01h
Attributes: 38h
Full size: 8018h (32792)
Header size: 18h (24)
Body size: 8000h (32768)
Tail size: 0h (0)
State: F8h
Header checksum: D0h, valid
Data checksum: AAh, valid
Header memory address: FFFBFFE8h
Data memory address: FFFC0000h
Compressed: No
Fixed: No
```

	Address	Size	Version	Checksum	Type	Information
1	_FIT_	00000080h	0100h	00h	FIT Header	
2	00000000FFE10090	00017400h	0100h	00h	Microcode	LocalOffset 00000018h, CPUID 000406E3h, Revision 00000074h, Date 01052016h
3	00000000FFE27490	00015000h	0100h	00h	Microcode	LocalOffset 00017418h, CPUID 000406E2h, Revision 00000028h, Date 04152015h
4	00000000FFE3C490	00017400h	0100h	00h	Microcode	LocalOffset 0002C418h, CPUID 000506E3h, Revision 00000074h, Date 01052016h
5	00000000FFE53890	00012C00h	0100h	00h	Microcode	LocalOffset 00043818h, CPUID 000506E2h, Revision 0000002Ch, Date 07012015h
6	00000000FFFC0000	00000000h	0100h	00h	BIOS ACM	
7	00000000FFFC9180	00000241h	0100h	00h	BootGuard Key Manifest	
8	00000000FFFC8100	000002DFh	0100h	00h	BootGuard Boot Policy	



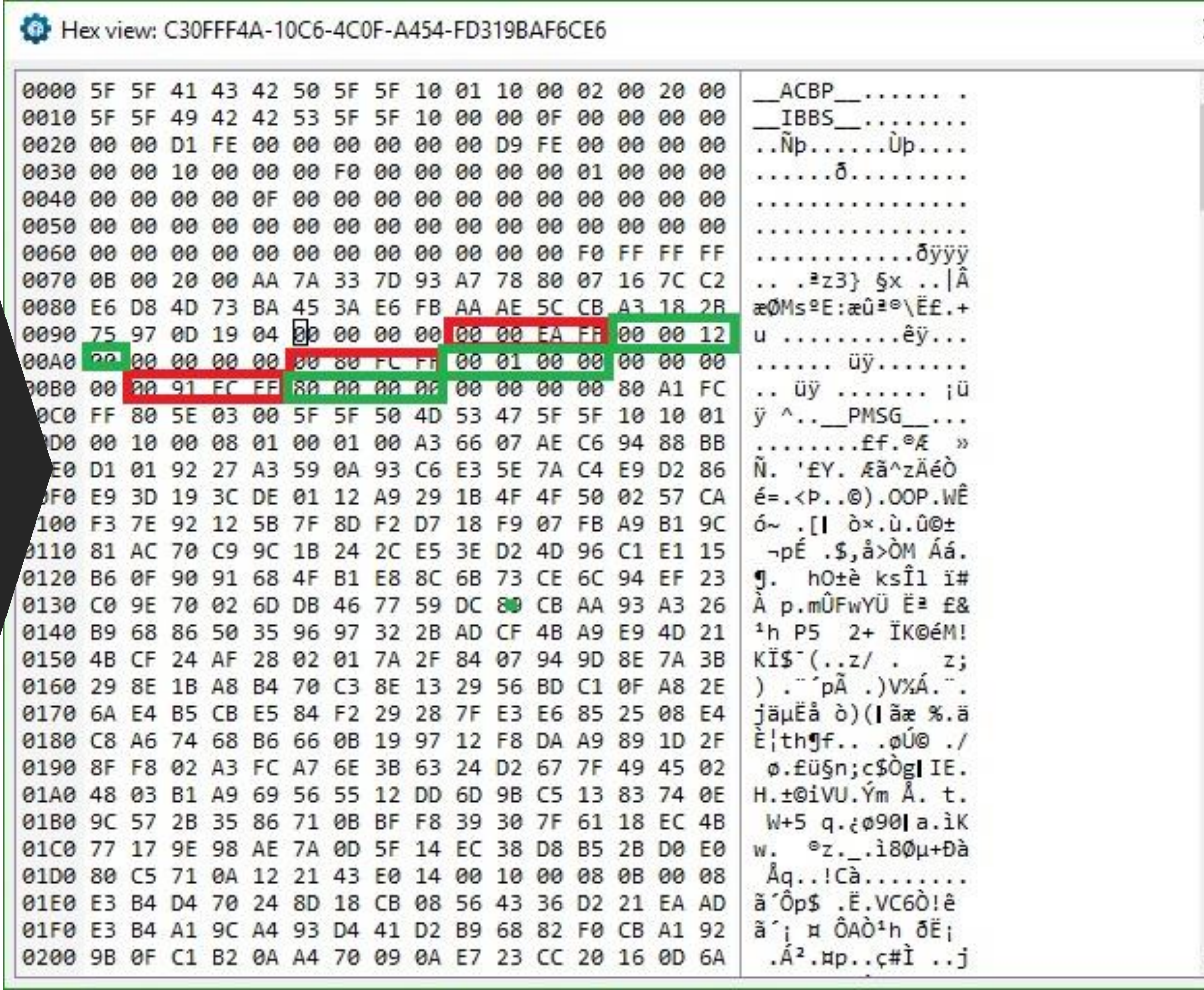
10C22623-DB6F-4721-AA30-4C12AF4236
00026AEB-F334-4C15-A7F0-E1E897E9FE
89F06049-F297-4436-8540-E0BF9E92B5
9B3F28D5-10A6-46C8-BA72-BD40B847A7
77D3DC50-D42B-4916-AC80-8F469035D1
Pad-file
6520F532-2A27-4195-B331-C0854683E0
8E295870-D377-4B75-BFDC-9AE2F6DBDE
5B85965C-455D-4CC6-9C4C-7F086967D2
Pad-file
C30FFF4A-10C6-4C0F-A454-FD319BAF6C
Pad-file
7C9A98F8-2B2B-4027-8F16-F7D277D58C
Pad-file

```
3h
20F532-2A27-4195-B331-C0854683E0BA
3h
18h (32792)
18h (24)
00h (32768)
 (0)
um: D0h, valid
: AAh, valid
 address: FFFBFFE8h
ddress: FFFC0000h
```

	Address	Size	Version			on
1	_FIT_	00000080h	0100h			
2	00000000FFE10090	00017400h	0100h			ision 00000074h, Date 01052016h
3	00000000FFE27490	00015000h	0100h			ision 00000028h, Date 04152015h
4	00000000FFE3C490	00017400h	0100h			ision 00000074h, Date 01052016h
5	00000000FFE53890	00012C00h	0100h			ision 0000002Ch, Date 07012015h
6	00000000FFFC0000	00000000h	0100h			
7	00000000FFFC9180	00000241h	0100h			
8	00000000FFFC8100	000002DFh	0100h	00h	BootGuard Boot Policy	

```
//
// FIT Entry type definitions
//
#define FIT_TYPE_00_HEADER                  0x00
#define FIT_TYPE_01_MICROCODE               0x01
#define FIT_TYPE_02_STARTUP_ACM             0x02
#define FIT_TYPE_07_BIOS_STARTUP_MODULE     0x07
#define FIT_TYPE_08_TPM_POLICY              0x08
#define FIT_TYPE_09_BIOS_POLICY             0x09
#define FIT_TYPE_0A_TXT_POLICY              0x0A
#define FIT_TYPE_0B_KEY_MANIFEST            0x0B
#define FIT_TYPE_0C_BOOT_POLICY_MANIFEST    0x0C
#define FIT_TYPE_10_CSE_SECURE_BOOT         0x10
#define FIT_TYPE_2D_TXTSX_POLICY            0x2D
#define FIT_TYPE_2F_JMP_DEBUG_POLICY        0x2F
#define FIT_TYPE_7F_SKIP                    0x7F
```

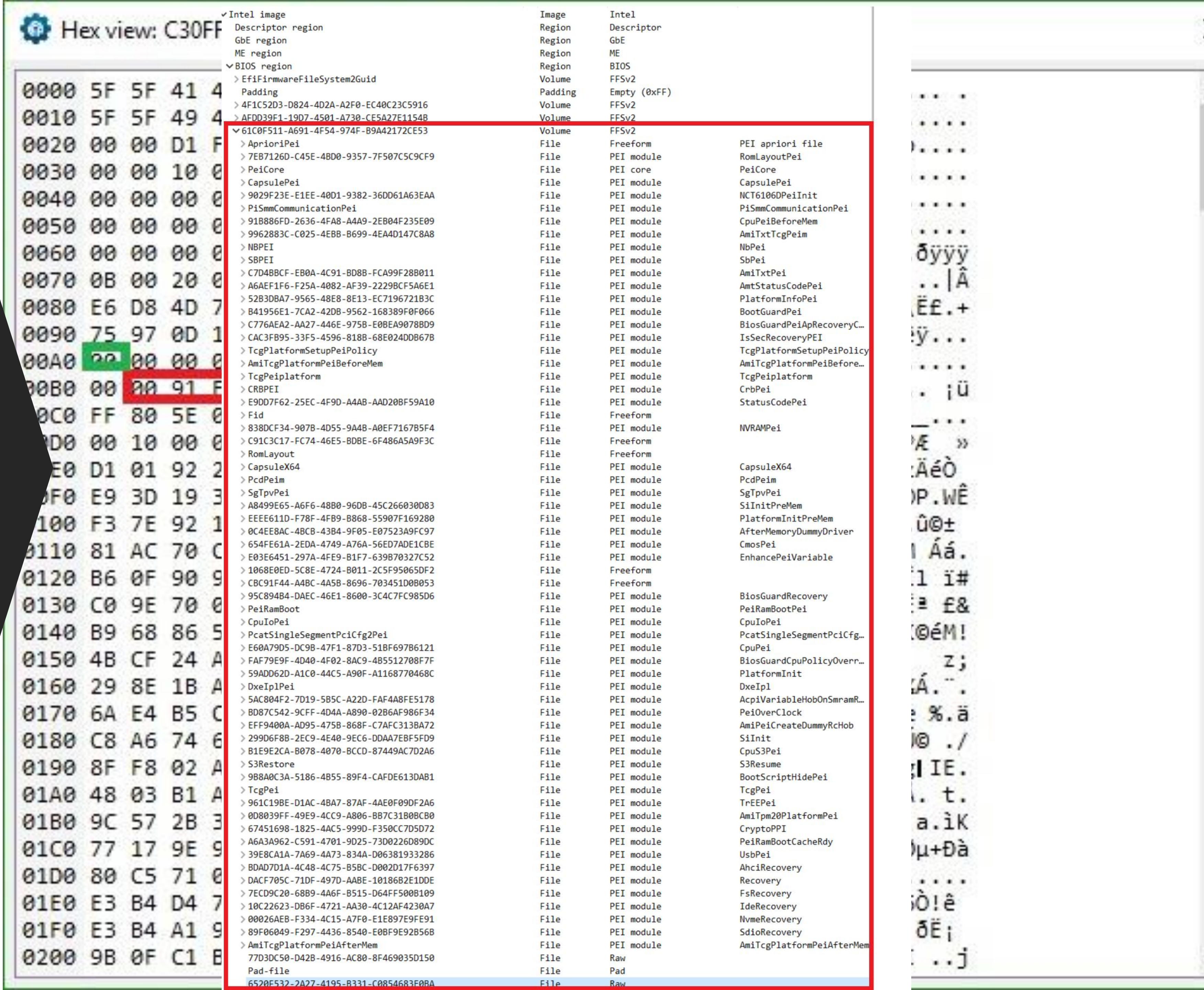
Boot Guard: Initial Boot Block (IBB)



Hex view: C30FFF4A-10C6-4C0F-A454-FD319BAF6CE6

```
0000 5F 5F 41 43 42 50 5F 5F 10 01 10 00 02 00 20 00  __ACBP__...... .
0010 5F 5F 49 42 42 53 5F 5F 10 00 00 0F 00 00 00 00  __IBBS__........
0020 00 00 D1 FE 00 00 00 00 00 00 D9 FE 00 00 00 00  ..Ñþ......Ùþ....
0030 00 00 10 00 00 00 F0 00 00 00 00 00 01 00 00 00  ......ð.........
0040 00 00 00 00 0F 00 00 00 00 00 00 00 00 00 00 00  ................
0050 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0060 00 00 00 00 00 00 00 00 00 00 00 00 F0 FF FF FF  ............ðÿÿÿ
0070 0B 00 20 00 AA 7A 33 7D 93 A7 78 80 07 16 7C C2  .. .ªz3} §x ..|Â
0080 E6 D8 4D 73 BA 45 3A E6 FB AA AE 5C CB A3 18 2B  æØMsºE:æûª®\Ë£.+
0090 75 97 0D 19 04 00 00 00 00 00 00 EA FF 00 00 12  u .........êÿ...
00A0 00 00 00 00 00 00 80 FC FF 00 01 00 00 00 00 00  ...... üÿ.......
00B0 00 00 91 FC FF 80 00 00 00 00 00 00 00 80 A1 FC  .. üÿ ....... ¡ü
 0C0 FF 80 5E 03 00 5F 5F 50 4D 53 47 5F 5F 10 10 01  ÿ ^..__PMSG__...
  D0 00 10 00 08 01 00 01 00 A3 66 07 AE C6 94 88 BB  ........£f.®Æ  »
  E0 D1 01 92 27 A3 59 0A 93 C6 E3 5E 7A C4 E9 D2 86  Ñ. '£Y. Æã^zÄéÒ
  F0 E9 3D 19 3C DE 01 12 A9 29 1B 4F 4F 50 02 57 CA  é=.<Þ..©).OOP.WÊ
 100 F3 7E 92 12 5B 7F 8D F2 D7 18 F9 07 FB A9 B1 9C  ó~ .[ ò×.ù.û©±
0110 81 AC 70 C9 9C 1B 24 2C E5 3E D2 4D 96 C1 E1 15   ¬pÉ .$,å>ÒM Áá.
0120 B6 0F 90 91 68 4F B1 E8 8C 6B 73 CE 6C 94 EF 23  ¶.  hO±è ksÎl ï#
0130 C0 9E 70 02 6D DB 46 77 59 DC 80 CB AA 93 A3 26  À p.mÛFwYÜ Ëª £&
0140 B9 68 86 50 35 96 97 32 2B AD CF 4B A9 E9 4D 21  ¹h P5  2+ ÏK©éM!
0150 4B CF 24 AF 28 02 01 7A 2F 84 07 94 9D 8E 7A 3B  KÏ$¯(..z/ .   z;
0160 29 8E 1B A8 B4 70 C3 8E 13 29 56 BD C1 0F A8 2E  ) .¨´pÃ .)V½Á.¨.
0170 6A E4 B5 CB E5 84 F2 29 28 7F E3 E6 85 25 08 E4  jäµËå ò)( ãæ %.ä
0180 C8 A6 74 68 B6 66 0B 19 97 12 F8 DA A9 89 1D 2F  È¦th¶f.. .øÚ© ./
0190 8F F8 02 A3 FC A7 6E 3B 63 24 D2 67 7F 49 45 02   ø.£ü§n;c$Òg IE.
01A0 48 03 B1 A9 69 56 55 12 DD 6D 9B C5 13 83 74 0E  H.±©iVU.Ým Å. t.
01B0 9C 57 2B 35 86 71 0B BF F8 39 30 7F 61 18 EC 4B   W+5 q.¿ø90 a.ìK
01C0 77 17 9E 98 AE 7A 0D 5F 14 EC 38 D8 B5 2B D0 E0  w.  ®z._.ì8Øµ+Ðà
01D0 80 C5 71 0A 12 21 43 E0 14 00 10 00 08 0B 00 08   Åq..!Cà........
01E0 E3 B4 D4 70 24 8D 18 CB 08 56 43 36 D2 21 EA AD  ã´Ôp$ .Ë.VC6Ò!ê
01F0 E3 B4 A1 9C A4 93 D4 41 D2 B9 68 82 F0 CB A1 92  ã´¡ ¤ ÔAÒ¹h ðË¡
0200 9B 0F C1 B2 0A A4 70 09 0A E7 23 CC 20 16 0D 6A   .Á².¤p..ç#Ì ..j
```

Boot Guard: Initial Boot Block (IBB)

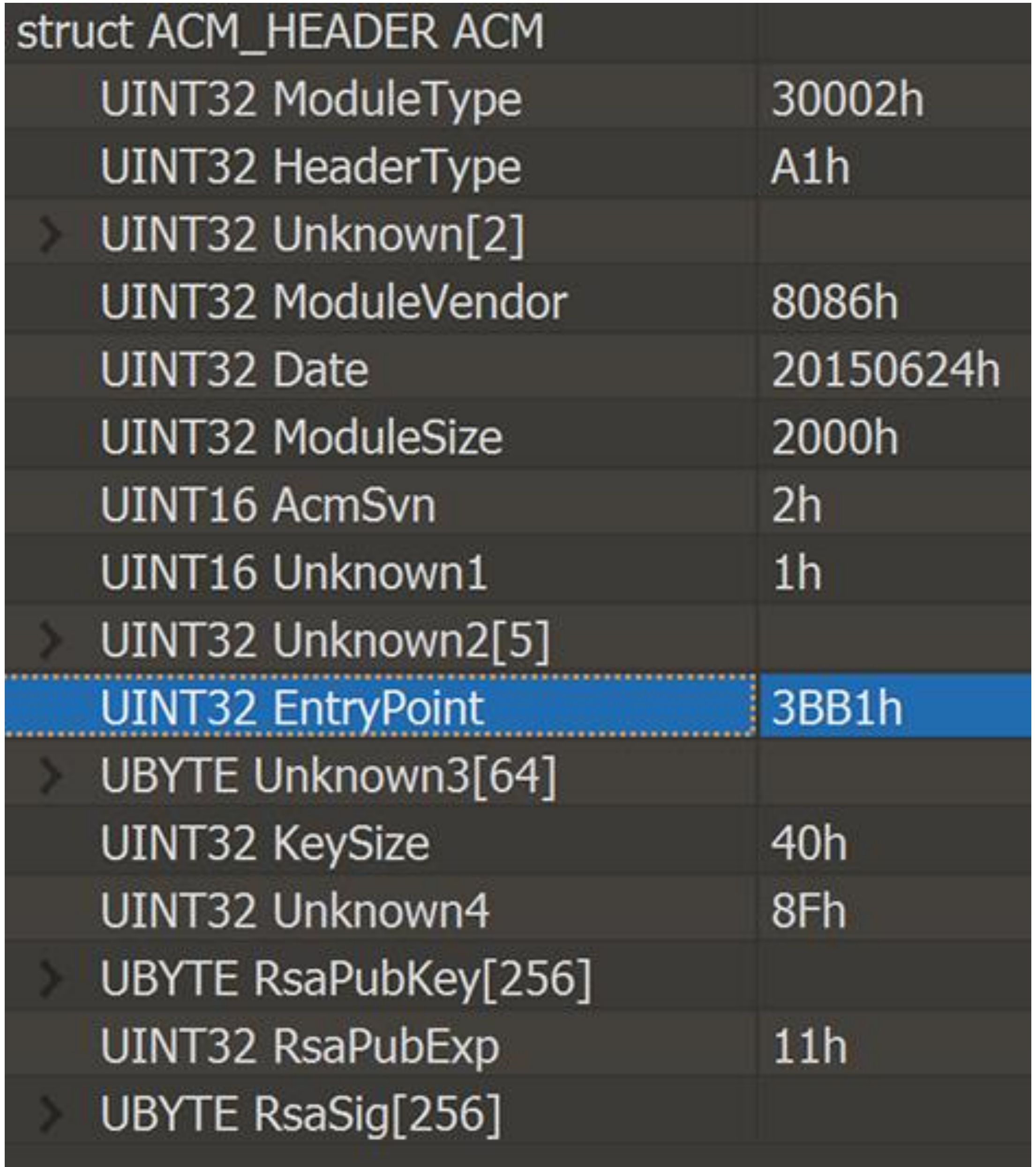


Hex view: C30FF

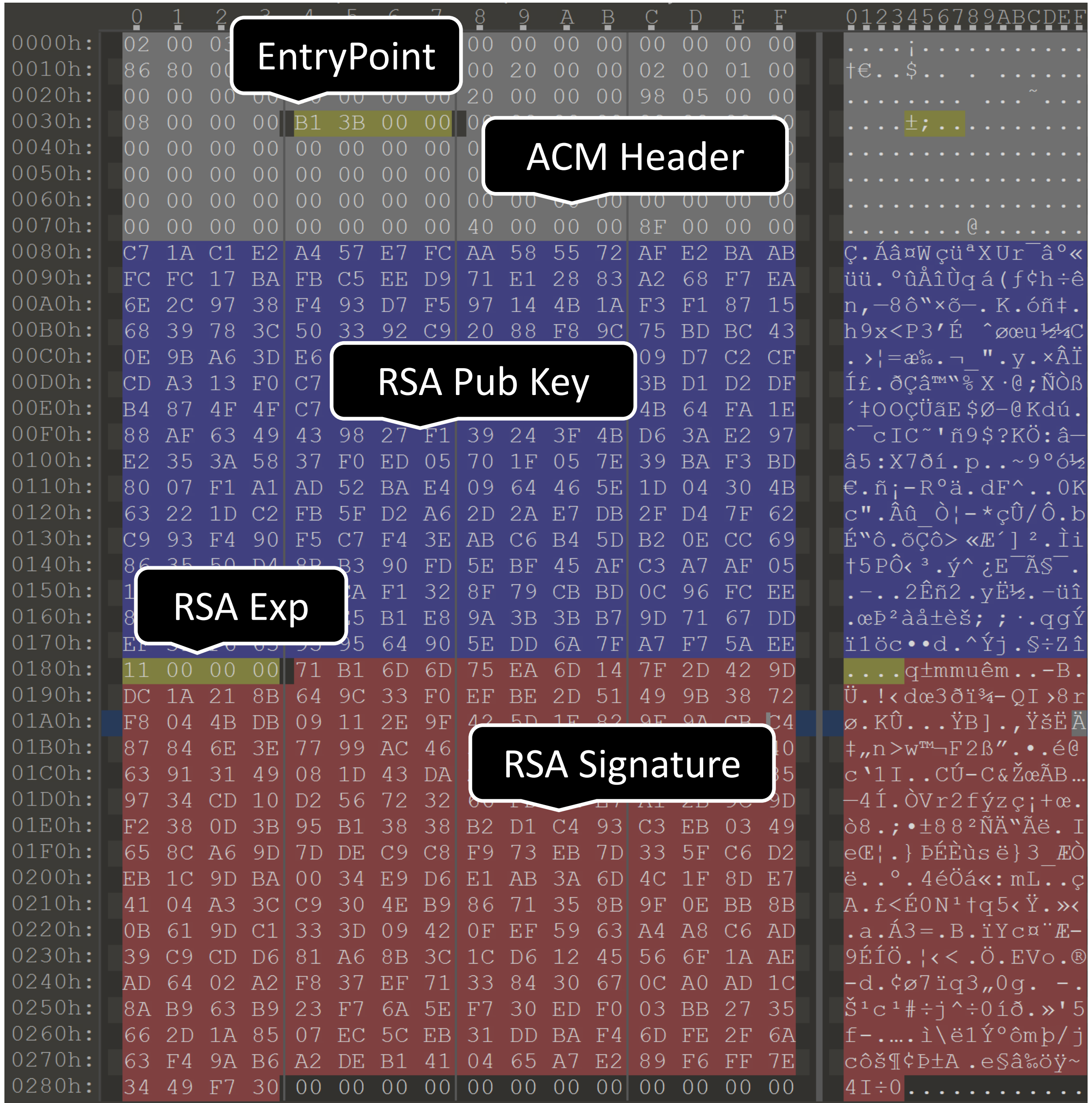
```
0000 5F 5F 41 4
0010 5F 5F 49 4
0020 00 00 D1 F
0030 00 00 10 0
0040 00 00 00 0
0050 00 00 00 0
0060 00 00 00 0
0070 0B 00 20 0
0080 E6 D8 4D 7
0090 75 97 0D 1
00A0 00 00 00 0
00B0 00 00 91 F
00C0 FF 80 5E 0
00D0 00 10 00 0
00E0 D1 01 92 2
00F0 E9 3D 19 3
0100 F3 7E 92 1
0110 81 AC 70 C
0120 B6 0F 90 9
0130 C0 9E 70 0
0140 B9 68 86 5
0150 4B CF 24 A
0160 29 8E 1B A
0170 6A E4 B5 C
0180 C8 A6 74 6
0190 8F F8 02 A
01A0 48 03 B1 A
01B0 9C 57 2B 3
01C0 77 17 9E 9
01D0 80 C5 71 0
01E0 E3 B4 D4 7
01F0 E3 B4 A1 9
0200 9B 0F C1 B
```

```
✓Intel image                                     Image      Intel
  Descriptor region                              Region     Descriptor
  GbE region                                     Region     GbE
  ME region                                      Region     ME
 ⌄BIOS region                                    Region     BIOS
   > EfiFirmwareFileSystem2Guid                  Volume     FFSv2
     Padding                                     Padding    Empty (0xFF)
   > 4F1C52D3-D824-4D2A-A2F0-EC40C23C5916        Volume     FFSv2
   > AFDD39F1-19D7-4501-A730-CE5A27E1154B        Volume     FFSv2
   ⌄ 61C0F511-A691-4F54-974F-B9A42172CE53        Volume     FFSv2
     > AprioriPei                                File       Freeform        PEI apriori file
     > 7EB7126D-C45E-4BD0-9357-7F507C5C9CF9      File       PEI module      RomLayoutPei
     > PeiCore                                   File       PEI core        PeiCore
     > CapsulePei                                File       PEI module      CapsulePei
     > 9029F23E-E1EE-40D1-9382-36DD61A63EAA      File       PEI module      NCT6106DPeiInit
     > PiSmmCommunicationPei                     File       PEI module      PiSmmCommunicationPei
     > 91B886FD-2636-4FA8-A4A9-2EB04F235E09      File       PEI module      CpuPeiBeforeMem
     > 9962883C-C025-4EBB-B699-4EA4D147C8A8      File       PEI module      AmiTxtTcgPeim
     > NBPEI                                     File       PEI module      NbPei
     > SBPEI                                     File       PEI module      SbPei
     > C7D4BBCF-EB0A-4C91-BD8B-FCA99F28B011      File       PEI module      AmiTxtPei
     > A6AEF1F6-F25A-4082-AF39-2229BCF5A6E1      File       PEI module      AmtStatusCodePei
     > 52B3DBA7-9565-48E8-8E13-EC7196721B3C      File       PEI module      PlatformInfoPei
     > B41956E1-7CA2-42DB-9562-168389F0F066      File       PEI module      BootGuardPei
     > C776AEA2-AA27-446E-975B-E0BEA9078BD9      File       PEI module      BiosGuardPeiApRecoveryC…
     > CAC3FB95-33F5-4596-818B-68E024DDB67B      File       PEI module      IsSecRecoveryPEI
     > TcgPlatformSetupPeiPolicy                 File       PEI module      TcgPlatformSetupPeiPolicy
     > AmiTcgPlatformPeiBeforeMem                File       PEI module      AmiTcgPlatformPeiBefore…
     > TcgPeiplatform                            File       PEI module      TcgPeiplatform
     > CRBPEI                                    File       PEI module      CrbPei
     > E9DD7F62-25EC-4F9D-A4AB-AAD20BF59A10      File       PEI module      StatusCodePei
     > Fid                                       File       Freeform
     > 838DCF34-907B-4D55-9A4B-A0EF7167B5F4      File       PEI module      NVRAMPei
     > C91C3C17-FC74-46E5-BDBE-6F486A5A9F3C      File       Freeform
     > RomLayout                                 File       Freeform
     > CapsuleX64                                File       PEI module      CapsuleX64
     > PcdPeim                                   File       PEI module      PcdPeim
     > SgTpvPei                                  File       PEI module      SgTpvPei
     > A8499E65-A6F6-48B0-96DB-45C266030D83      File       PEI module      SiInitPreMem
     > EEEE611D-F78F-4FB9-B868-55907F169280      File       PEI module      PlatformInitPreMem
     > 0C4EE8AC-4BCB-43B4-9F05-E07523A9FC97      File       PEI module      AfterMemoryDummyDriver
     > 654FE61A-2EDA-4749-A76A-56ED7ADE1CBE      File       PEI module      CmosPei
     > E03E6451-297A-4FE9-B1F7-639B70327C52      File       PEI module      EnhancePeiVariable
     > 1068E0ED-5C8E-4724-B011-2C5F95065DF2      File       Freeform
     > CBC91F44-A4BC-4A5B-8696-703451D0B053      File       Freeform
     > 95C894B4-DAEC-46E1-8600-3C4C7FC985D6      File       PEI module      BiosGuardRecovery
     > PeiRamBoot                                File       PEI module      PeiRamBootPei
     > CpuIoPei                                  File       PEI module      CpuIoPei
     > PcatSingleSegmentPciCfg2Pei               File       PEI module      PcatSingleSegmentPciCfg…
     > E60A79D5-DC9B-47F1-87D3-51BF697B6121      File       PEI module      CpuPei
     > FAF79E9F-4D40-4F02-8AC9-4B5512708F7F      File       PEI module      BiosGuardCpuPolicyOverr…
     > 59ADD62D-A1C0-44C5-A90F-A1168770468C      File       PEI module      PlatformInit
     > DxeIplPei                                 File       PEI module      DxeIpl
     > 5AC804F2-7D19-5B5C-A22D-FAF4A8FE5178      File       PEI module      AcpiVariableHobOnSmramR…
     > BD87C542-9CFF-4D4A-A890-02B6AF986F34      File       PEI module      PeiOverClock
     > EFF9400A-AD95-475B-868F-C7AFC313BA72      File       PEI module      AmiPeiCreateDummyRcHob
     > 299D6F8B-2EC9-4E40-9EC6-DDAA7EBF5FD9      File       PEI module      SiInit
     > B1E9E2CA-B078-4070-BCCD-87449AC7D2A6      File       PEI module      CpuS3Pei
     > S3Restore                                 File       PEI module      S3Resume
     > 9B8A0C3A-5186-4B55-89F4-CAFDE613DAB1      File       PEI module      BootScriptHidePei
     > TcgPei                                    File       PEI module      TcgPei
     > 961C19BE-D1AC-4BA7-87AF-4AE0F09DF2A6      File       PEI module      TrEEPei
     > 0D8039FF-49E9-4CC9-A806-BB7C31B0BCB0      File       PEI module      AmiTpm20PlatformPei
     > 67451698-1825-4AC5-999D-F350CC7D5D72      File       PEI module      CryptoPPI
     > A6A3A962-C591-4701-9D25-73D0226D89DC      File       PEI module      PeiRamBootCacheRdy
     > 39E8CA1A-7A69-4A73-834A-D06381933286      File       PEI module      UsbPei
     > BDAD7D1A-4C48-4C75-B5BC-D002D17F6397      File       PEI module      AhciRecovery
     > DACF705C-71DF-497D-AABE-10186B2E1DDE      File       PEI module      Recovery
     > 7ECD9C20-68B9-4A6F-B515-D64FF500B109      File       PEI module      FsRecovery
     > 10C22623-DB6F-4721-AA30-4C12AF4230A7      File       PEI module      IdeRecovery
     > 00026AEB-F334-4C15-A7F0-E1E897E9FE91      File       PEI module      NvmeRecovery
     > 89F06049-F297-4436-8540-E0BF9E92B56B      File       PEI module      SdioRecovery
     > AmiTcgPlatformPeiAfterMem                 File       PEI module      AmiTcgPlatformPeiAfterMem
       77D3DC50-D42B-4916-AC80-8F469035D150      File       Raw
       Pad-file                                  File       Pad
       6520F532-2A27-4195-B331-C0854683F0BA      File       Raw
```

Boot Guard: Authenticated Code Module (ACM)



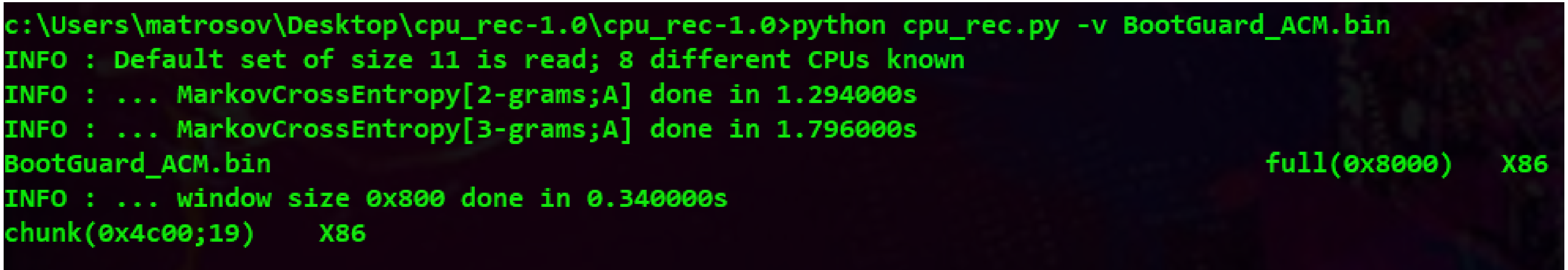
struct ACM_HEADER ACM	
UINT32 ModuleType	30002h
UINT32 HeaderType	A1h
UINT32 Unknown[2]	
UINT32 ModuleVendor	8086h
UINT32 Date	20150624h
UINT32 ModuleSize	2000h
UINT16 AcmSvn	2h
UINT16 Unknown1	1h
UINT32 Unknown2[5]	
UINT32 EntryPoint	3BB1h
UBYTE Unknown3[64]	
UINT32 KeySize	40h
UINT32 Unknown4	8Fh
UBYTE RsaPubKey[256]	
UINT32 RsaPubExp	11h
UBYTE RsaSig[256]	



```
        0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F   0123456789ABCDEF
0000h: 02 00 03                00 00 00 00 00 00 00 00  ....¡...........
0010h: 86 80 00                00 20 00 00 02 00 01 00  †€..$.. . ......
0020h: 00 00 00 00    00 00 00 20 00 00 00 98 05 00 00  ........ ...˜...
0030h: 08 00 00 00 B1 3B 00 00                          ....±;..........
0040h: 00 00 00 00 00 00 00 00                          ................
0050h: 00 00 00 00 00 00 00 00                          ................
0060h: 00 00 00 00 00 00 00 00 00 00    00 00 00 00 00  ................
0070h: 00 00 00 00 00 00 00 00 40 00 00 00 8F 00 00 00  ........@.......
0080h: C7 1A C1 E2 A4 57 E7 FC AA 58 55 72 AF E2 BA AB  Ç.Áâ¤WçüªXUr¯â°«
0090h: FC FC 17 BA FB C5 EE D9 71 E1 28 83 A2 68 F7 EA  üü.°ûÅîÙqá(ƒ¢h÷ê
00A0h: 6E 2C 97 38 F4 93 D7 F5 97 14 4B 1A F3 F1 87 15  n,—8ô“×õ—.K.óñ‡.
00B0h: 68 39 78 3C 50 33 92 C9 20 88 F8 9C 75 BD BC 43  h9x<P3’É ˆøœu½¼C
00C0h: 0E 9B A6 3D E6                      09 D7 C2 CF  .›¦=æ‰.¬_".y.×ÂÏ
00D0h: CD A3 13 F0 C7                      3B D1 D2 DF  Í£.ðÇâ™”‰X·@;ÑÒß
00E0h: B4 87 4F 4F C7                      4B 64 FA 1E  ´‡OOÇÜãE$Ø–@Kdú.
00F0h: 88 AF 63 49 43 98 27 F1 39 24 3F 4B D6 3A E2 97  ˆ¯cIC˜'ñ9$?KÖ:â—
0100h: E2 35 3A 58 37 F0 ED 05 70 1F 05 7E 39 BA F3 BD  â5:X7ðí.p..~9°ó½
0110h: 80 07 F1 A1 AD 52 BA E4 09 64 46 5E 1D 04 30 4B  €.ñ¡–R°ä.dF^..0K
0120h: 63 22 1D C2 FB 5F D2 A6 2D 2A E7 DB 2F D4 7F 62  c".Âû_Ò¦-*çÛ/Ô.b
0130h: C9 93 F4 90 F5 C7 F4 3E AB C6 B4 5D B2 0E CC 69  É“ô.õÇô>«Æ´]².Ìi
0140h: 86 35 50 D4 8B B3 90 FD 5E BF 45 AF C3 A7 AF 05  †5PÔ‹³.ý^¿E¯ÃS¯.
0150h:                   F1 32 8F 79 CB BD 0C 96 FC EE  .–..2Êñ2.yË½.–üî
0160h:                   B1 E8 9A 3B 3B B7 9D 71 67 DD  .œÞ²àå±èš;;·.qgÝ
0170h:                95 64 90 5E DD 6A 7F A7 F7 5A EE  ï1öc••d.^Ýj.§÷Zî
0180h: 11 00 00 00 71 B1 6D 6D 75 EA 6D 14 7F 2D 42 9D  ....q±mmuêm..–B.
0190h: DC 1A 21 8B 64 9C 33 F0 EF BE 2D 51 49 9B 38 72  Ü.!‹dœ3ðï¾–QI›8r
01A0h: F8 04 4B DB 09 11 2E 9F 42 5D 1F 82 9F 9A CB C4  ø.KÛ...ŸB].,ŸšËÄ
01B0h: 87 84 6E 3E 77 99 AC 46                      40  ‡„n>w™¬F2ß”.•.é@
01C0h: 63 91 31 49 08 1D 43 DA                          c‘1I..CÚ–C&ŽœÃB…
01D0h: 97 34 CD 10 D2 56 72 32                      9D  —4Í.ÒVr2fýzç¡+œ.
01E0h: F2 38 0D 3B 95 B1 38 38 B2 D1 C4 93 C3 EB 03 49  ò8.;•±88²ÑÄ“Ãë.I
01F0h: 65 8C A6 9D 7D DE C9 C8 F9 73 EB 7D 33 5F C6 D2  eŒ¦.}ÞÉÈùsë}3_ÆÒ
0200h: EB 1C 9D BA 00 34 E9 D6 E1 AB 3A 6D 4C 1F 8D E7  ë..°.4éÖá«:mL..ç
0210h: 41 04 A3 3C C9 30 4E B9 86 71 35 8B 9F 0E BB 8B  A.£<É0N¹†q5‹Ÿ.»‹
0220h: 0B 61 9D C1 33 3D 09 42 0F EF 59 63 A4 A8 C6 AD  .a.Á3=.B.ïYc¤¨Æ-
0230h: 39 C9 CD D6 81 A6 8B 3C 1C D6 12 45 56 6F 1A AE  9ÉÍÖ.¦‹<.Ö.EVo.®
0240h: AD 64 02 A2 F8 37 EF 71 33 84 30 67 0C A0 AD 1C  -d.¢ø7ïq3„0g. -.
0250h: 8A B9 63 B9 23 F7 6A 5E F7 30 ED F0 03 BB 27 35  Š¹c¹#÷j^÷0íð.»'5
0260h: 66 2D 1A 85 07 EC 5C EB 31 DD BA F4 6D FE 2F 6A  f-.….ì\ë1Ý°ômþ/j
0270h: 63 F4 9A B6 A2 DE B1 41 04 65 A7 E2 89 F6 FF 7E  côš¶¢Þ±A.e§â‰öÿ~
0280h: 34 49 F7 30 00 00 00 00 00 00 00 00 00 00 00 00  4I÷0............
```

Boot Guard: Authenticated Code Module (ACM)

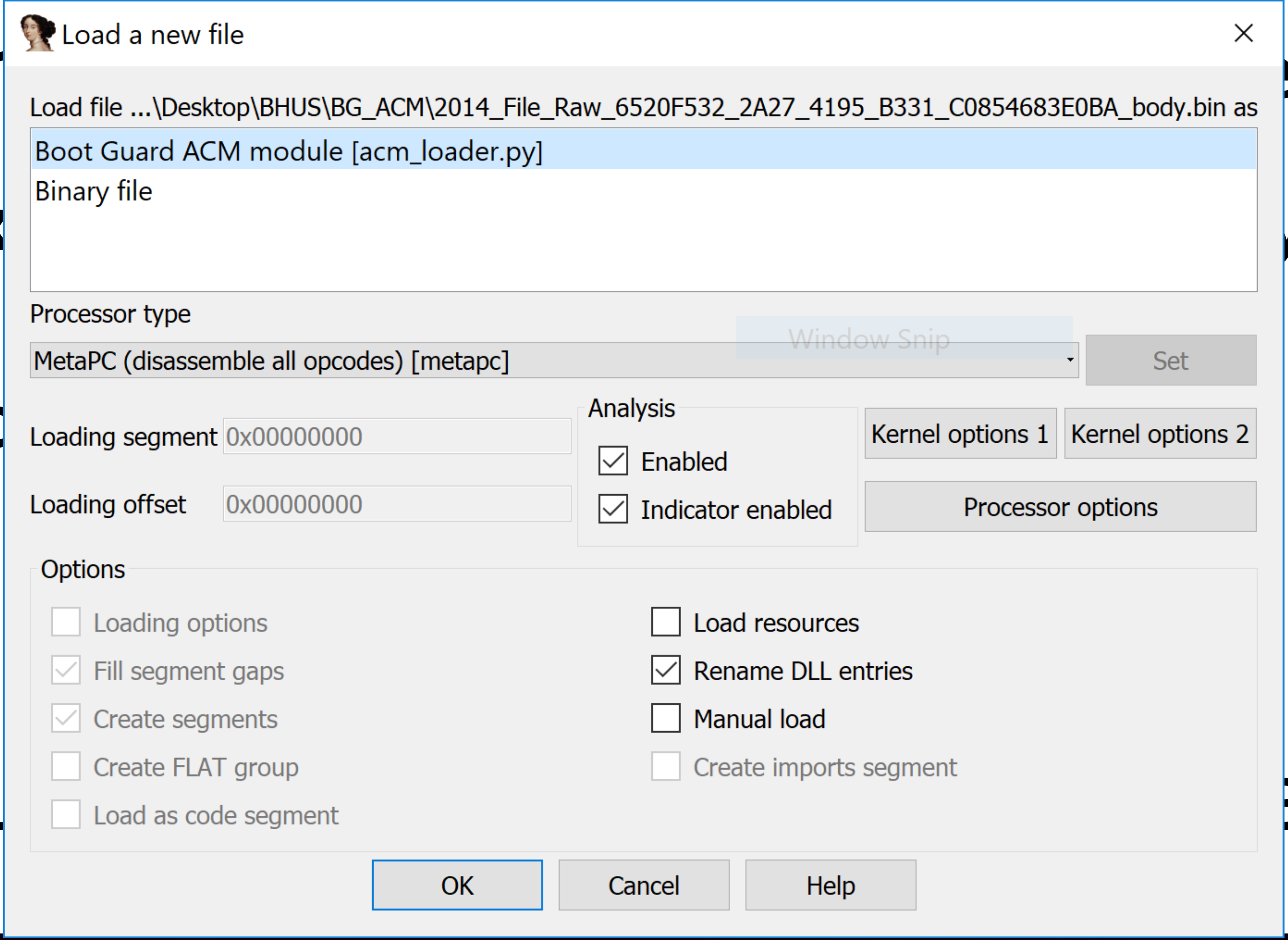
- ACM is x86 (32-bit) code developed by Intel
- ACM executes in AC-RAM (Cache-as-RAM or NEM)
- ACM has CPU and Chipset specifics
- ACM verifies Key Manifest (KEYM) + IBB (IBBM)



```
c:\Users\matrosov\Desktop\cpu_rec-1.0\cpu_rec-1.0>python cpu_rec.py -v BootGuard_ACM.bin
INFO : Default set of size 11 is read; 8 different CPUs known
INFO : ... MarkovCrossEntropy[2-grams;A] done in 1.294000s
INFO : ... MarkovCrossEntropy[3-grams;A] done in 1.796000s
BootGuard_ACM.bin                                                   full(0x8000)   X86
INFO : ... window size 0x800 done in 0.340000s
chunk(0x4c00;19)    X86
```

Boot Guar… (ACM)

- ACM is x… y Intel
- ACM exec… or NEM)
- ACM has
- ACM veri… BB (IBBM)



Load a new file

Load file ...\Desktop\BHUS\BG_ACM\2014_File_Raw_6520F532_2A27_4195_B331_C0854683E0BA_body.bin as

Boot Guard ACM module [acm_loader.py]
Binary file

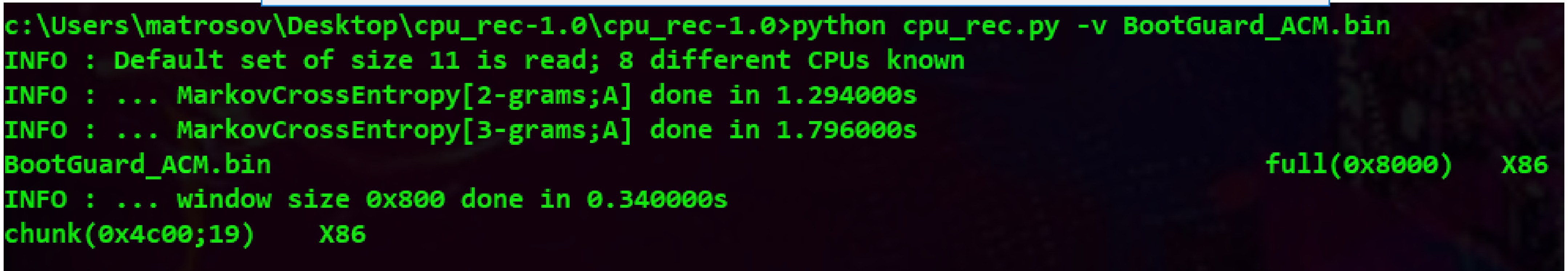
Processor type: MetaPC (disassemble all opcodes) [metapc]

Loading segment: 0x00000000

Loading offset: 0x00000000

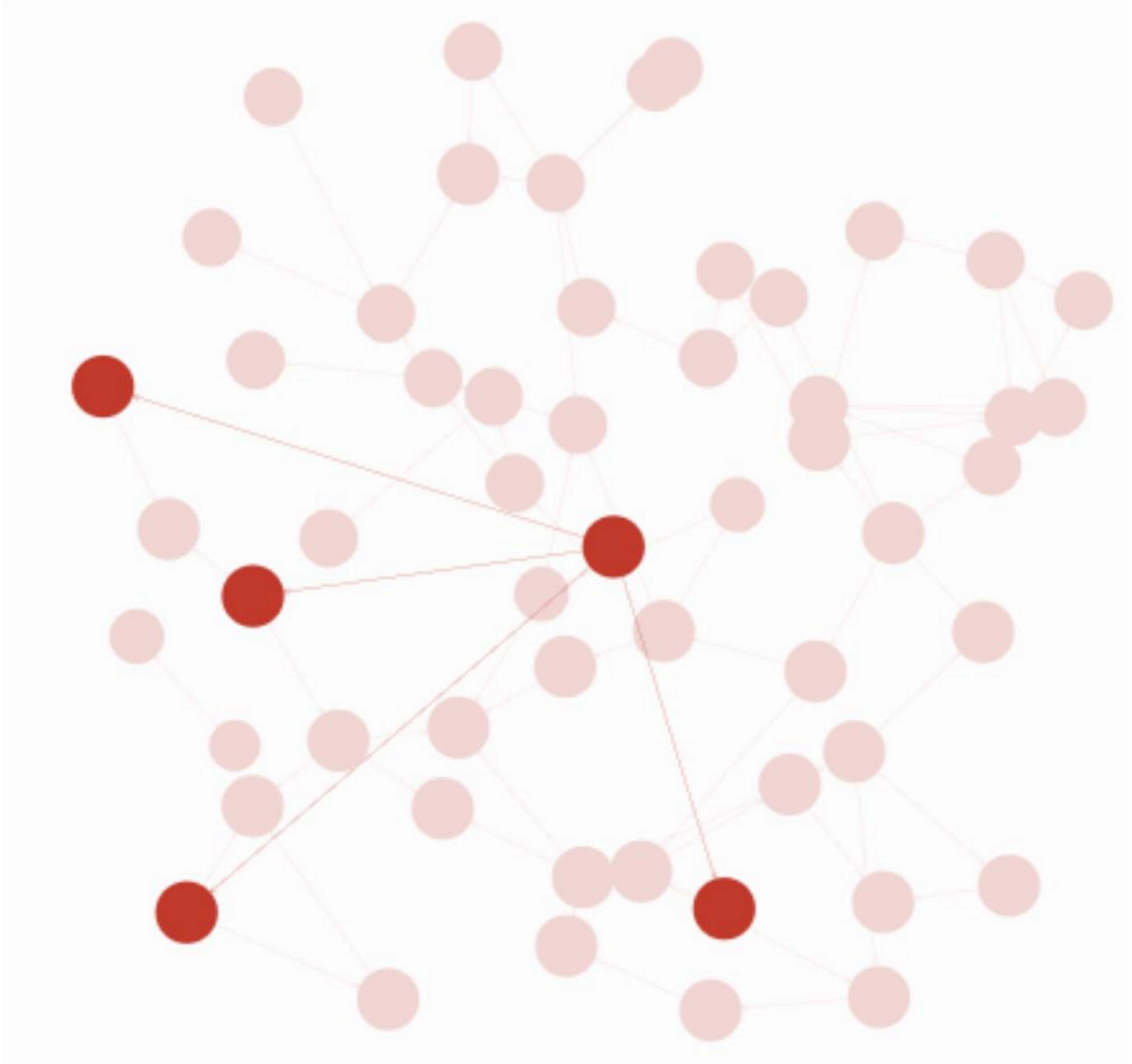
Analysis
- ☑ Enabled
- ☑ Indicator enabled

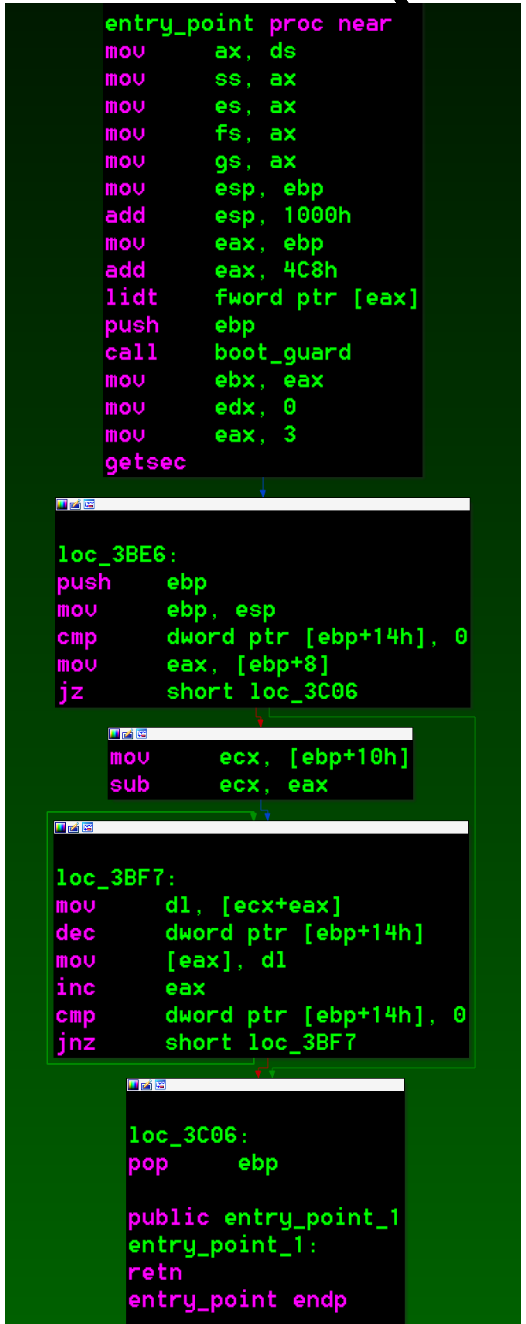
Options
- □ Loading options
- ☑ Fill segment gaps
- ☑ Create segments
- □ Create FLAT group
- □ Load as code segment
- □ Load resources
- ☑ Rename DLL entries
- □ Manual load
- □ Create imports segment



```
c:\Users\matrosov\Desktop\cpu_rec-1.0\cpu_rec-1.0>python cpu_rec.py -v BootGuard_ACM.bin
INFO : Default set of size 11 is read; 8 different CPUs known
INFO : ... MarkovCrossEntropy[2-grams;A] done in 1.294000s
INFO : ... MarkovCrossEntropy[3-grams;A] done in 1.796000s
BootGuard_ACM.bin                                                         full(0x8000)   X86
INFO : ... window size 0x800 done in 0.340000s
chunk(0x4c00;19)    X86
```

Boot Guard: Authenticated Code Module (ACM)





```
entry_point proc near
mov     ax, ds
mov     ss, ax
mov     es, ax
mov     fs, ax
mov     gs, ax
mov     esp, ebp
add     esp, 1000h
mov     eax, ebp
add     eax, 4C8h
lidt    fword ptr [eax]
push    ebp
call    boot_guard
mov     ebx, eax
mov     edx, 0
mov     eax, 3
getsec
```

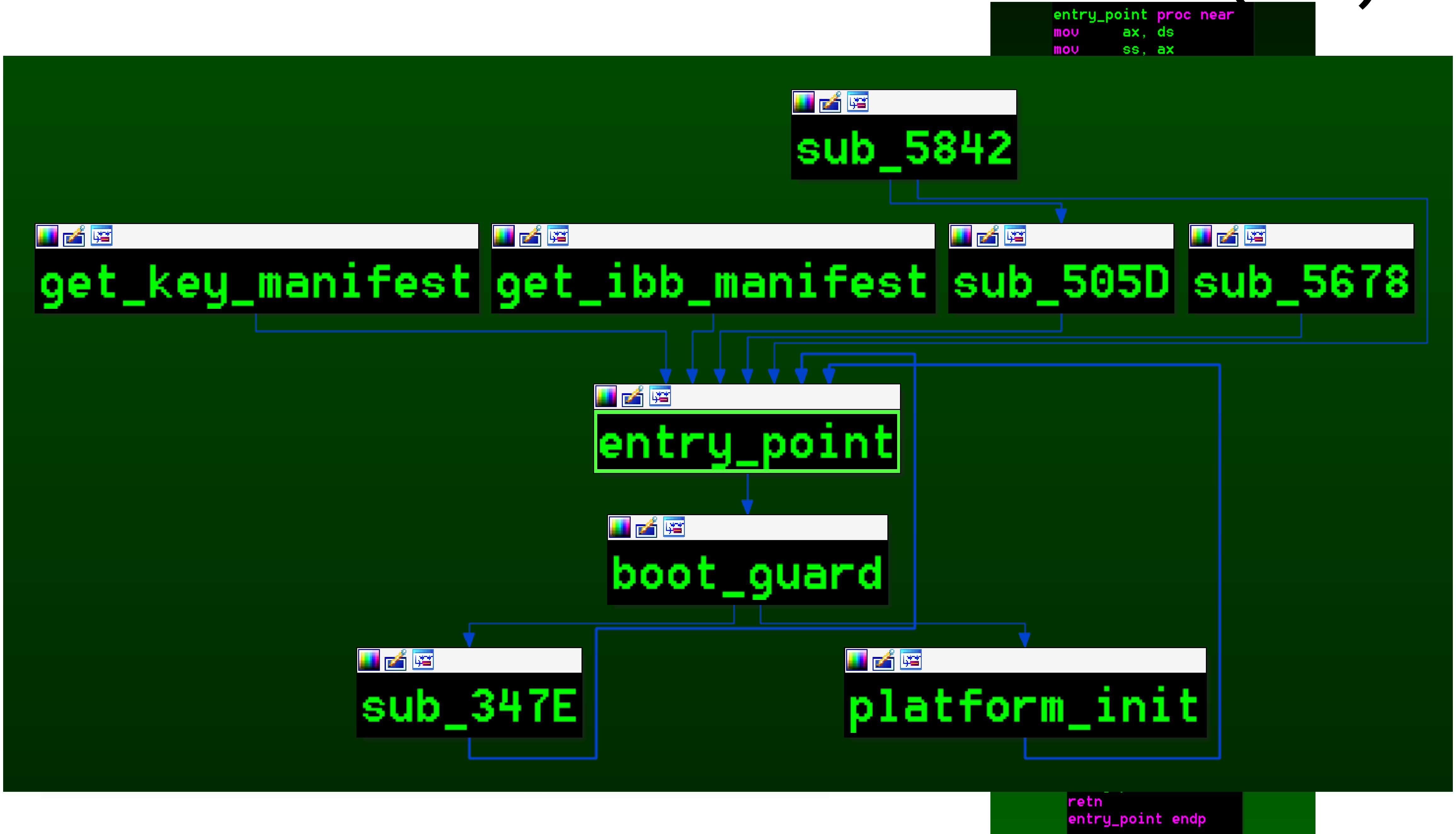
```
loc_3BE6:
push    ebp
mov     ebp, esp
cmp     dword ptr [ebp+14h], 0
mov     eax, [ebp+8]
jz      short loc_3C06
```

```
mov     ecx, [ebp+10h]
sub     ecx, eax
```

```
loc_3BF7:
mov     dl, [ecx+eax]
dec     dword ptr [ebp+14h]
mov     [eax], dl
inc     eax
cmp     dword ptr [ebp+14h], 0
jnz     short loc_3BF7
```

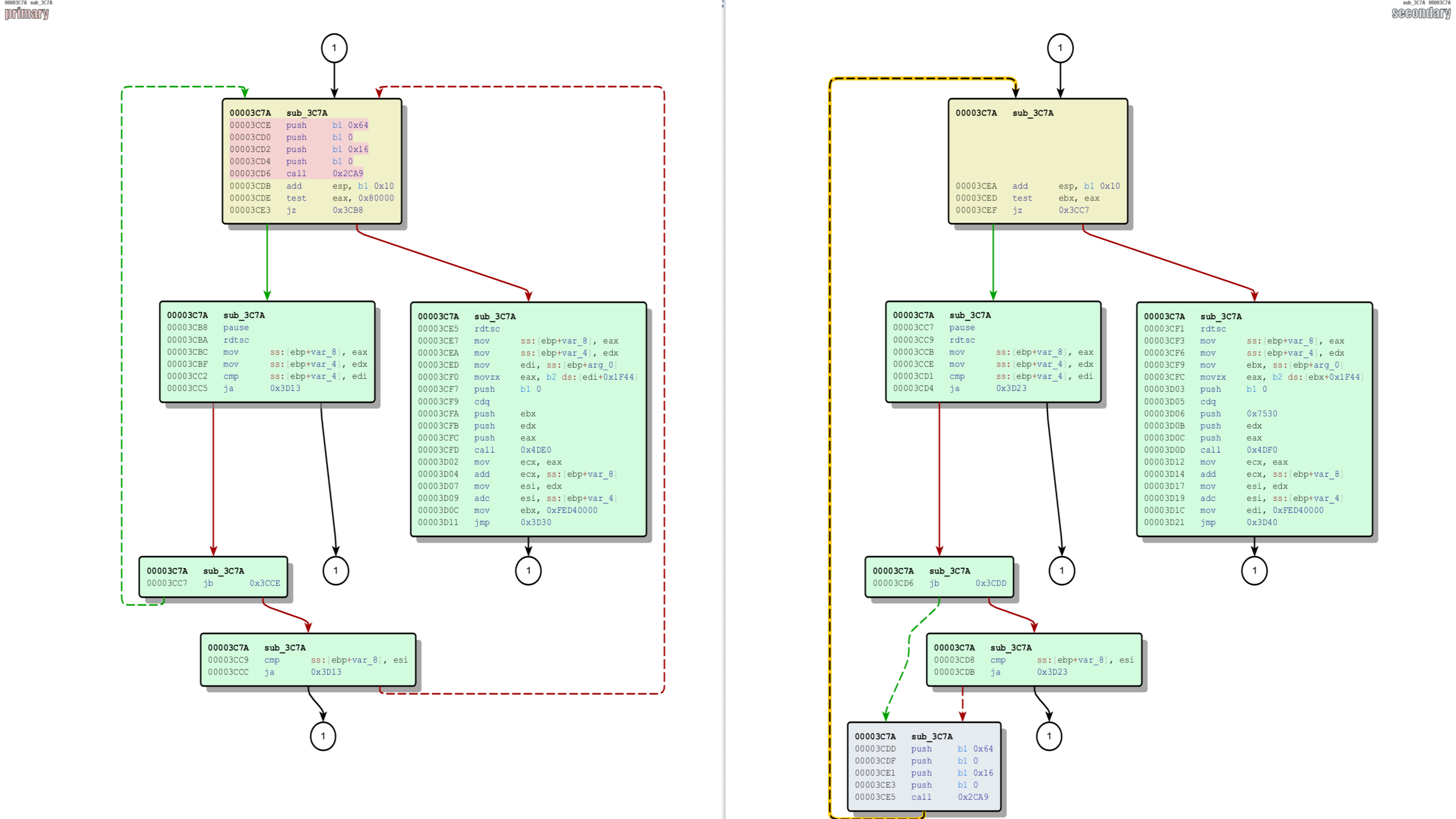
```
loc_3C06:
pop     ebp

public entry_point_1
entry_point_1:
retn
entry_point endp
```

Boot Guard: Authenticated Code Module (ACM)



```
entry_point proc near
mov     ax, ds
mov     ss, ax
```

```
retn
entry_point endp
```



00003C7A sub_3C7A
primary

```
00003C7A   sub_3C7A
00003CCE   push      bl 0x64
00003CD0   push      bl 0
00003CD2   push      bl 0x16
00003CD4   push      bl 0
00003CD6   call      0x2CA9
00003CDB   add       esp, bl 0x10
00003CDE   test      eax, 0x80000
00003CE3   jz        0x3CB8
```

```
00003C7A   sub_3C7A
00003CB8   pause
00003CBA   rdtsc
00003CBC   mov       ss:[ebp+var_8], eax
00003CBF   mov       ss:[ebp+var_4], edx
00003CC2   cmp       ss:[ebp+var_4], edi
00003CC5   ja        0x3D13
```

```
00003C7A   sub_3C7A
00003CE5   rdtsc
00003CE7   mov       ss:[ebp+var_8], eax
00003CEA   mov       ss:[ebp+var_4], edx
00003CED   mov       edi, ss:[ebp+arg_0]
00003CF0   movzx     eax, b2 ds:[edi+0x1F44]
00003CF7   push      bl 0
00003CF9   cdq
00003CFA   push      ebx
00003CFB   push      edx
00003CFC   push      eax
00003CFD   call      0x4DE0
00003D02   mov       ecx, eax
00003D04   add       ecx, ss:[ebp+var_8]
00003D07   mov       esi, edx
00003D09   adc       esi, ss:[ebp+var_4]
00003D0C   mov       ebx, 0xFED40000
00003D11   jmp       0x3D30
```

```
00003C7A   sub_3C7A
00003CC7   jb        0x3CCE
```

```
00003C7A   sub_3C7A
00003CC9   cmp       ss:[ebp+var_8], esi
00003CCC   ja        0x3D13
```

sub_3C7A 00003C7A
secondary

```
00003C7A   sub_3C7A



00003CEA   add       esp, bl 0x10
00003CED   test      ebx, eax
00003CEF   jz        0x3CC7
```

```
00003C7A   sub_3C7A
00003CC7   pause
00003CC9   rdtsc
00003CCB   mov       ss:[ebp+var_8], eax
00003CCE   mov       ss:[ebp+var_4], edx
00003CD1   cmp       ss:[ebp+var_4], edi
00003CD4   ja        0x3D23
```

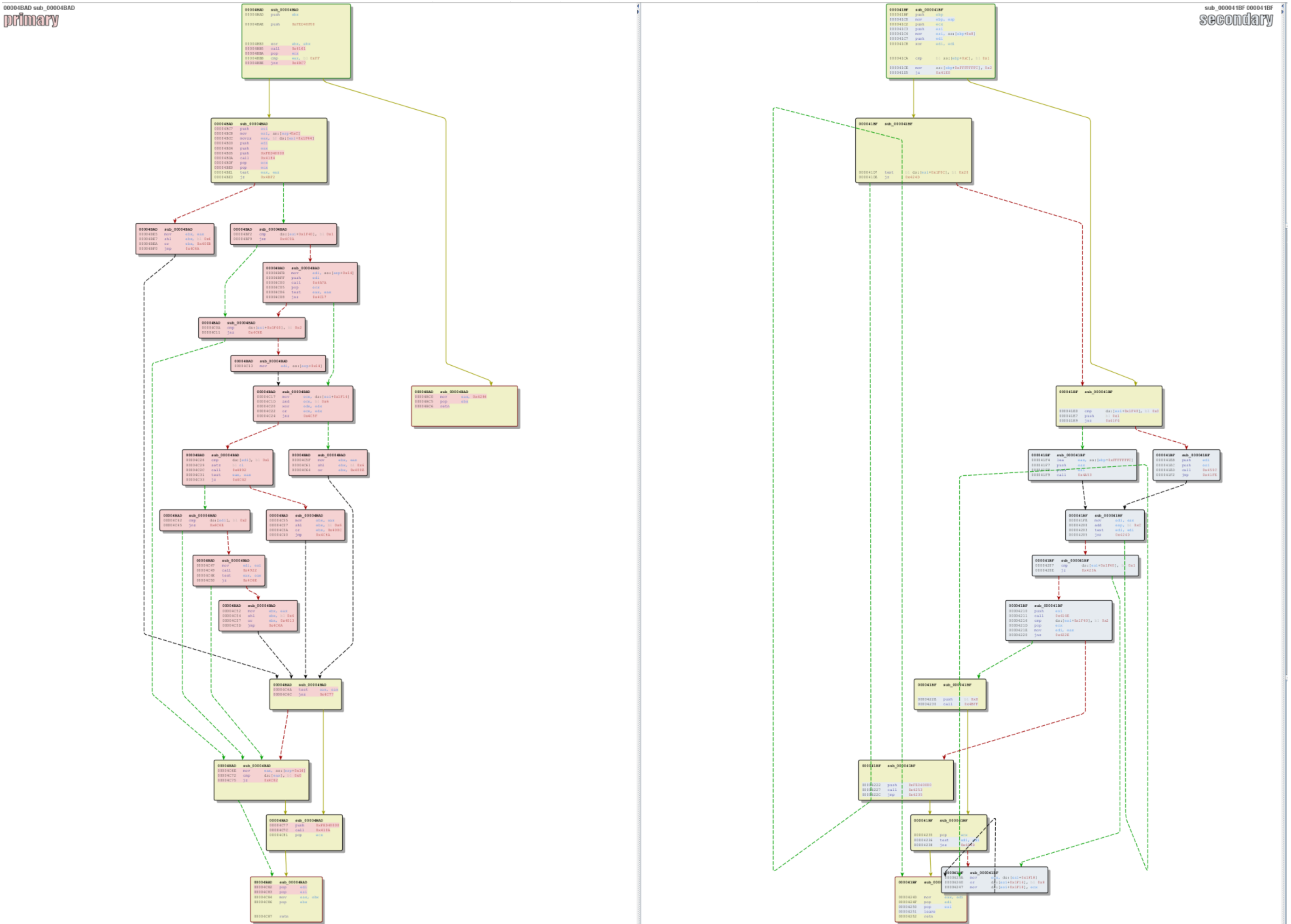
```
00003C7A   sub_3C7A
00003CF1   rdtsc
00003CF3   mov       ss:[ebp+var_8], eax
00003CF6   mov       ss:[ebp+var_4], edx
00003CF9   mov       ebx, ss:[ebp+arg_0]
00003CFC   movzx     eax, b2 ds:[ebx+0x1F44]
00003D03   push      bl 0
00003D05   cdq
00003D06   push      0x7530
00003D0B   push      edx
00003D0C   push      eax
00003D0D   call      0x4DF0
00003D12   mov       ecx, eax
00003D14   add       ecx, ss:[ebp+var_8]
00003D17   mov       esi, edx
00003D19   adc       esi, ss:[ebp+var_4]
00003D1C   mov       edi, 0xFED40000
00003D21   jmp       0x3D40
```

```
00003C7A   sub_3C7A
00003CD6   jb        0x3CDD
```

```
00003C7A   sub_3C7A
00003CD8   cmp       ss:[ebp+var_8], esi
00003CDB   ja        0x3D23
```

```
00003C7A   sub_3C7A
00003CDD   push      bl 0x64
00003CDF   push      bl 0
00003CE1   push      bl 0x16
00003CE3   push      bl 0
00003CE5   call      0x2CA9
```

Boot Guard ACM BinDiff: Broadwell vs Skylake



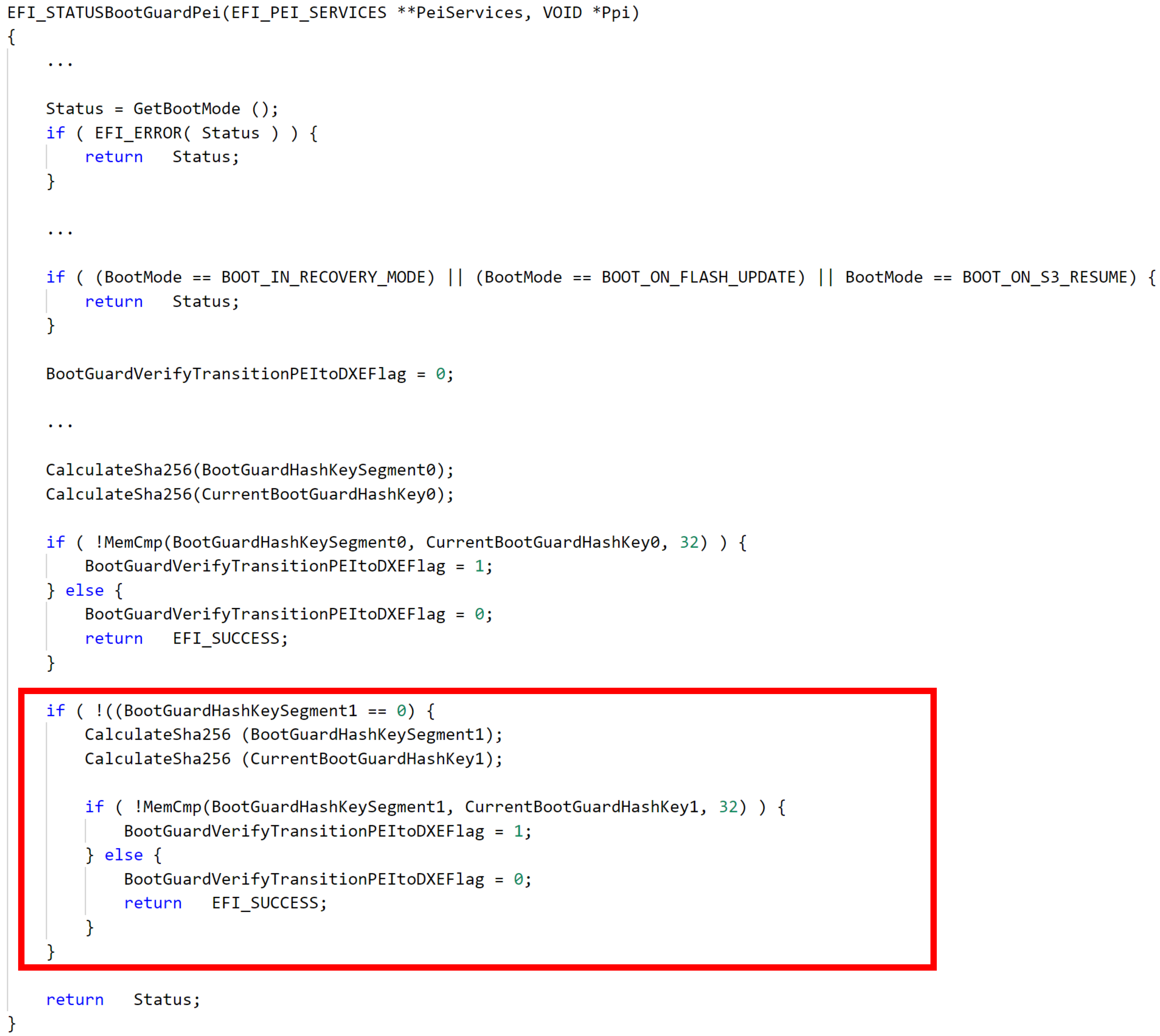
Boot Guard BIOS Components (AMI)

- **PEI**
  - **BootGuardPei** [B41956E1-7CA2-42db-9562-168389F0F066]

- **SMM**
  - **VerifyFwBootGuard** [EE89F590-A816-4ac5-B3A9-1BC759B12439]

- **DXE**
  - **BootGuardDxe** [1DB43EC9-DF5F-4cf5-AAF0-0E85DB4E149A]

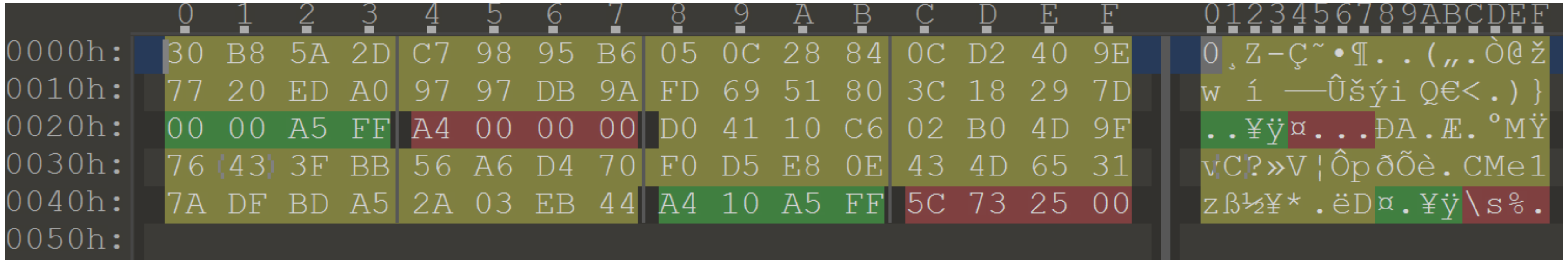
BootGuardPei Validation Flow



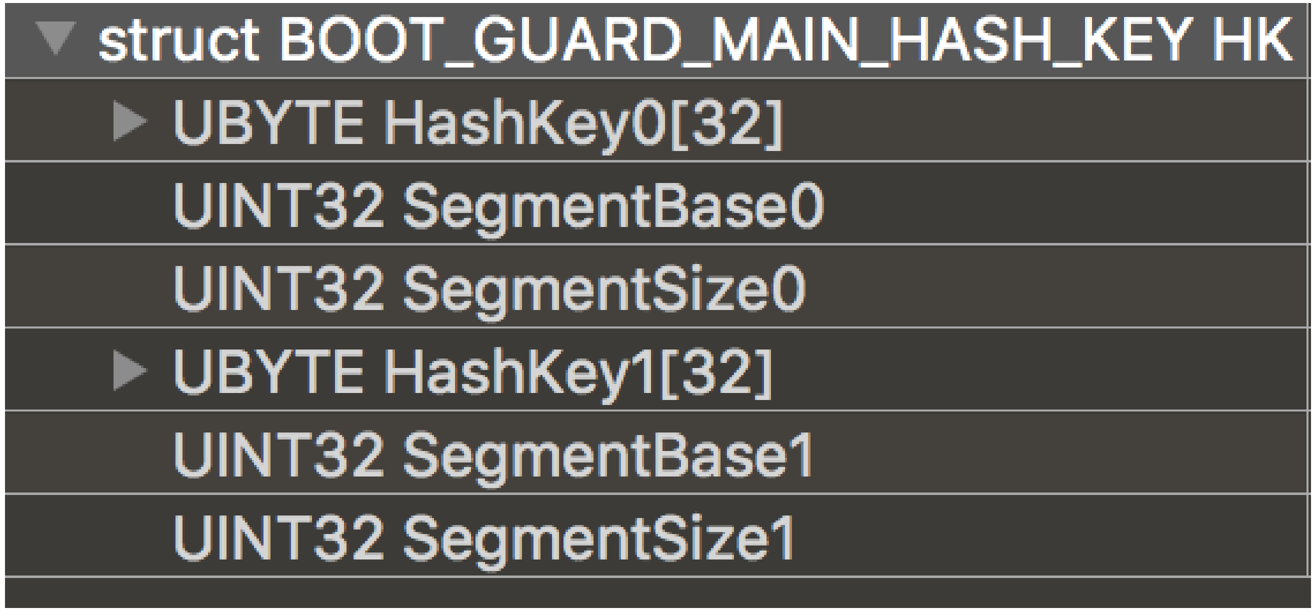
```
EFI_STATUSBootGuardPei(EFI_PEI_SERVICES **PeiServices, VOID *Ppi)
{
    ...

    Status = GetBootMode ();
    if ( EFI_ERROR( Status ) ) {
        return   Status;
    }

    ...

    if ( (BootMode == BOOT_IN_RECOVERY_MODE) || (BootMode == BOOT_ON_FLASH_UPDATE) || BootMode == BOOT_ON_S3_RESUME) {
        return   Status;
    }

    BootGuardVerifyTransitionPEItoDXEFlag = 0;

    ...

    CalculateSha256(BootGuardHashKeySegment0);
    CalculateSha256(CurrentBootGuardHashKey0);

    if ( !MemCmp(BootGuardHashKeySegment0, CurrentBootGuardHashKey0, 32) ) {
        BootGuardVerifyTransitionPEItoDXEFlag = 1;
    } else {
        BootGuardVerifyTransitionPEItoDXEFlag = 0;
        return   EFI_SUCCESS;
    }

    if ( !((BootGuardHashKeySegment1 == 0) {
        CalculateSha256 (BootGuardHashKeySegment1);
        CalculateSha256 (CurrentBootGuardHashKey1);

        if ( !MemCmp(BootGuardHashKeySegment1, CurrentBootGuardHashKey1, 32) ) {
            BootGuardVerifyTransitionPEItoDXEFlag = 1;
        } else {
            BootGuardVerifyTransitionPEItoDXEFlag = 0;
            return   EFI_SUCCESS;
        }
    }

    return   Status;
}
```

Boot Guard: PEI FV_HASH

- FV_HASH_KEY [CBC91F44-A4BC-4A5B-8696-703451D0B053]



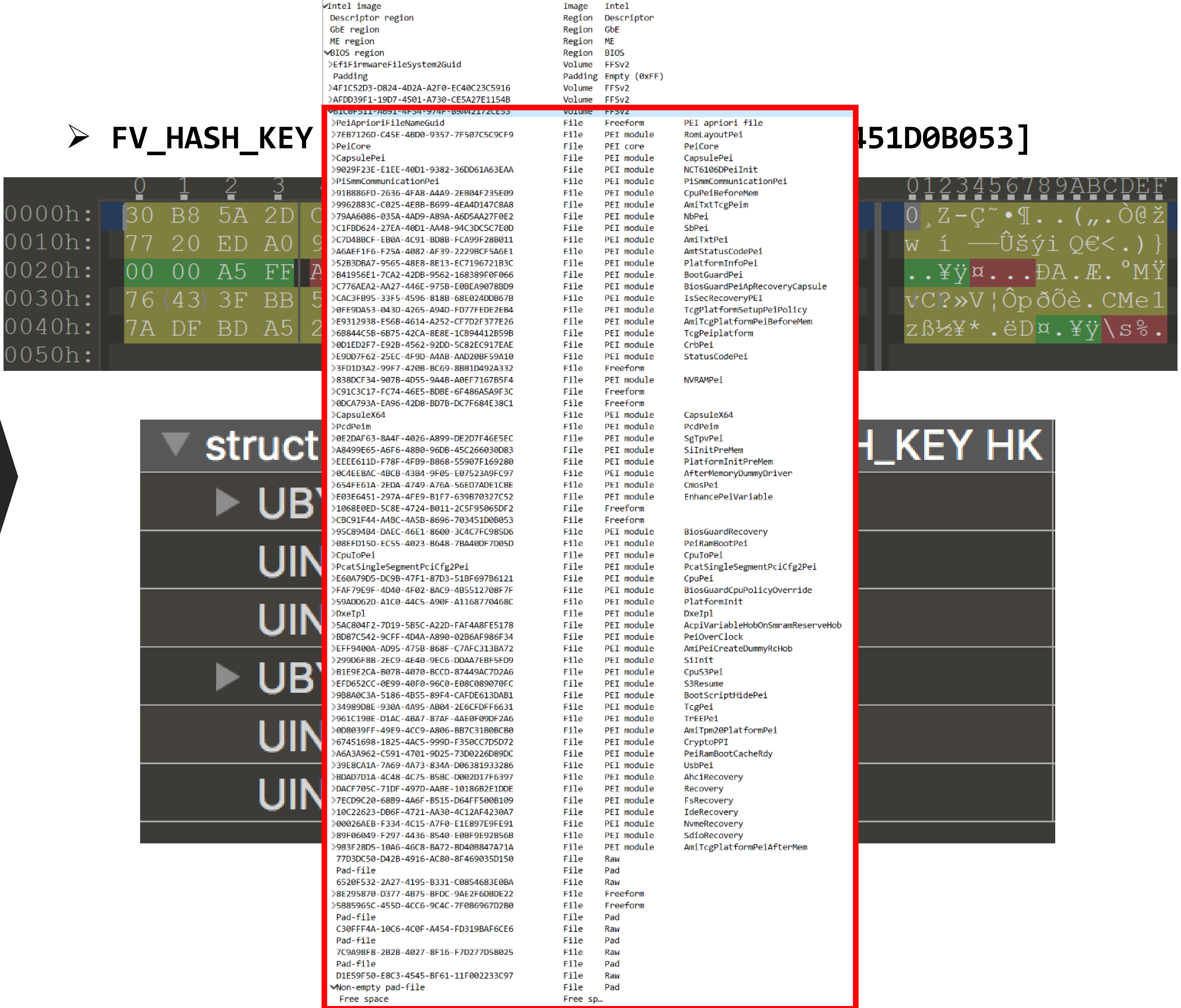
```
        0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F   0123456789ABCDEF
0000h: 30 B8 5A 2D C7 98 95 B6 05 0C 28 84 0C D2 40 9E   0¸Z-Ç˜•¶..(„.Ò@ž
0010h: 77 20 ED A0 97 97 DB 9A FD 69 51 80 3C 18 29 7D   w í ——Ûšýi Q€<.)}
0020h: 00 00 A5 FF A4 00 00 00 D0 41 10 C6 02 B0 4D 9F   ..¥ÿ¤...ÐA.Æ.°MŸ
0030h: 76 43 3F BB 56 A6 D4 70 F0 D5 E8 0E 43 4D 65 31   vC?»V¦ÔpðÕè.CMe1
0040h: 7A DF BD A5 2A 03 EB 44 A4 10 A5 FF 5C 73 25 00   zß½¥*.ëD¤.¥ÿ\s%.
0050h:
```



```
▼ struct BOOT_GUARD_MAIN_HASH_KEY HK
    ▶ UBYTE HashKey0[32]
      UINT32 SegmentBase0
      UINT32 SegmentSize0
    ▶ UBYTE HashKey1[32]
      UINT32 SegmentBase1
      UINT32 SegmentSize1
```

Boot Guard: PEI FV_HASH

➢ FV_HASH_KEY 451D0B053]



```
0000h: 30 B8 5A 2D C
0010h: 77 20 ED A0 9
0020h: 00 00 A5 FF A
0030h: 76 43 3F BB 5
0040h: 7A DF BD A5 2
0050h:
```

```
⌄Intel image                              Image    Intel
  Descriptor region                       Region   Descriptor
  GbE region                              Region   GbE
  ME region                               Region   ME
⌄BIOS region                              Region   BIOS
  >EfiFirmwareFileSystem2Guid             Volume   FFSv2
   Padding                                Padding  Empty (0xFF)
  >4F1C52D3-D824-4D2A-A2F0-EC40C23C5916   Volume   FFSv2
  >AFDD39F1-19D7-4501-A730-CE5A27E1154B   Volume   FFSv2
  ⌄61C0F511-A691-4F54-974F-B9A42172CE53   Volume   FFSv2
   >PeiAprioriFileNameGuid                File     Freeform     PEI apriori file
   >7EB7126D-C45E-4BD0-9357-7F507C5C9CF9  File     PEI module   RomLayoutPei
   >PeiCore                               File     PEI core     PeiCore
   >CapsulePei                            File     PEI module   CapsulePei
   >9029F23E-E1EE-40D1-9382-36DD61A63EAA  File     PEI module   NCT6106DPeiInit
   >PiSmmCommunicationPei                 File     PEI module   PiSmmCommunicationPei
   >91B886FD-2636-4FA8-A4A9-2EB04F235E09  File     PEI module   CpuPeiBeforeMem
   >9962883C-C025-4EBB-B699-4EA4D147C8A8  File     PEI module   AmiTxtTcgPeim
   >79AA6086-035A-4AD9-A89A-A6D5AA27F0E2  File     PEI module   NbPei
   >C1FBD624-27EA-40D1-AA48-94C3DC5C7E0D  File     PEI module   SbPei
   >C7D4BBCF-EB0A-4C91-BD8B-FCA99F28B011  File     PEI module   AmiTxtPei
   >A6AEF1F6-F25A-4082-AF39-2229BCF5A6E1  File     PEI module   AmtStatusCodePei
   >52B3DBA7-9565-48E8-8E13-EC7196721B3C  File     PEI module   PlatformInfoPei
   >B41956E1-7CA2-42DB-9562-168389F0F066  File     PEI module   BootGuardPei
   >C776AEA2-AA27-446E-975B-E0BEA9078BD9  File     PEI module   BiosGuardPeiApRecoveryCapsule
   >CAC3FB95-33F5-4596-818B-68E024DDB67B  File     PEI module   IsSecRecoveryPEI
   >0FE9DA53-043D-4265-A94D-FD77FEDE2EB4  File     PEI module   TcgPlatformSetupPeiPolicy
   >E9312938-E56B-4614-A252-CF7D2F377E26  File     PEI module   AmiTcgPlatformPeiBeforeMem
   >6B844C5B-6B75-42CA-8E8E-1CB94412B59B  File     PEI module   TcgPeiplatform
   >0D1ED2F7-E92B-4562-92DD-5C82EC917EAE  File     PEI module   CrbPei
   >E9DD7F62-25EC-4F9D-A4AB-AAD20BF59A10  File     PEI module   StatusCodePei
   >3FD1D3A2-99F7-420B-BC69-8BB1D492A332  File     Freeform
   >838DCF34-907B-4D55-9A4B-A0EF7167B5F4  File     PEI module   NVRAMPei
   >C91C3C17-FC74-46E5-BDBE-6F486A5A9F3C  File     Freeform
   >0DCA793A-EA96-42D8-BD7B-DC7F684E38C1  File     Freeform
   >CapsuleX64                            File     PEI module   CapsuleX64
   >PcdPeim                               File     PEI module   PcdPeim
   >0E2DAF63-8A4F-4026-A899-DE2D7F46E5EC  File     PEI module   SgTpvPei
   >A8499E65-A6F6-48B0-96DB-45C266030D83  File     PEI module   SiInitPreMem
   >EEEE611D-F78F-4FB9-B868-55907F169280  File     PEI module   PlatformInitPreMem
   >0C4EE8AC-4BCB-43B4-9F05-E07523A9FC97  File     PEI module   AfterMemoryDummyDriver
   >654FE61A-2EDA-4749-A76A-56ED7ADE1CBE  File     PEI module   CmosPei
   >E03E6451-297A-4FE9-B1F7-639B70327C52  File     PEI module   EnhancePeiVariable
   >1068E0ED-5C8E-4724-B011-2C5F95065DF2  File     Freeform
   >CBC91F44-A4BC-4A5B-8696-703451D0B053  File     Freeform
   >95C894B4-DAEC-46E1-8600-3C4C7FC985D6  File     PEI module   BiosGuardRecovery
   >08EFD15D-EC55-4023-B648-7BA40DF7D05D  File     PEI module   PeiRamBootPei
   >CpuToPei                              File     PEI module   CpuIoPei
   >PcatSingleSegmentPciCfg2Pei           File     PEI module   PcatSingleSegmentPciCfg2Pei
   >E60A79D5-DC9B-47F1-87D3-51BF697B6121  File     PEI module   CpuPei
   >FAF79E9F-4D40-4F02-8AC9-4B5512708F7F  File     PEI module   BiosGuardCpuPolicyOverride
   >59ADD62D-A1C0-44C5-A90F-A1168770468C  File     PEI module   PlatformInit
   >DxeIpl                                File     PEI module   DxeIpl
   >5AC804F2-7D19-5B5C-A22D-FAF4A8FE5178  File     PEI module   AcpiVariableHobOnSmramReserveHob
   >BD87C542-9CFF-4D4A-A890-02B6AF986F34  File     PEI module   PeiOverClock
   >EFF9400A-AD95-475B-868F-C7AFC313BA72  File     PEI module   AmiPeiCreateDummyRcHob
   >299D6F8B-2EC9-4E40-9EC6-DDAA7EBF5FD9  File     PEI module   SiInit
   >B1E9E2CA-B078-4070-BCCD-87449AC7D2A6  File     PEI module   CpuS3Pei
   >EFD652CC-0E99-40F0-96C0-E08C089070FC  File     PEI module   S3Resume
   >9B8A0C3A-5186-4B55-89F4-CAFDE613DAB1  File     PEI module   BootScriptHidePei
   >34989D8E-930A-4A95-AB04-2E6CFDFF6631  File     PEI module   TcgPei
   >961C19BE-D1AC-4BA7-87AF-4AE0F09DF2A6  File     PEI module   TrEEPei
   >0D8039FF-49E9-4CC9-A806-BB7C31B0BCB0  File     PEI module   AmiTpm20PlatformPei
   >67451698-1825-4AC5-999D-F350CC7D5D72  File     PEI module   CryptoPPI
   >A6A3A962-C591-4701-9D25-73D0226D89DC  File     PEI module   PeiRamBootCacheRdy
   >39E8CA1A-7A69-4A73-834A-D06381933286  File     PEI module   UsbPei
   >BDAD7D1A-4C48-4C75-B5BC-D002D17F6397  File     PEI module   AhciRecovery
   >DACF705C-71DF-497D-AABE-10186B2E1DDE  File     PEI module   Recovery
   >7ECD9C20-68B9-4A6F-B515-D64FF500B109  File     PEI module   FsRecovery
   >10C22623-DB6F-4721-AA30-4C12AF4230A7  File     PEI module   IdeRecovery
   >00026AEB-F334-4C15-A7F0-E1E897E9FE91  File     PEI module   NvmeRecovery
   >89F06049-F297-4436-8540-E0BF9E92B56B  File     PEI module   SdioRecovery
   >9B3F28D5-10A6-46C8-BA72-BD40B847A71A  File     PEI module   AmiTcgPlatformPeiAfterMem
    77D3DC50-D42B-4916-AC80-8F469035D150  File     Raw
    Pad-file                              File     Pad
    6520F532-2A27-4195-B331-C0854683E0BA  File     Raw
   >8E295870-D377-4B75-BFDC-9AE2F6DBDE22  File     Freeform
   >5B85965C-455D-4CC6-9C4C-7F086967D2B0  File     Freeform
    Pad-file                              File     Pad
    C30FFF4A-10C6-4C0F-A454-FD319BAF6CE6  File     Raw
    Pad-file                              File     Pad
    7C9A98F8-2B2B-4027-8F16-F7D277D58025  File     Raw
    Pad-file                              File     Pad
    D1E59F50-E8C3-4545-BF61-11F002233C97  File     Raw
   ⌄Non-empty pad-file                    File     Pad
     Free space                           Free sp…
```

VerifyFwBootGuard SMM Validation Flow
(Intel ME communications over HECI)

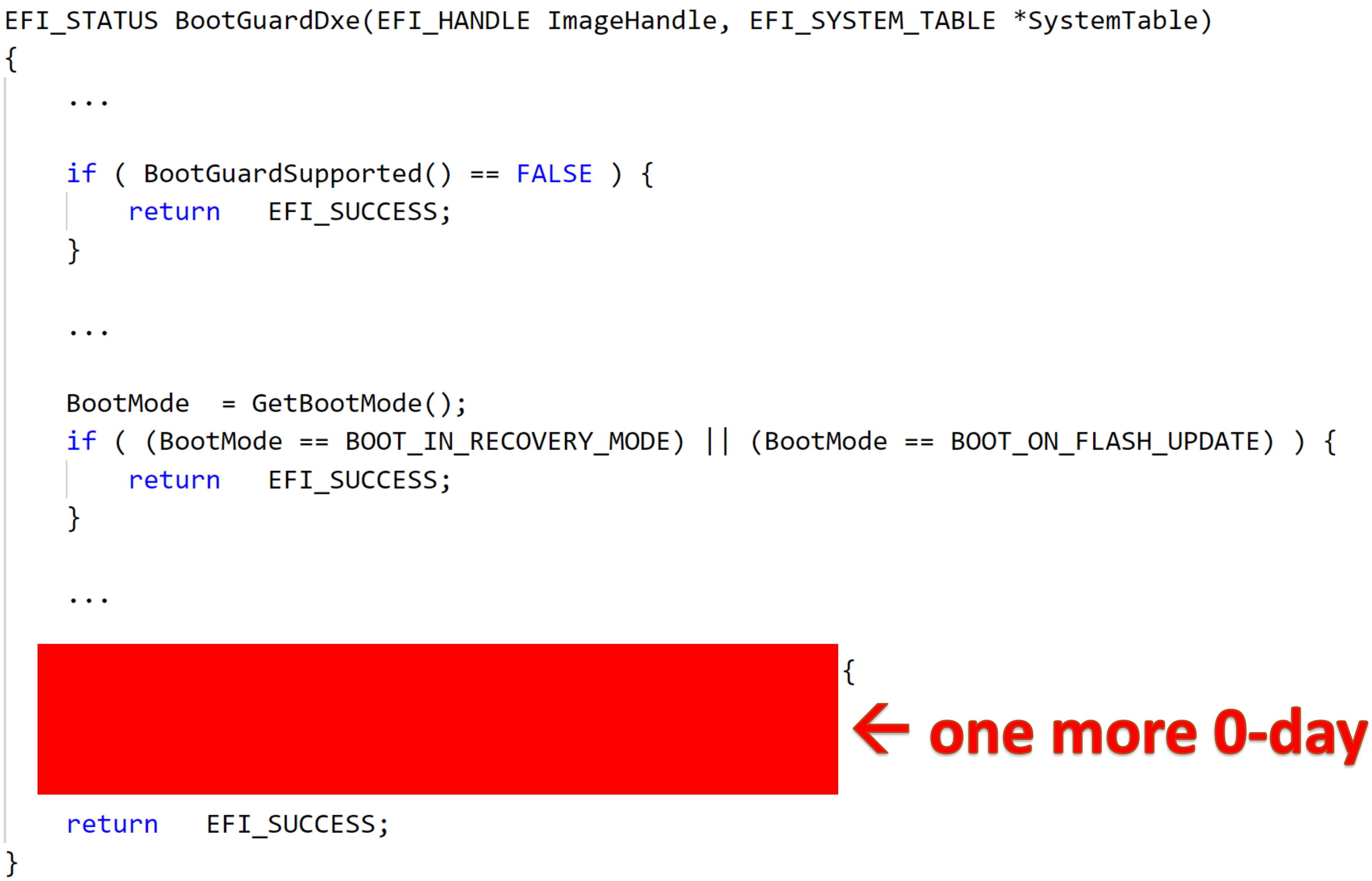
- Find and Verify ACM
  - Verify ACM SVN

- Find and Verify Key Manifest (KM)
  - Verify KM SVN

- Find and Verify Boot Policy Manifest (BPM)
  - Verify BPM SVN

- If something wrong return EFI_SECURITY_VIOLATION

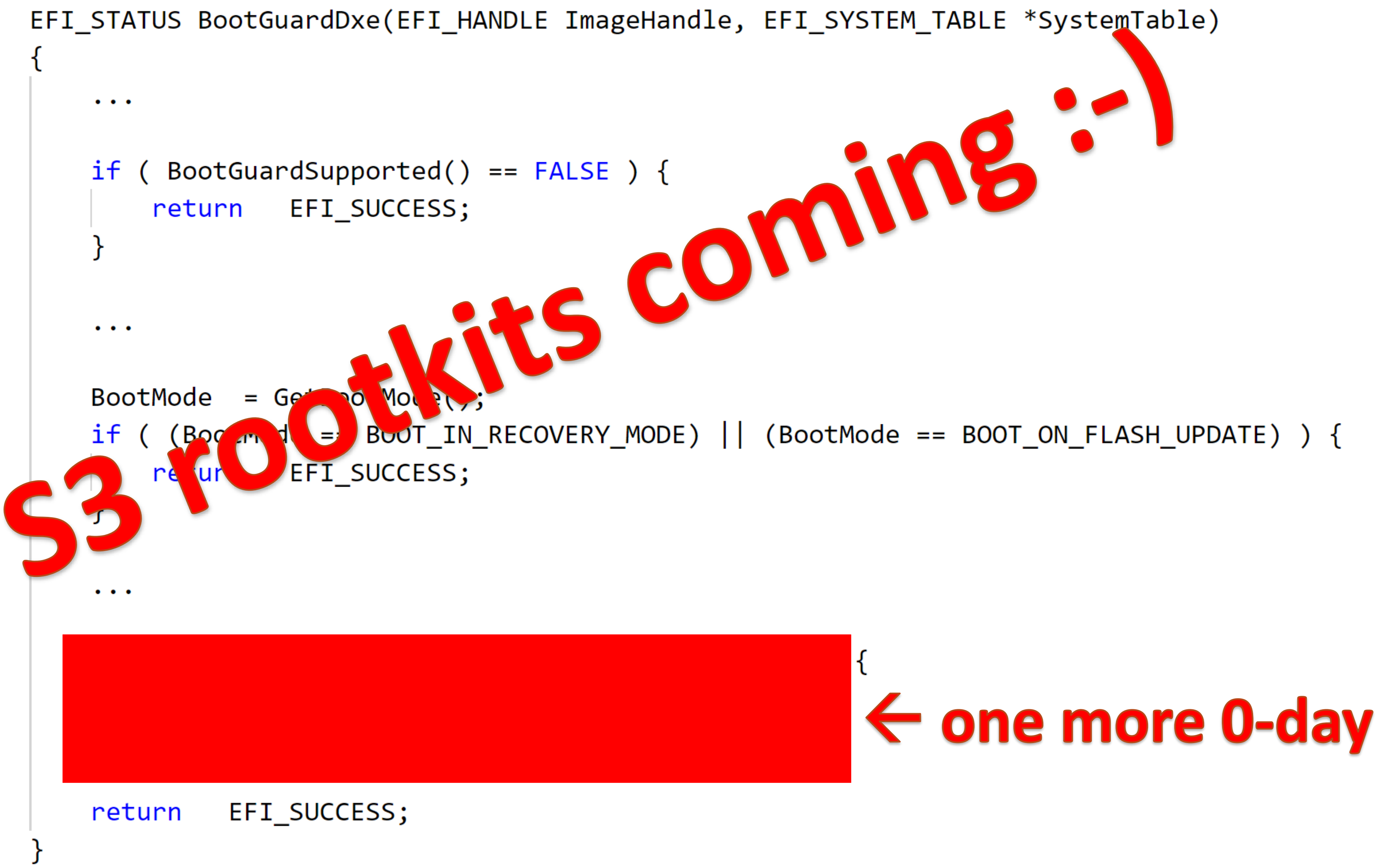
BootGuardDxe Validation Flow



```
EFI_STATUS BootGuardDxe(EFI_HANDLE ImageHandle, EFI_SYSTEM_TABLE *SystemTable)
{
    ...

    if ( BootGuardSupported() == FALSE ) {
        return   EFI_SUCCESS;
    }

    ...

    BootMode   = GetBootMode();
    if ( (BootMode == BOOT_IN_RECOVERY_MODE) || (BootMode == BOOT_ON_FLASH_UPDATE) ) {
        return   EFI_SUCCESS;
    }

    ...

    [redacted] {

    return   EFI_SUCCESS;
}
```

← one more 0-day bug?

BootGuardDxe Validation Flow

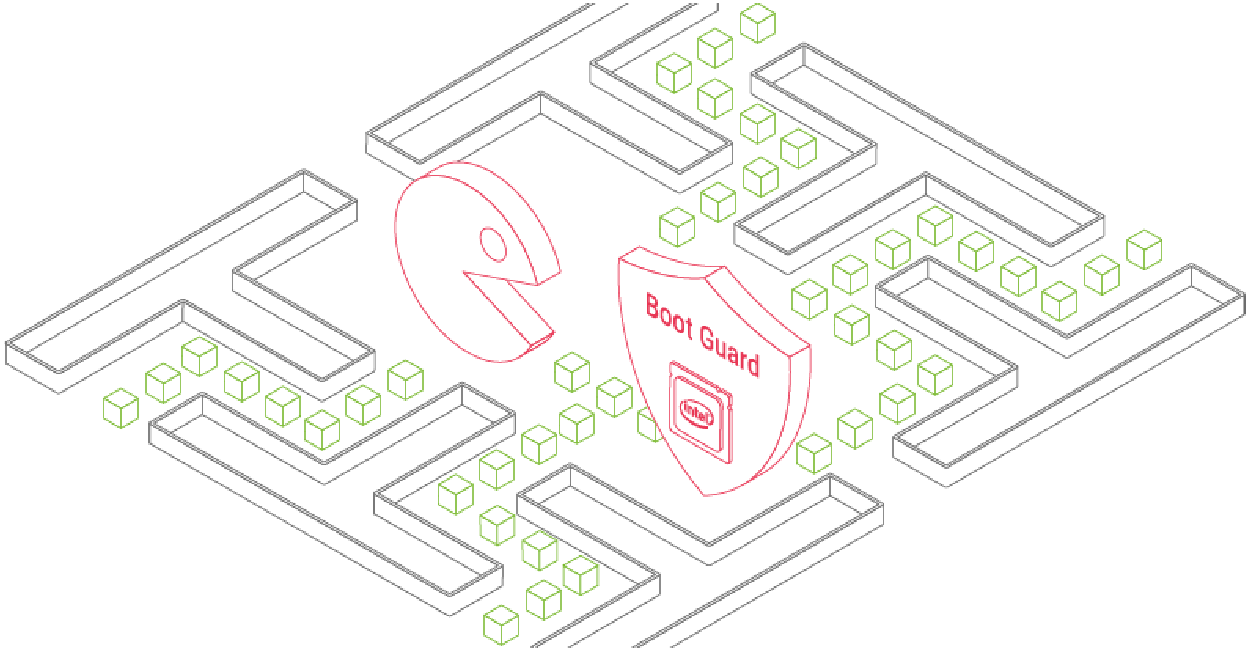


```
EFI_STATUS BootGuardDxe(EFI_HANDLE ImageHandle, EFI_SYSTEM_TABLE *SystemTable)
{
    ...

    if ( BootGuardSupported() == FALSE ) {
        return   EFI_SUCCESS;
    }

    ...

    BootMode  = GetBootMode();
    if ( (BootMode == BOOT_IN_RECOVERY_MODE) || (BootMode == BOOT_ON_FLASH_UPDATE) ) {
        return   EFI_SUCCESS;
    }

    ...

    [redacted] {

    return   EFI_SUCCESS;
}
```

S3 rootkits coming :-)

← one more 0-day bug?

BootGuardDxe Validation Flow

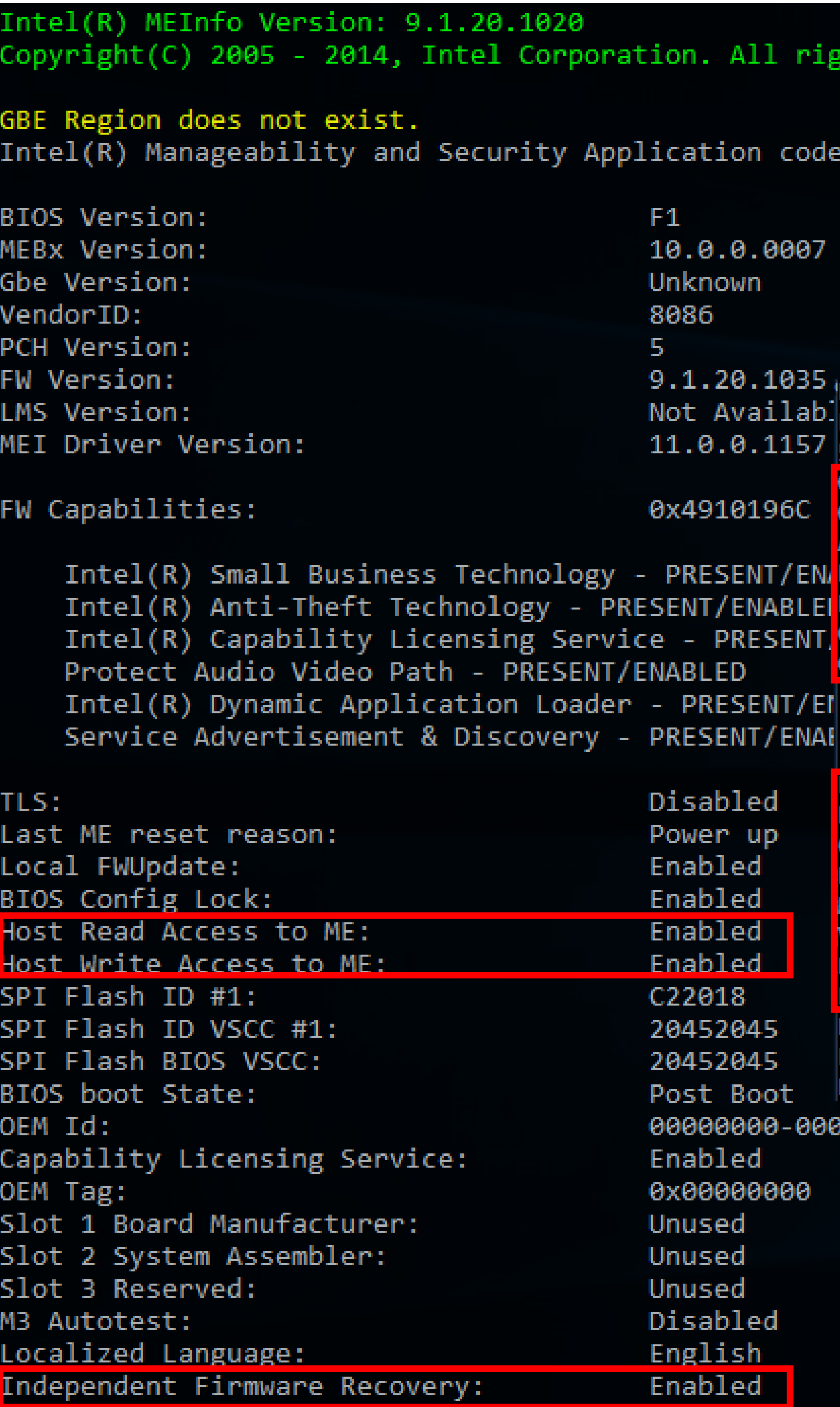


- https://embedi.com/blog/bypassing-intel-boot-guard
- Intel NUC Boot Guard Bypass CVE-2017-5722 kudos to Alex Ermolov
- https://security-center.intel.com/advisory.aspx?intelid=INTEL-SA-00084

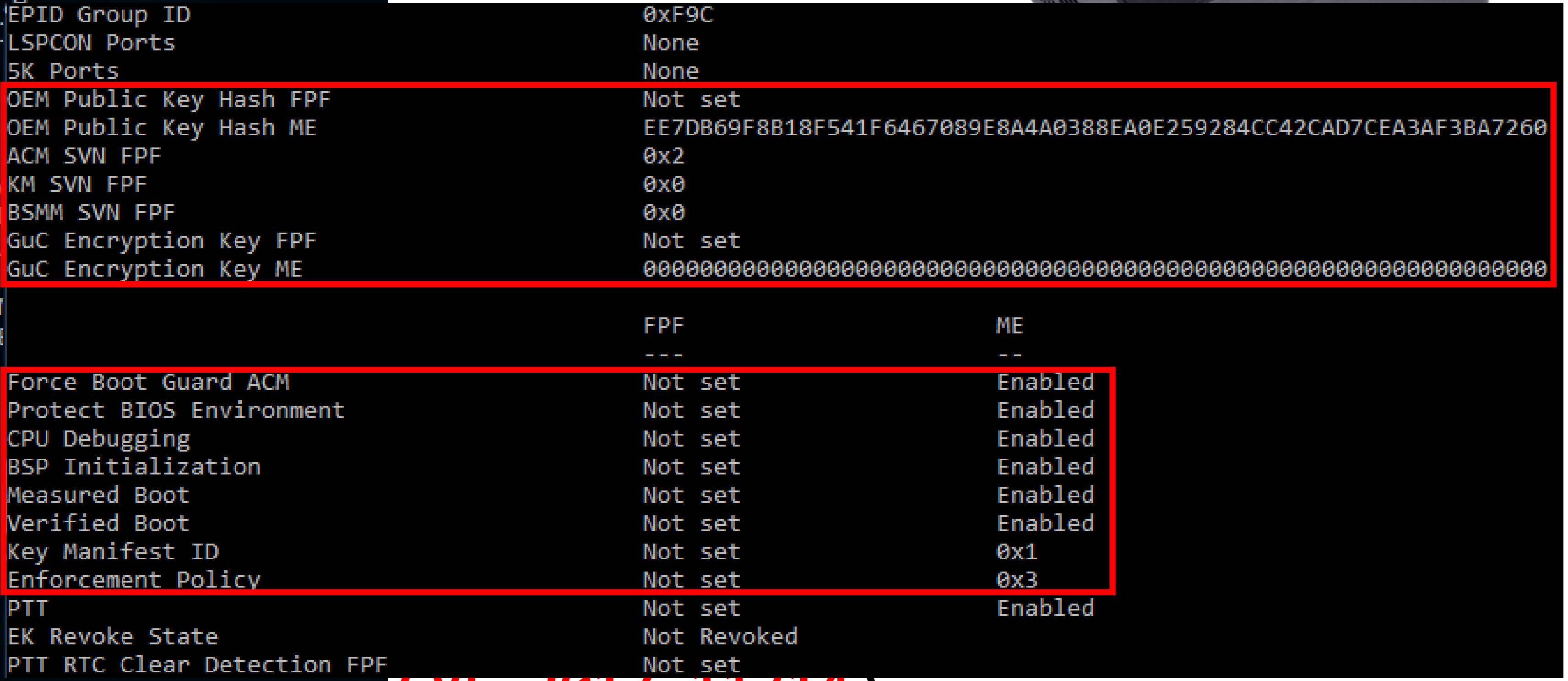
Target Platform

- ➢ Gigabyte (GB-BSi7HA-6500)
  - ✓ Intel 6th generation Core i7 CPU (Skylake) with vPro
  - ✓ Intel Boot Guard – ENABLED
  - ✓ Intel BIOS Guard – NOT ENABLED

- ➢ Vulnerabilities
  - ✓ Host Write/Read Access to ME (CVE-2017-11314)
  - ✓ Intel Boot Guard Configuration not Locked (CVE-2017-11313)



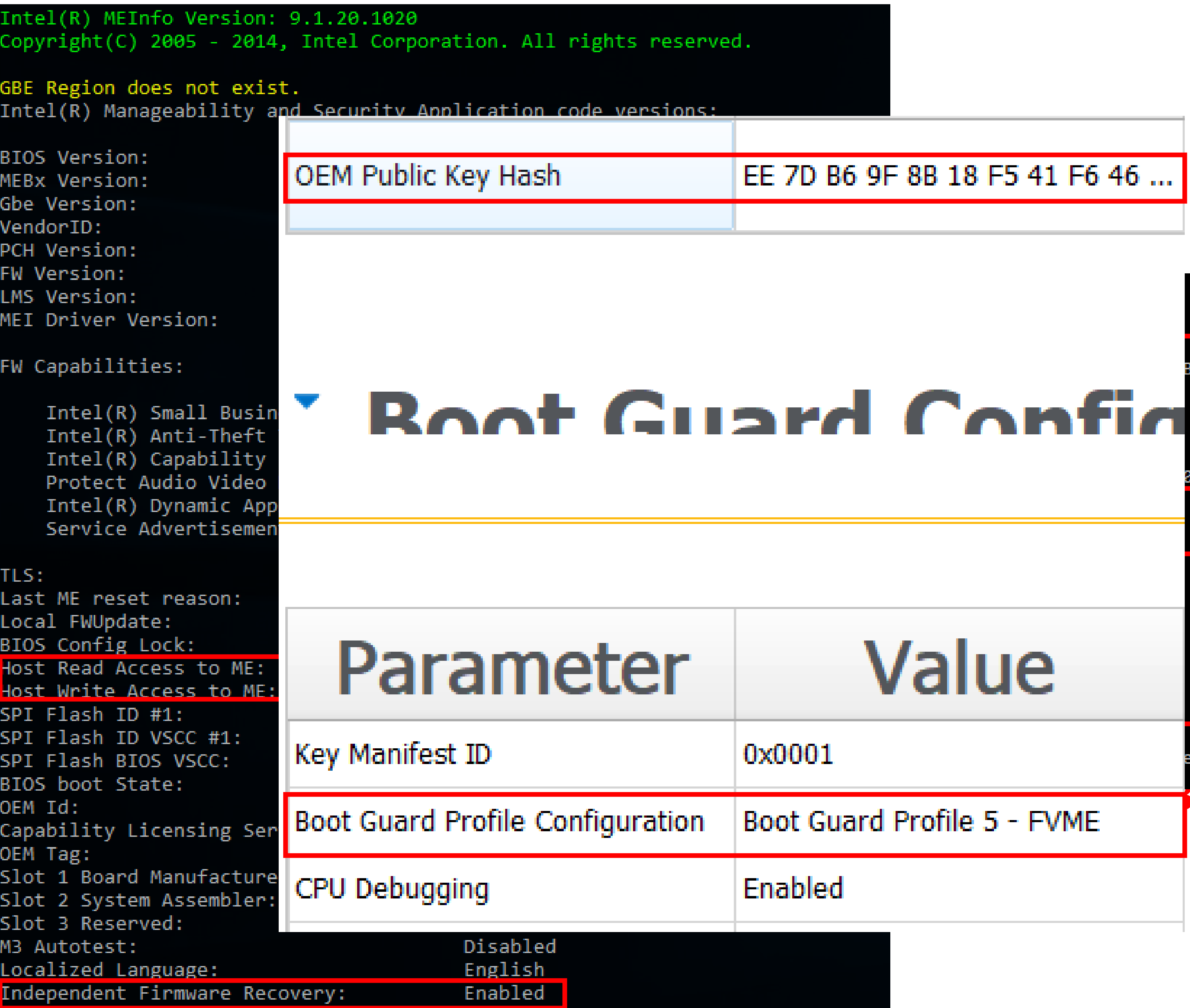
```
Intel(R) MEInfo Version: 9.1.20.1020
Copyright(C) 2005 - 2014, Intel Corporation. All rights reserved.

GBE Region does not exist.
Intel(R) Manageability and Security Application code versions:

BIOS Version:                           F1
MEBx Version:                           10.0.0.0007
Gbe Version:                            Unknown
VendorID:                               8086
PCH Version:                            5
FW Version:                             9.1.20.1035 H
LMS Version:                            Not Availab
MEI Driver Version:                     11.0.0.1157

FW Capabilities:                        0x4910196C

    Intel(R) Small Business Technology - PRESENT/ENA
    Intel(R) Anti-Theft Technology - PRESENT/ENABLE
    Intel(R) Capability Licensing Service - PRESENT
    Protect Audio Video Path - PRESENT/ENABLED
    Intel(R) Dynamic Application Loader - PRESENT/E
    Service Advertisement & Discovery - PRESENT/ENAB

TLS:                                    Disabled
Last ME reset reason:                   Power up
Local FWUpdate:                         Enabled
BIOS Config Lock:                       Enabled
Host Read Access to ME:                 Enabled
Host Write Access to ME:                Enabled
SPI Flash ID #1:                        C22018
SPI Flash ID VSCC #1:                   20452045
SPI Flash BIOS VSCC:                    20452045
BIOS boot State:                        Post Boot
OEM Id:                                 00000000-0000-0000-0000-000000000000
Capability Licensing Service:           Enabled
OEM Tag:                                0x00000000
Slot 1 Board Manufacturer:              Unused
Slot 2 System Assembler:                Unused
Slot 3 Reserved:                        Unused
M3 Autotest:                            Disabled
Localized Language:                     English
Independent Firmware Recovery:          Enabled
```



```
EPID Group ID                           0xF9C
LSPCON Ports                            None
5K Ports                                None
OEM Public Key Hash FPF                 Not set
OEM Public Key Hash ME                  EE7DB69F8B18F541F6467089E8A4A0388EA0E259284CC42CAD7CEA3AF3BA7260
ACM SVN FPF                             0x2
KM SVN FPF                              0x0
BSMM SVN FPF                            0x0
GuC Encryption Key FPF                  Not set
GuC Encryption Key ME                   0000000000000000000000000000000000000000000000000000000000000000

                                        FPF                     ME
                                        ---                     --
Force Boot Guard ACM                    Not set                 Enabled
Protect BIOS Environment                Not set                 Enabled
CPU Debugging                           Not set                 Enabled
BSP Initialization                      Not set                 Enabled
Measured Boot                           Not set                 Enabled
Verified Boot                           Not set                 Enabled
Key Manifest ID                         Not set                 0x1
Enforcement Policy                      Not set                 0x3
PTT                                     Not set                 Enabled
EK Revoke State                         Not Revoked
PTT RTC Clear Detection FPF             Not set
```

CVE-2017-11314)

not Locked (CVE-2017-11313)

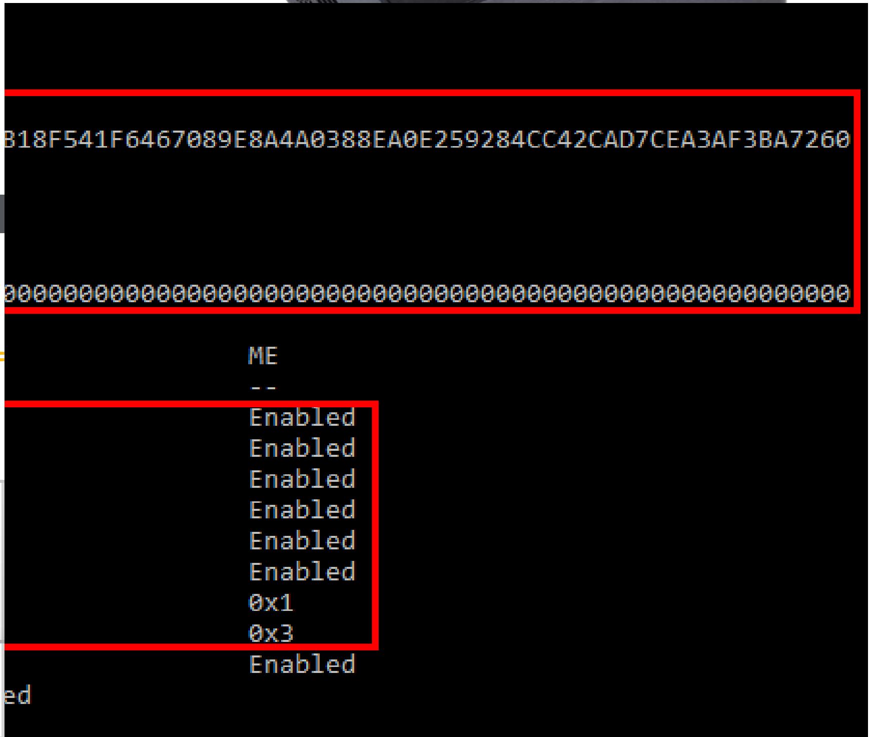


```
Intel(R) MEInfo Version: 9.1.20.1020
Copyright(C) 2005 - 2014, Intel Corporation. All rights reserved.

GBE Region does not exist.
Intel(R) Manageability and Security Application code versions:

BIOS Version:
MEBx Version:
Gbe Version:
VendorID:
PCH Version:
FW Version:
LMS Version:
MEI Driver Version:

FW Capabilities:

    Intel(R) Small Busin
    Intel(R) Anti-Theft
    Intel(R) Capability
    Protect Audio Video
    Intel(R) Dynamic App
    Service Advertisemen

TLS:
Last ME reset reason:
Local FWUpdate:
BIOS Config Lock:
Host Read Access to ME:
Host Write Access to ME:
SPI Flash ID #1:
SPI Flash ID VSCC #1:
SPI Flash BIOS VSCC:
BIOS boot State:
OEM Id:
Capability Licensing Ser
OEM Tag:
Slot 1 Board Manufacture
Slot 2 System Assembler:
Slot 3 Reserved:
M3 Autotest:                                Disabled
Localized Language:                         English
Independent Firmware Recovery:              Enabled
```

OEM Public Key Hash	EE 7D B6 9F 8B 18 F5 41 F6 46 ...

Boot Guard Config

Parameter	Value
Key Manifest ID	0x0001
Boot Guard Profile Configuration	Boot Guard Profile 5 - FVME
CPU Debugging	Enabled

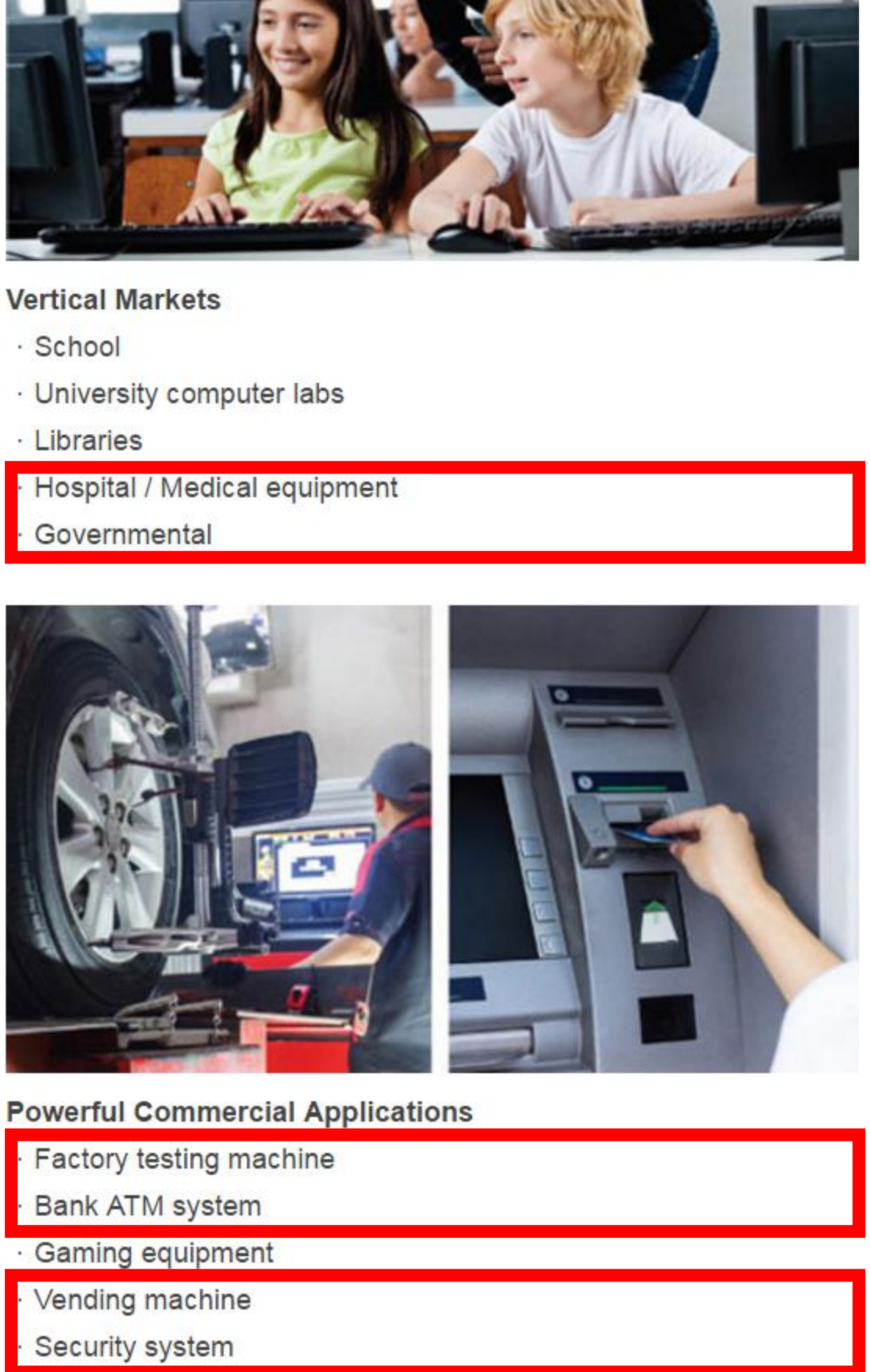


```
B18F541F6467089E8A4A0388EA0E259284CC42CAD7CEA3AF3BA7260

0000000000000000000000000000000000000000000000000000000

                 ME
                 --
                 Enabled
                 Enabled
                 Enabled
                 Enabled
                 Enabled
                 Enabled
                 0x1
                 0x3
                 Enabled
ed
```

314)

(CVE-2017-11313)

copy from Gigabyte official website



Vertical Markets

- School
- University computer labs
- Libraries
- Hospital / Medical equipment
- Governmental

Powerful Commercial Applications

- Factory testing machine
- Bank ATM system
- Gaming equipment
- Vending machine
- Security system

Five steps to bypass Boot Guard

1) **Modify UEFI firmware update image with rootkit/implant**

   or

   Disable Intel Boot Guard

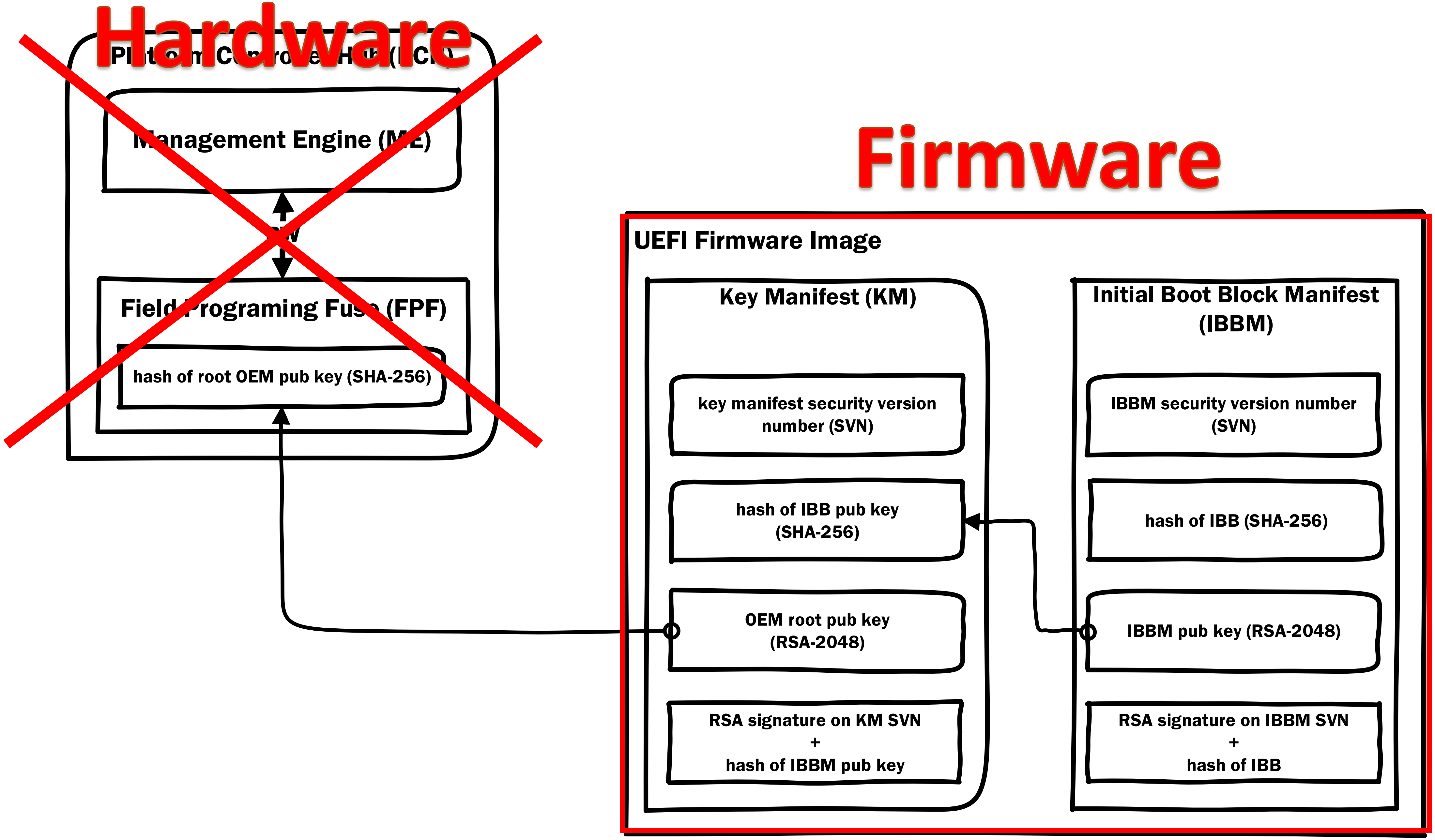
2) **Initial Boot Block (IBB)**
   - ✓ Recalculate signature on 2048-bit RSA key pair for IBB
   - ✓ Modify IBB manifest inside UEFI firmware update file
   - ✓ Recalculate signature for IBB manifest with different 2048-bit RSA key pair

3) **Modify Root Key manifest**
   - ✓ Recalculate SHA256 hash of the public key from Root Key Manifest

4) **Modify ME region with new key (CVE-2017-11314)**
   - ✓ Modify Boot Guard configuration with active verified boot policy

5) **Lock Boot Guard configuration with by FPF (CVE-2017-11313)**

Boot Guard: Chain of Trust



Hardware

Platform Controller Hub (PCH)

Management Engine (ME)

RW

Field Programing Fuse (FPF)

hash of root OEM pub key (SHA-256)

Firmware

UEFI Firmware Image

Key Manifest (KM)

key manifest security version number (SVN)

hash of IBB pub key (SHA-256)

OEM root pub key (RSA-2048)

RSA signature on KM SVN + hash of IBBM pub key

Initial Boot Block Manifest (IBBM)

IBBM security version number (SVN)

hash of IBB (SHA-256)

IBBM pub key (RSA-2048)

RSA signature on IBBM SVN + hash of IBB

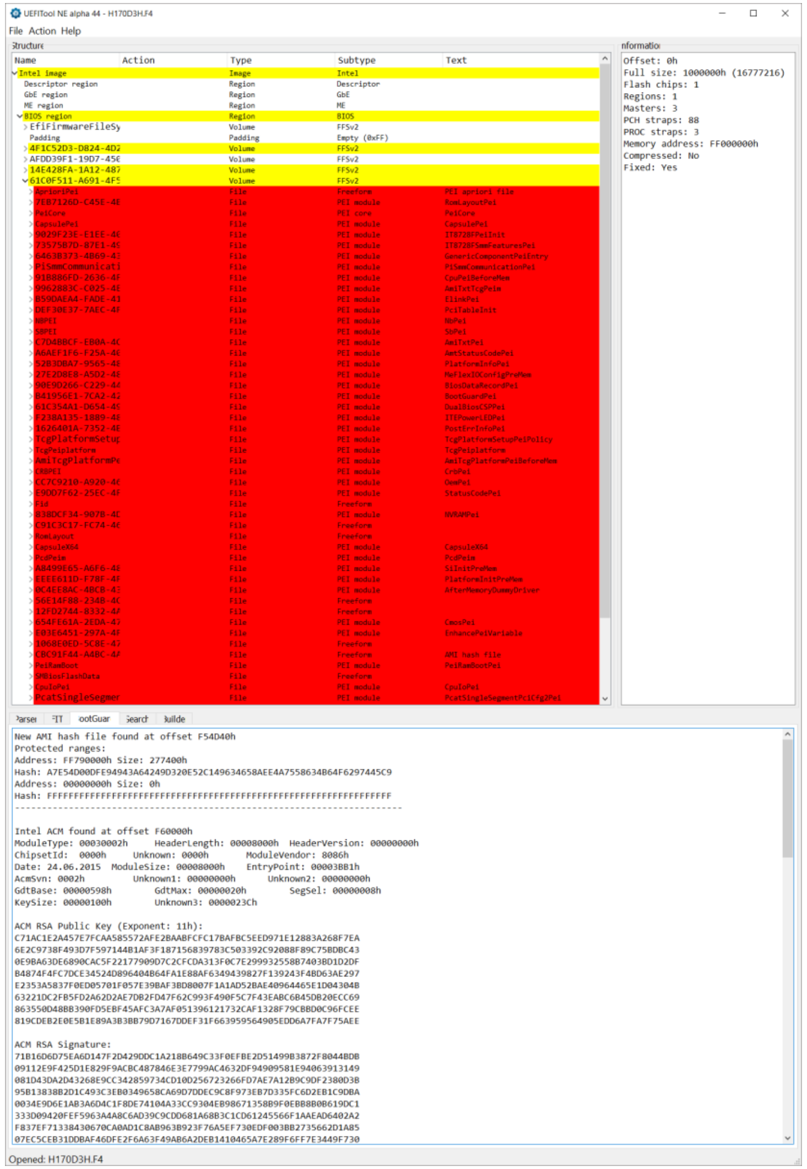
Intel Statement

“Intel provides a 6th and 7th generation Core Platforms Secure Configuration Specification, which covers how to securely configure the platform. Additionally, Intel makes available a utility that our ecosystem partners can use to test and identify potential configuration issues.”

Gigabyte Statement

“For FPF issue, we discuss with internal the BIOS don’t need any update but we will add ME Lock tool to our production process soon, the new production ship will include ME Lock.”

UEFITool for Intel Boot Guard visual validation



Name	Action	Type	Subtype	Text
Intel image		Image	Intel	
Descriptor region		Region	Descriptor	
GbE region		Region	GbE	
ME region		Region	ME	
BIOS region		Region	BIOS	
EfiFirmwareFileSy		Volume	FFSv2	
Padding		Padding	Empty (0xFF)	
4F1C52D3-D824-4D2		Volume	FFSv2	
AFDD39F1-19D7-456		Volume	FFSv2	
14E428FA-1A12-487		Volume	FFSv2	
61C0F511-A691-4F5		Volume	FFSv2	
AprioriPei		File	Freeform	PEI apriori file
7EB7126D-C45E-4E		File	PEI module	RomLayoutPei
PeiCore		File	PEI core	PeiCore
CapsulePei		File	PEI module	CapsulePei
9029F23E-E1EE-4E		File	PEI module	IT8728FPeiInit
73575B7D-87E1-49		File	PEI module	IT8728FSmmFeaturesPei
6463B373-4B69-43		File	PEI module	GenericComponentPeiEntry
PiSmmCommunicati		File	PEI module	PiSmmCommunicationPei
91B886FD-2636-4F		File	PEI module	CpuPeiBeforeMem
9962883C-C025-4E		File	PEI module	AmiTxtTcgPeim
B59DAEA4-FADE-41		File	PEI module	ElinkPei
DEF30E37-7AEC-4F		File	PEI module	PciTableInit
NBPEI		File	PEI module	NbPei
SBPEI		File	PEI module	SbPei
C7D4BBCF-EB0A-4C		File	PEI module	AmiTxtPei
A6AEF1F6-F25A-4E		File	PEI module	AmtStatusCodePei
52B3DBA7-9565-48		File	PEI module	PlatformInfoPei
27E2D8E8-A5D2-48		File	PEI module	MeFlexIOConfigPreMem
90E9D266-C229-44		File	PEI module	BiosDataRecordPei
B41956E1-7CA2-42		File	PEI module	BootGuardPei
61C354A1-D654-49		File	PEI module	DualBiosCSPPei
F238A135-1889-48		File	PEI module	ITEPowerLEDPei
1626401A-7352-4E		File	PEI module	PostErrInfoPei
TcgPlatformSetup		File	PEI module	TcgPlatformSetupPeiPolicy
TcgPeiplatform		File	PEI module	TcgPeiplatform
AmiTcgPlatformPe		File	PEI module	AmiTcgPlatformPeiBeforeMem
CRBPEI		File	PEI module	CrbPei
CC7C9210-A920-46		File	PEI module	OemPei
E9DD7F62-25EC-4F		File	PEI module	StatusCodePei
Fid		File	Freeform	
838DCF34-907B-4D		File	PEI module	NVRAMPei
C91C3C17-FC74-46		File	Freeform	
RomLayout		File	Freeform	
CapsuleX64		File	PEI module	CapsuleX64
PcdPeim		File	PEI module	PcdPeim
A8499E65-A6F6-48		File	PEI module	SiInitPreMem
EEEE611D-F78F-4F		File	PEI module	PlatformInitPreMem
0C4EE8AC-4BCB-43		File	PEI module	AfterMemoryDummyDriver
56E14F88-234B-4C		File	Freeform	
12FD2744-8332-4A		File	Freeform	
654FE61A-2EDA-47		File	PEI module	CmosPei
E03E6451-297A-4F		File	PEI module	EnhancePeiVariable
1068E0ED-5C8E-47		File	Freeform	
CBC91F44-A4BC-4A		File	Freeform	AMI hash file
PeiRamBoot		File	PEI module	PeiRamBootPei
SMBiosFlashData		File	Freeform	
CpuIoPei		File	PEI module	CpuIoPei
PcatSingleSegmer		File	PEI module	PcatSingleSegmentPciCfg2Pei

```
Offset: 0h
Full size: 1000000h (16777216)
Flash chips: 1
Regions: 1
Masters: 3
PCH straps: 88
PROC straps: 3
Memory address: FF000000h
Compressed: No
Fixed: Yes
```

```
New AMI hash file found at offset F54D40h
Protected ranges:
Address: FF790000h Size: 277400h
Hash: A7E54D00DFE94943A64249D320E52C149634658AEE4A7558634B64F6297445C9
Address: 00000000h Size: 0h
Hash: FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
------------------------------------------------------------------------

Intel ACM found at offset F60000h
ModuleType: 00030002h     HeaderLength: 00008000h  HeaderVersion: 00000000h
ChipsetId:  0000h     Unknown: 0000h       ModuleVendor: 8086h
Date: 24.06.2015  ModuleSize: 00008000h    EntryPoint: 00003BB1h
AcmSvn: 0002h         Unknown1: 00000000h      Unknown2: 00000000h
GdtBase: 00000598h       GdtMax: 00000020h       SegSel: 00000008h
KeySize: 00000100h       Unknown3: 0000023Ch

ACM RSA Public Key (Exponent: 11h):
C71AC1E2A457E7FCAA585572AFE2BAABFCFC17BAFBC5EED971E12883A268F7EA
6E2C9738F493D7F597144B1AF3F187156839783C503392C92088F89C75BDBC43
0E9BA63DE6890CAC5F22177909D7C2CFCDA313F0C7E299932558B7403BD1D2DF
B4874F4FC7DCE34524D896404B64FA1E88AF6349439827F139243F4BD63AE297
E2353A5837F0ED05701F057E39BAF3BD8007F1A1AD52BAE40964465E1D04304B
63221DC2FB5FD2A62D2AE7DB2FD47F62C993F490F5C7F43EABC6B45DB20ECC69
863550D48BB390FD5EBF45AFC3A7AF051396121732CAF1328F79CBBD0C96FCEE
819CDEB2E0E5B1E89A3B3BB79D7167DDEF31F663959564905EDD6A7FA7F75AEE

ACM RSA Signature:
71B16D6D75EA6D147F2D429DDC1A218B649C33F0EFBE2D51499B3872F8044BDB
09112E9F425D1E829F9ACBC487846E3E7799AC4632DF94909581E94063913149
081D43DA2D43268E9CC342859734CD10D256723266FD7AE7A12B9C9DF2380D3B
95B13838B2D1C493C3EB0349658CA69D7DDEC9C8F973EB7D335FC6D2EB1C9DBA
0034E9D6E1AB3A6D4C1F8DE74104A33CC9304EB98671358B9F0EBB8B0B619DC1
333D09420FEF5963A4A8C6AD39C9CDD681A68B3C1CD61245566F1AAEAD6402A2
F837EF71338430670CA0AD1C8AB963B923F76A5EF730EDF003BB2735662D1A85
07EC5CEB31DDBAF46DFE2F6A63F49AB6A2DEB1410465A7E289F6FF7E3449F730
```

Opened: H170D3H.F4

https://github.com/LongSoft/UEFITool/releases/tag/A43

https://medium.com/@matrosov/bypass-intel-boot-guard-cc05edfca3a9

Intel BIOS Guard

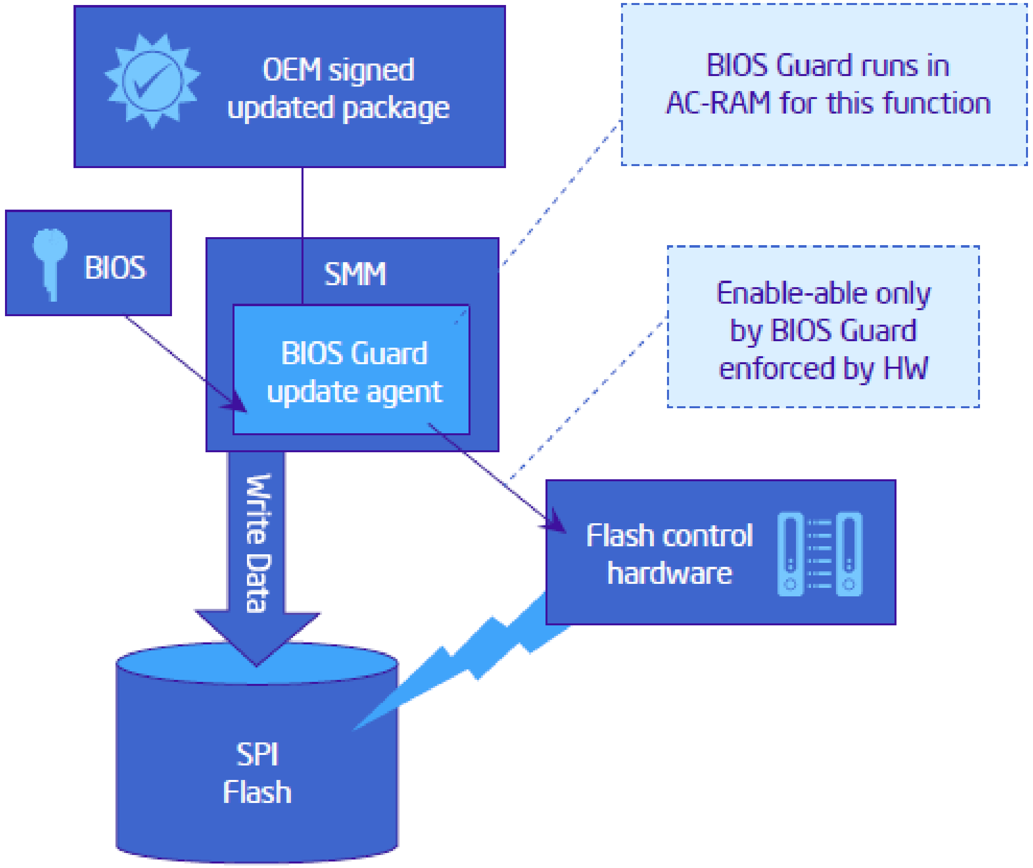
Intel BIOS Guard

- ➢ **Armoring SPI Flash access**
  - ✓ Access controlled by BIOS Guard ACM
  - ✓ Attack Surface = Firmware

- ➢ **BIOS update authentication**
  - ✓ Root of Trust = Hardware -> Trusted Platform Module (TPM)
  - ✓ Attack Surface = Firmware

- ➢ **Verified Boot -> since 2013**
  - ✓ Root of Trust = Hardware -> Field Programming Fuse (FPF)->Locked
  - ✓ Attack Surface = Firmware + Hardware

Demystifying Intel BIOS Guard



OEM signed updated package

BIOS Guard runs in AC-RAM for this function

BIOS

SMM

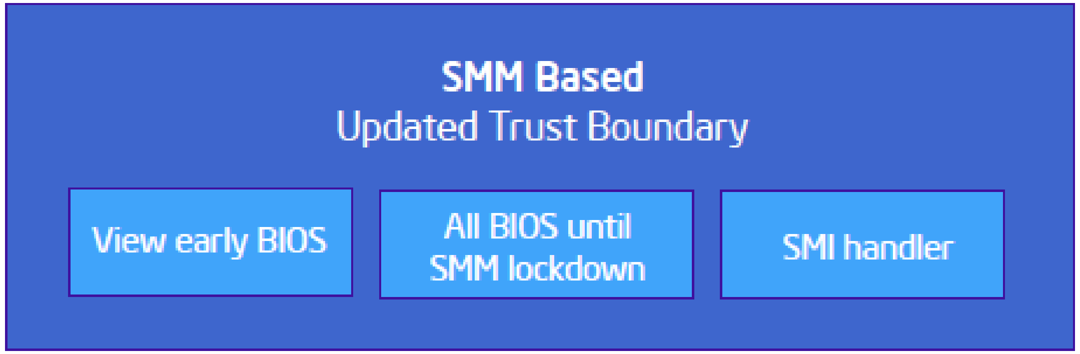
BIOS Guard update agent

Enable-able only by BIOS Guard enforced by HW

Write Data

Flash control hardware

SPI Flash

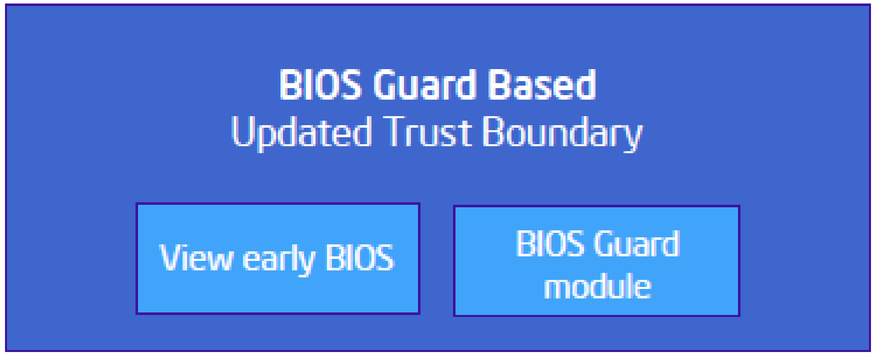


SMM Based
Updated Trust Boundary

View early BIOS

All BIOS until SMM lockdown

SMI handler



BIOS Guard Based
Updated Trust Boundary

View early BIOS

BIOS Guard module

http://www.intel.com/content/dam/www/public/us/en/documents/white-papers/security-technologies-4th-gen-core-retail-paper.pdf

Boot Guard BIOS Components (AMI)

- **PEI**
  - **BiosGuardPeiApRecoveryCapsule** [C776AEA2-AA27-446e-975B-E0BEA9078BD9]
  - **BiosGuardRecovery** [95C894B4-DAEC-46E1-8600-3C4C7FC985D6]
  - **BiosGuardCpuPolicyOverride** [FAF79E9F-4D40-4F02-8AC9-4B5512708F7F]

- **SMM**
  - **BiosGuardSmm** [44FE07D3-C312-4ad4-B892-269AB069C8E1]
  - **BiosGuardServices** [6D4BAA0B-F431-4370-AF19-99D6209239F6]

- **DXE**
  - **BiosGuardDxe** [6D1D13B3-8874-4e92-AED5-22FC7C4F7391]
  - **BiosGuardNvs** [17565311-4B71-4340-88AA-DC9F4422E53A]

Boot Guard BIOS Components (AMI)

- PEI
  - BiosGuardPeiApRecoveryCapsule – AMI Capsule Update Validation
  - BiosGuardRecovery – Recovery Update Image parser
  - BiosGuardCpuPolicyOverride
    - ✓ Find Public Key
    - ✓ Find and Load BIOS Guard ACM
- SMM
  - BiosGuardSmm - Recovery SMI Handlers
- DXE
  - BiosGuardDxe - Recovery helper for update process
    - ✓ UEFI variable cleanup
  - BiosGuardNvs – ACPI helper for update process
    - ✓ AMI Capsule validation

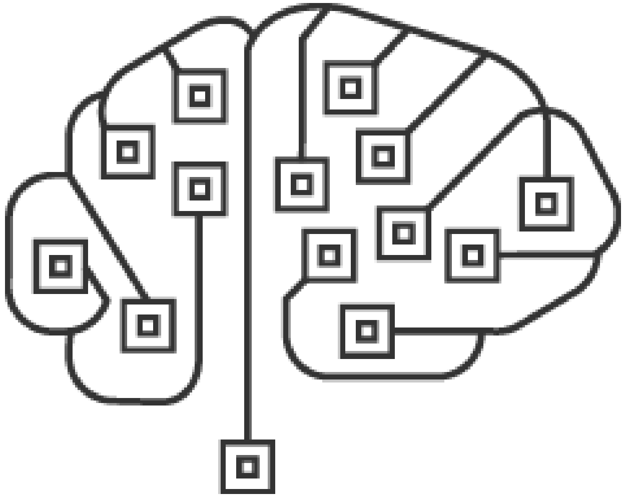
BIOS Guard Commands (AMI)

- PEI
  - BG_READ
  - BG_WRITE
  - BG_ERASE
  - BG_WRITE_ENABLE
  - BG_WRITE_DISABLE

- SMM
  - BG_READ
  - BG_WRITE
  - BG_ERASE

All the stuff will be released on public

save the link:



https://github.com/REhints/BlackHat_2017

Thank you for your attention!

Alex Matrosov

@matrosov