Self-Encrypting Deception:
weaknesses in the encryption of solid state drives (SSDs)

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Radboud University Nijmegen
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whoami

Carlo Meijer

- PhD Student at Radboud University Nijmegen
- Focused on analysis of crypto systems deployed in the wild
- Known for
  - New cryptanalytic attack on Mifare Classic (2015)
  - Password generators in wireless routers (2015)
  - Self-Encrypting Drives (2018)
- Independent security researcher at Midnight Blue Labs

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https://midnightbluelabs.com/

Acknowledgements

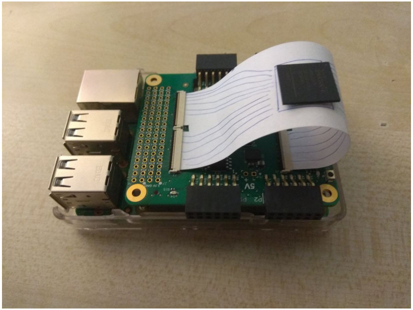
Philipp Gühring

For the bulk of the Samsung 840 EVO reverse engineering work

See `http://www.futureware.at/~philipp/ssd/TheMissingManual.pdf`

If you like reversing, check out his projects at

`http://www.futureware.at/~philipp/ssd/`



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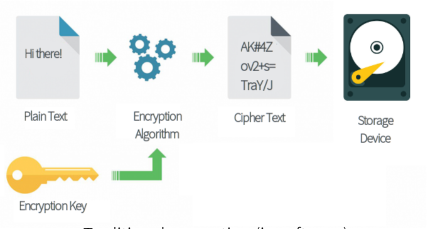

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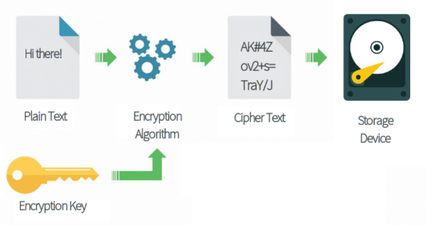

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What is a Self-Encrypting Drive? (2)

Samsung 840 EVO mSATA SSD Specifications:

- Max capacity: 1TB
- Memory: 1GB LPDDDR2 DRAM
- Controller: Samsung MEX (3x ARM Cortex R4 cores @400MHz)
- NAND: 19nm Samsung TLC
- Interface: SATA
- Form Factor: mSATA
- Power Consumption
  - Start-up: 2.01W
  - Idle: 0.44W
- Dimensions Height x length x Thickness: 3cm x 5cm x 3.85mm
- Weight: 8.5 grams
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The Marvell 88SS9189 controller supports high-speed NAND flash interfaces up to 200
channel and integrates a dual-core Marvell 88FR102 V5 CPU with shared DTCM and ITCM
can support up to eight NAND flash channels, ~500MBps sequential write performance,
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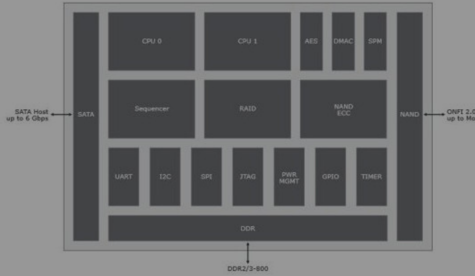

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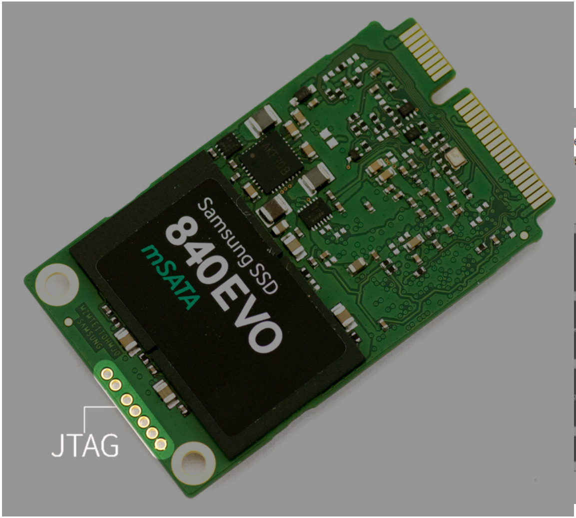

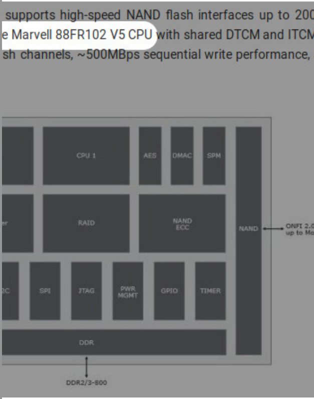

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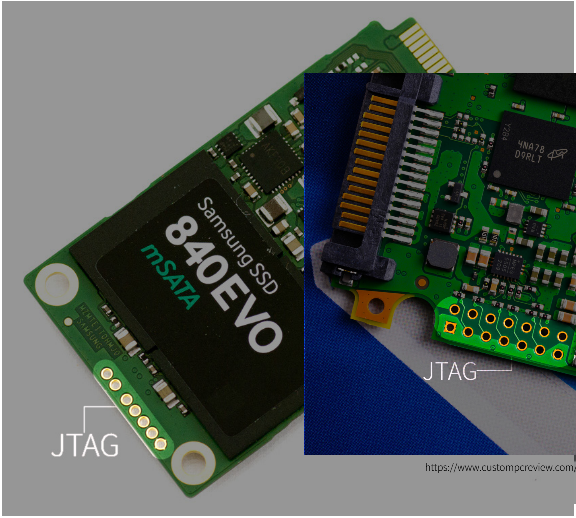

https://www.custompcreview.com/reviews/crucial-mx100-512gb-ssd-review/

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Democratically proven

The best way to enhance data security:

Swap out vulnerable hard drives for self-encrypting SSDs

The best way to protect data stored on servers, desktops, or laptops is to encrypt it at the hardware level on a device's storage drive. This is just one of many standard data security steps, but it's critical – and often overlooked. The reason: New systems often come with low-grade, preinstalled hard drives, which often lack encryption technology. Or, if the hard drive offers encryption, it's typically software-based, which is one of the weakest forms of encryption and may severely slow system performance, plus it's also easier for hackers to attack. Here's why.

https://www.crucial.com/usa/en/how-self-encrypting-ssds-protect-your-business-and-enhance-data-security-and-limit-liability

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https://www.esecurityplanet.com/network-security/The-Pros-and-Cons-of-Opal-Compliant-Drives-3939016.htm

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Hardware based encryption is very secure; far more secure than any software-based offering. Software can be corrupted or negated, while hardware cannot.

Software runs under an operating system that is vulnerable to viruses and other attacks. An operating system, by definition, provides open access to applications and thus exposes these access points to improper use.

Hardware based security can more effectively restrict access from the outside, especially to unauthorized use. Additionally, dedicated hardware can have superior performance compared to software.

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- **Transparency**: No system or application modifications required; encryption key generated in the factory by on-drive random number process; drive is always encrypting
- **Ease of management:** No encryption key to manage; software vendors exploit standardized interface to manage SEDs, including remote management, pre-boot authentication, and password recovery
- **Disposal or re-purposing cost:** With an SED, erase on-board encryption key
- **Re-encryption:** With SED, there is no need to ever re-encrypt the data
- **Performance:** No degradation in SED performance; hardware-based
- **Standardization:** Whole drive industry is building to the TCG/SED Specifications
- **Simplified:** No interference with upstream processes

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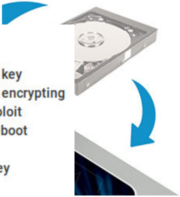

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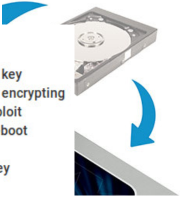

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BitLocker (built into Windows) opts for hardware encryption **by default** if available, software as a fall-back

Security guarantees

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Overall: Attack opportunities are more or less equivalent

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Overall: SEDs don't offer added protection → equivalent

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- Additional pitfalls that apply particularly to hardware encryption (later)

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Thus, security guarantees are equivalent. **At best**.

Standards

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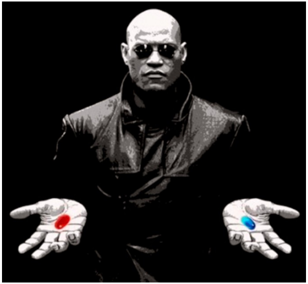
Standards for Self-Encrypting Drives

Two widely used standards exist

(i) **ATA Security Feature Set**

Originally designed for access control only



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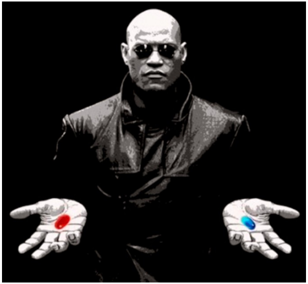

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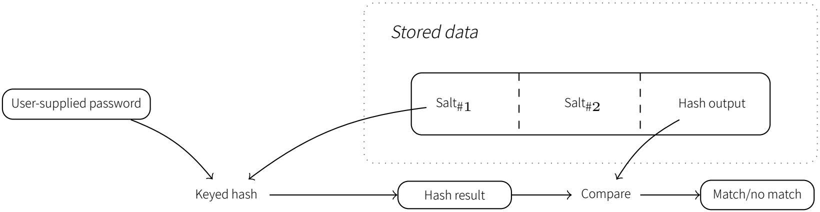

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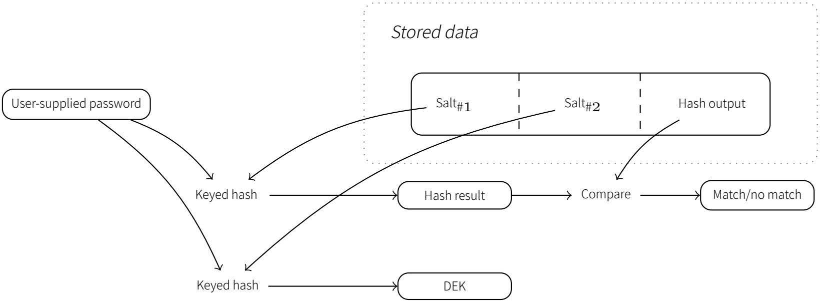

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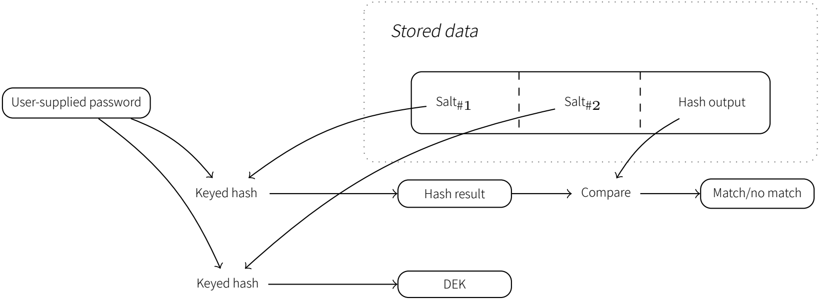

So far, easy

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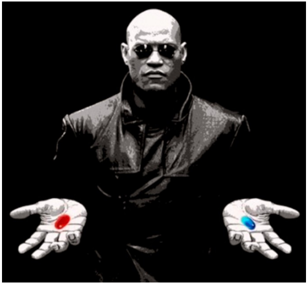

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  - **High**: both User and Master password unlock drive
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- Bottom line: **Always** change the Master password or set to Maximum

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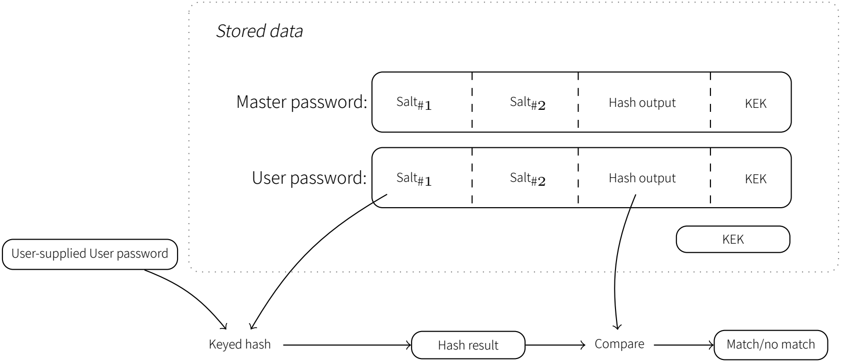

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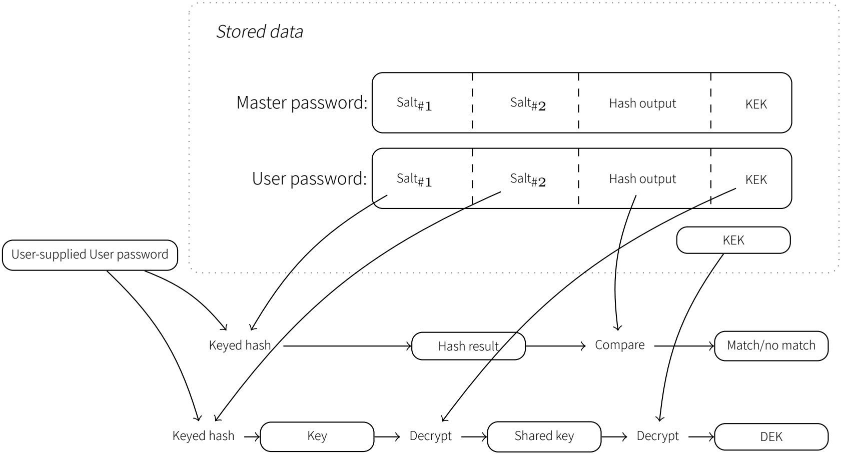


Standards for Self-Encrypting Drives

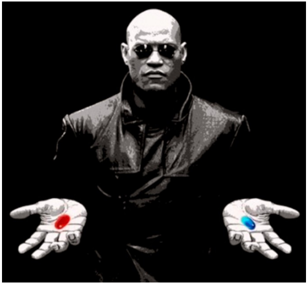
Two widely used standards exist

(i) **ATA Security Feature Set**

Originally designed for access control only

(ii) **TCG Opal**

Modern standard designed specifically for SEDs



https://medium.com/@andrewpgsweeny/beyond-the-red-pill-and-the-blue-pill-9ef953d6e133

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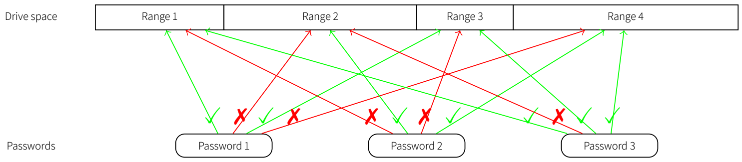

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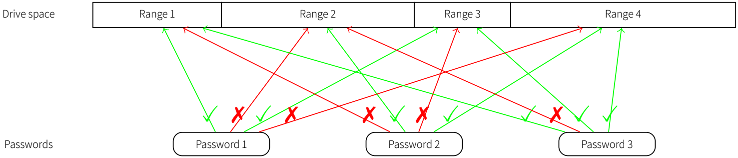

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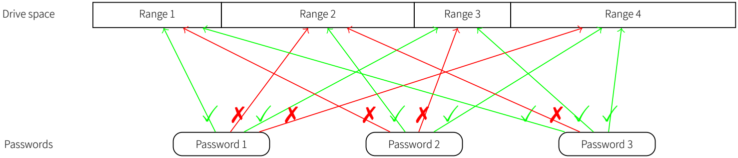
- Fully trusted by BitLocker

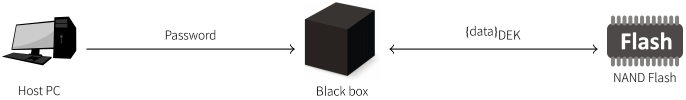


Pitfalls

Midnight Blue

Radboud University

Pitfall 1: Password and DEK not linked



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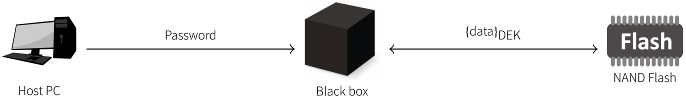

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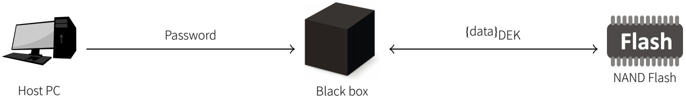

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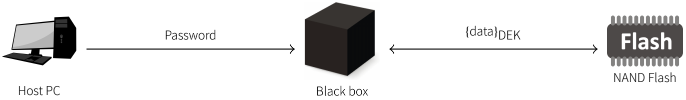

- Password unlocks drive and DEK is used to encrypt data
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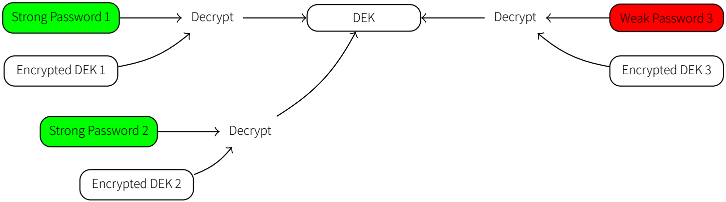
Pitfall 2: Single DEK for entire drive



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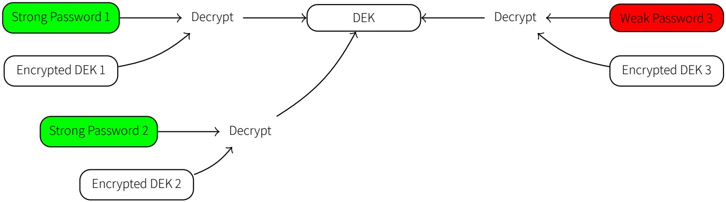

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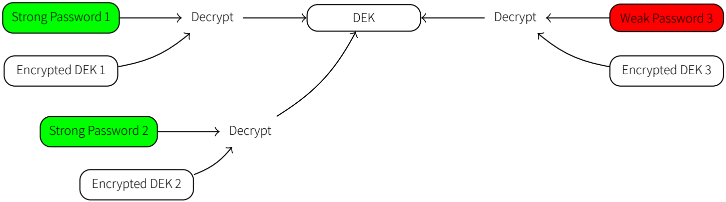

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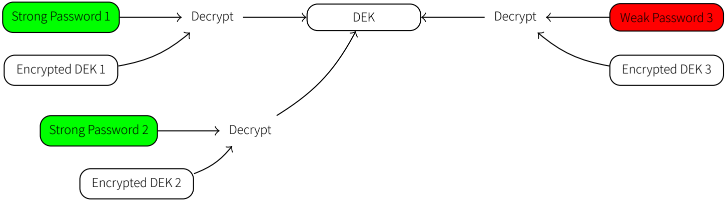

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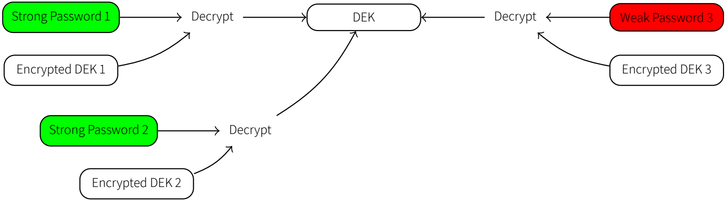

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  → Thus, in this case, DEK is retrievable **without** a key

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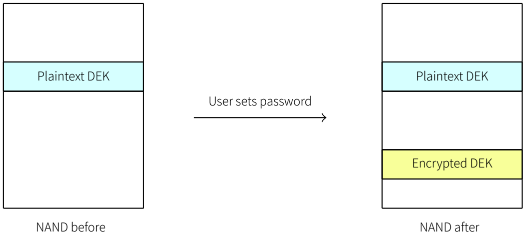

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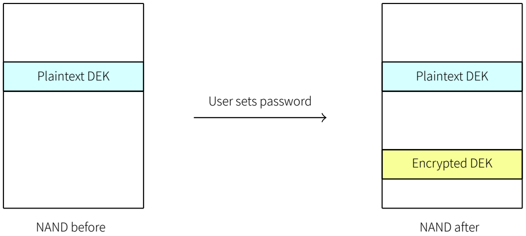

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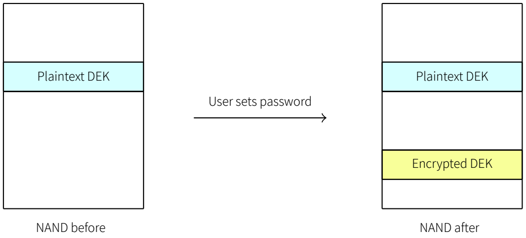

- Set password → overwrite of unprotected DEK with encrypted variant
- Unprotected DEK may still be present in physical flash

Pitfall 5: Power-saving mode: DEVSLP

PC sends DEVSLP signal to drive when idle

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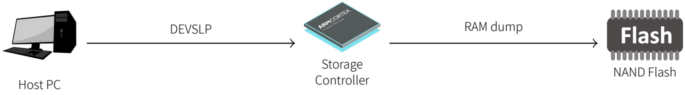

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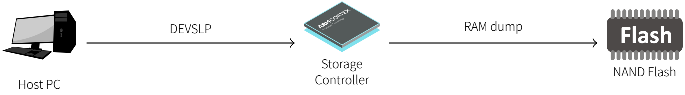

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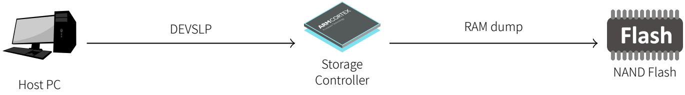

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- Erasing on resume is **crucial**

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Everything that applies to software encryption still applies

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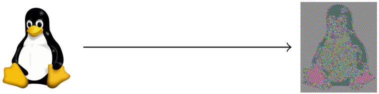

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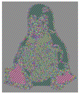

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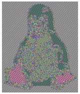

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Methodology

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Decompilation of Samsung Magician tool

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(ii) Pull the firmware from RAM through JTAG (next)

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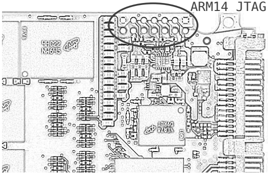

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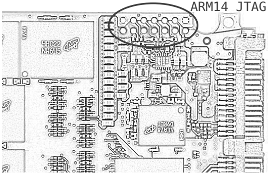

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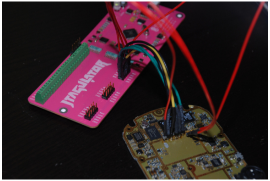

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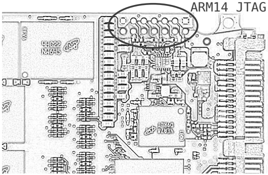

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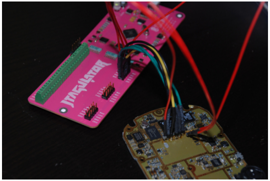

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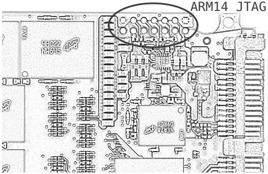

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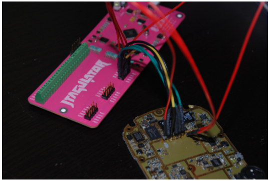

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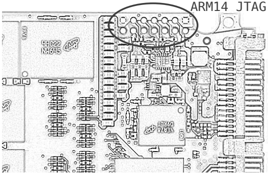

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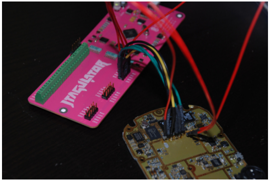

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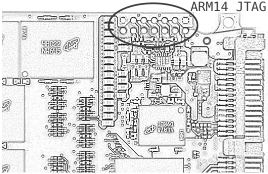

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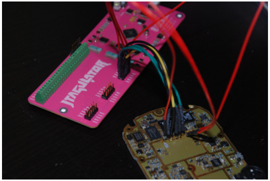

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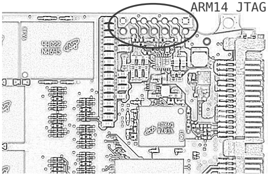
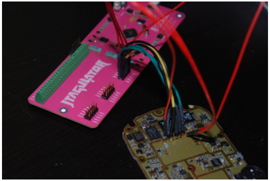
- Some models have it in plain sight
- Others need some figuring out

(ii) Obtain unsigned code execution

- Find an undocumented command that allows this
- Exploit a vulnerability
- Modify code stored on memory chips
- Bypass cryptographic signatures with fault injection



JTAG pins on the Crucial MX100.



JTAGulator

Methodology

General approach

(i) Obtain a firmware image
(ii) Gain low level control over the device
(iii) Analyze the firmware

Analyze the firmware

(i) Figure out the section information

Analyze the firmware

```
user@pinacolada:~/Documents/ssdproject/crucial$ php parse_fw.php firmware_mx300/M0CR060.bin
[+] found MCRN header -- B0KB
[*] [segment] [type] [source] [dest] [size]
[*]     0     0  0x00000010 0x00000000 117456
[*]     1     0  0x0001cae0 0x0001fa00 352
[*]     2     0  0x0001cc40 0x04002100 2488
[*]     3     0  0x0001d5f8 0x80001000 240
[*]     4     0  0x00000000 0x80000000 16
[*]     5     0  0x0001d6e8 0x80041000 264
[*]     6     0  0x0001d7f0 0x801c4000 1035224
[*]   255   255  0xffffffff 0xffffffff 4294967295
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[*]   255   255  0xffffffff 0xffffffff 4294967295
[*]   255   255  0xffffffff 0xffffffff 4294967295
[*] new offset : 0x11aa00
[*] new offset : 0x133c00
[*] new offset : 0xfa540c00
user@pinacolada:~/Documents/ssdproject/crucial$
```

Parsed header of MX300 FW image

(i) Figure out the section information
- From image header

Analyze the firmware

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user@pinacolada:~/Documents/ssdproject/crucial$
```

Parsed header of MX300 FW image

(i) Figure out the section information
- From image header

(ii) Load the image into a disassembler

(We used IDA Pro for this purpose)

Analyze the firmware

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Parsed header of MX300 FW image

(i) Figure out the section information
- From image header

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(We used IDA Pro for this purpose)

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```

Parsed header of MX300 FW image

(i) Figure out the section information
- From image header

(ii) Load the image into a disassembler

(We used IDA Pro for this purpose)

(iii) Figure out what the firmware does
- Try to find the ATA dispatch table

```
AtaCommand <0x93, sub_80262F58, 0x454A0003>
AtaCommand <0x45, sub_80264DC0, 0x45DA0023>
AtaCommand <0xF1, sub_8022CA10, 0x47CB0000>
AtaCommand <0xF2, sub_8022CAE8, 0x7890000>
AtaCommand <0xF3, sub_8022C76C, 0x67C90000>
AtaCommand <0xF4, sub_8022C7F4, 0x67C90002>
AtaCommand <0xF5, sub_8022C98C, 0x7CA0000>
AtaCommand <0xF6, sub_8022C6C4, 0x47CB0000>
AtaCommand <0xB0, AtaSmart, 0x4880003>
AtaCommand <0x10, sub_80264CD0, 0x4CA0000>
AtaCommand <0x78, sub_801C6B00, 0x45CA0020>
AtaCommand <0xB4, sub_801C9D60, 0x2E880023>
AtaCommand <6, sub_801CBB74, 0x65DA0023>
AtaCommand <0xE7, sub_801CAF14, 0x45DA0000>
AtaCommand <0xEA, sub_801CAF14, 0x45DA0022>
AtaCommand <0xEF, sub_80264780, 0x5C80000>
AtaCommand <0xC6, sub_801CB3A8, 0x5C80000>
AtaCommand <0xEC, sub_802640C8, 0x4080000>
```

ATA Dispatch table in firmware

Command feature set		
Retired	11h..1Fh, 71h..7Fh, 94h.	
Sanitize Device	B4h	O
SECURITY DISABLE PASSWORD	F6h	O
SECURITY ERASE PREPARE	F3h	O
SECURITY ERASE UNIT	F4h	O
SECURITY FREEZE LOCK	F5h	O
SECURITY SET PASSWORD	F1h	O
SECURITY UNLOCK	F2h	O
SET FEATURES	EFh	M
SET MAX ADDRESS	F9h	O
SET MAX ADDRESS EXT	37h	O
SET MULTIPLE MODE	C6h	O
SLEEP	E6h	M
SMART	B0h	O
STANDBY	E2h	M
STANDBY IMMEDIATE	E0h	M
TRUSTED NON-DATA	5Bh	O
TRUSTED RECEIVE	5Ch	O

ATA specification

Analyze the firmware

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```

Parsed header of MX300 FW image

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AtaCommand <0x93, sub_80262F58, 0x454A0003>
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```

ATA Dispatch table in firmware

(i) Figure out the section information
- From image header

(ii) Load the image into a disassembler

(We used IDA Pro for this purpose)

(iii) Figure out what the firmware does
- Try to find the ATA dispatch table
- Look through functions with interesting opcodes

Command feature set		
Retired	11h..1Fh, 71h..7Fh, 94h.	
Sanitize Device	B4h	O
SECURITY DISABLE PASSWORD	F6h	O
SECURITY ERASE PREPARE	F3h	O
SECURITY ERASE UNIT	F4h	O
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SLEEP	E6h	M
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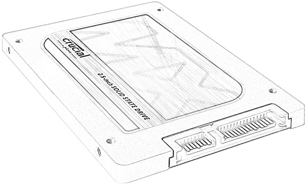
STANDBY	E2h	M
STANDBY IMMEDIATE	E0h	M
TRUSTED NON-DATA	5Bh	O
TRUSTED RECEIVE	5Ch	O

ATA specification

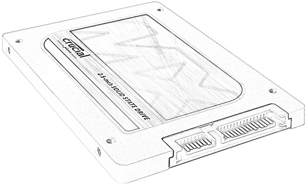
Case studies

Crucial MX100



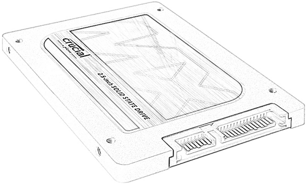
- Marvell 88SS9189 controller

Crucial MX100



- Marvell 88SS9189 controller
- Dual-core 88FR102 V5 (ARM)

Crucial MX100



- Marvell 88SS9189 controller
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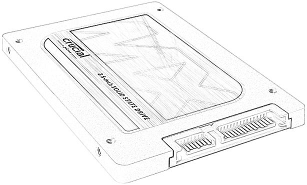
- Hardware crypto co-processor

Crucial MX100



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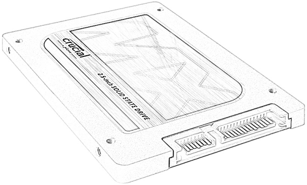
Firmware images

Crucial MX100



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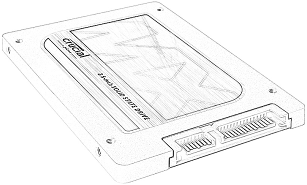
Firmware images

- Bootable ISO image

Crucial MX100



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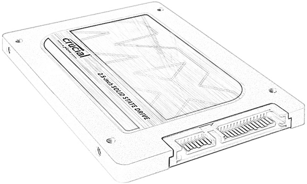
Firmware images

- Bootable ISO image
- Cryptographically signed (RSA)

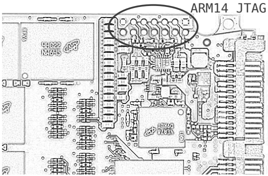
Crucial MX100



- Marvell 88SS9189 controller
- Dual-core 88FR102 V5 (ARM)
- Hardware crypto co-processor

Firmware images

- Bootable ISO image
- Cryptographically signed (RSA)
- Has a JTAG debugging interface



JTAG pinout on a Crucial MX100

Crucial MX100 (2)

Findings

Crucial MX100 (2)

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- Incoming ATA password is hashed, compared, **discarded**

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Vendor commands

- Require unlock command first (`FDh`, `55h`)
  - Set LBA to: **`306775h`** and block count to **`65h`**

Crucial MX100 (2)

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- Write to a page in SPI flash (**`FBh`**, **`D2h`**)

Crucial MX100 (2)

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It's great

Crucial MX200

- Successor to MX100

Crucial MX200

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- JTAG pins moved

Crucial MX200

- Successor to MX100
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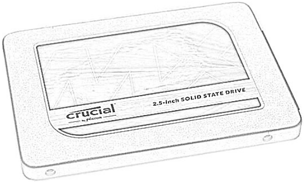
- Same controller, similar firmware

Crucial MX200

- Successor to MX100
- JTAG pins moved
- Same controller, similar firmware
- **Same vulnerabilities**

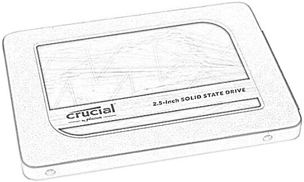
Crucial MX300

- Successor to MX200



Crucial MX300

- Successor to MX200
- Move to TLC memory, newer controller



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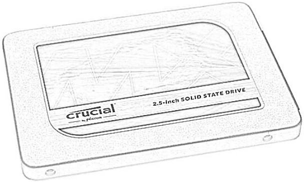
Differences

- JTAG switched off



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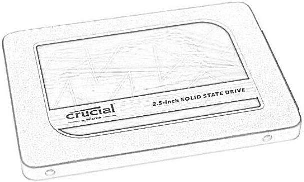
- Complete rewrite of security code



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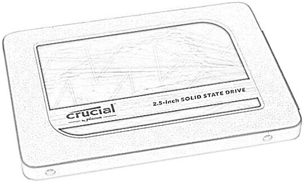

Differences

- JTAG switched off
- Complete rewrite of security code
- Vendor commands still there **but**
    unlock via cryptographic signatures

Crucial MX300

- Successor to MX200
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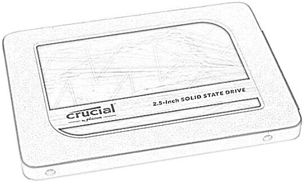
- Few buffer overflows, none exploitable



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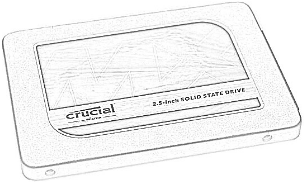

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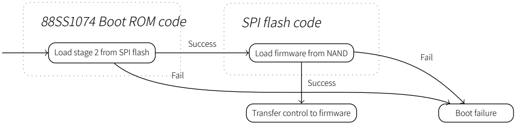
Code execution?

Crucial MX300 (2)

MX300 boot process

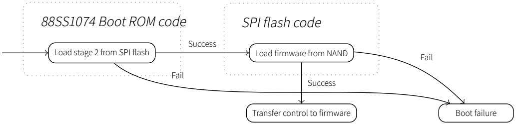


Crucial MX300 boot process.

(i) Boot code in ROM

Crucial MX300 (2)

MX300 boot process

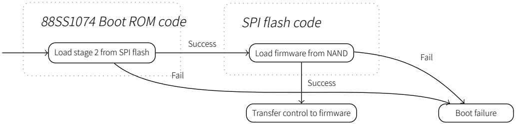


Crucial MX300 boot process.

(i) Boot code in ROM
(ii) Stage 2 in SPI flash

Crucial MX300 (2)

MX300 boot process



Crucial MX300 boot process.

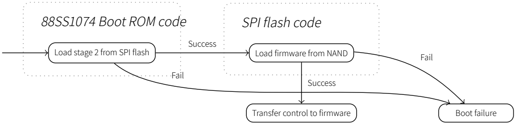
(i) Boot code in ROM

(ii) Stage 2 in SPI flash

(iii) Firmware in NAND flash

Crucial MX300 (2)

MX300 boot process



Crucial MX300 boot process.

(i) Boot code in ROM

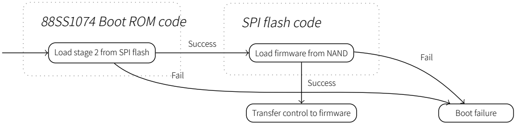
(ii) Stage 2 in SPI flash

(iii) Firmware in NAND flash

→ Modify Stage 2

Crucial MX300 (2)

MX300 boot process



Crucial MX300 boot process.

(i) Boot code in ROM
(ii) Stage 2 in SPI flash
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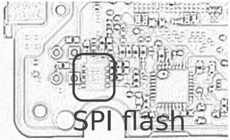
→ Modify Stage 2

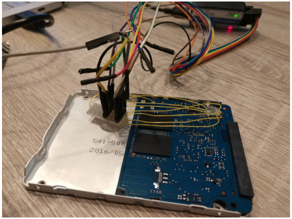


SPI flash chip on the MX300 PCB.

Crucial MX300 (2)

Code execution walkthrough

(i) Connect reader to SPI flash chip



Crucial MX300 (2)

Code execution walkthrough

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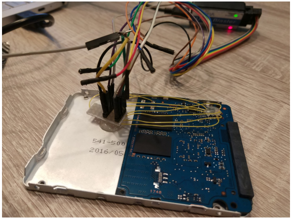

Crucial MX300 (2)

Code execution walkthrough

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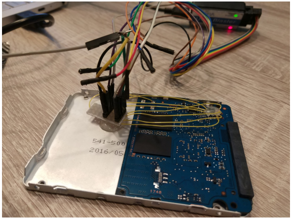

Crucial MX300 (2)

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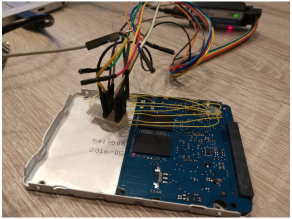

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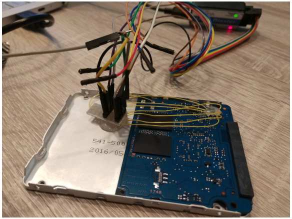
Drive now accepts fw updates with invalid signatures



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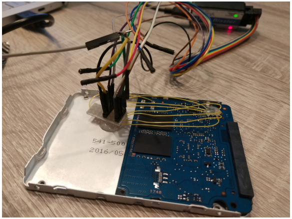

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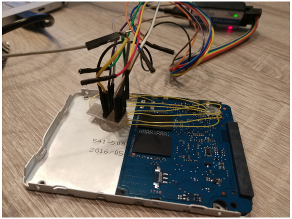

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(vi) Take a firmware image and add additional “features”, such as arbitrary read/write/execute capabilities

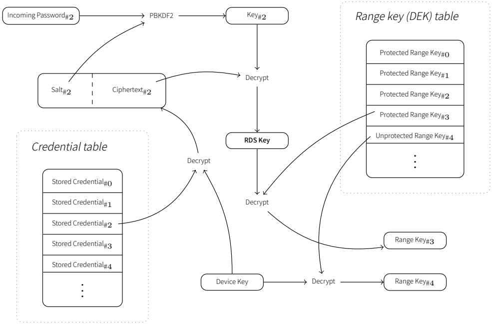
(vii) Send the modified firmware as you would for any update

Now we have full control over the device

Crucial MX300 (3)

Key derivation scheme

- Binding between password and DEK introduced



Scheme used to obtain a range key (DEK) from the user-supplied password. In this example, credential #2 is used to unlock range #3.

Crucial MX300 (3)

Key derivation scheme

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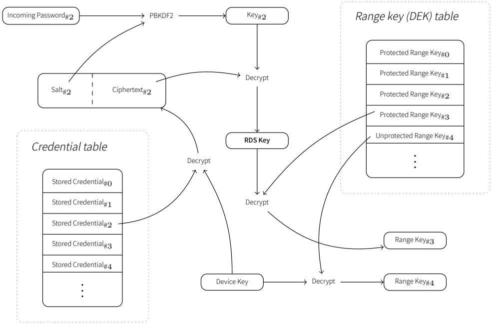
- As required by Opal: multiple credentials and ranges



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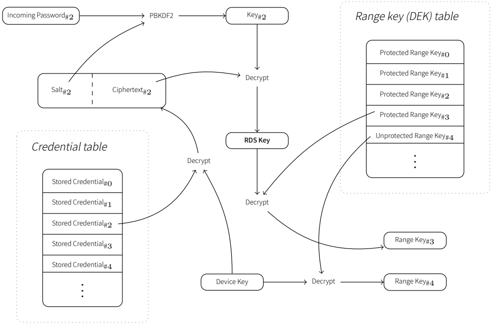

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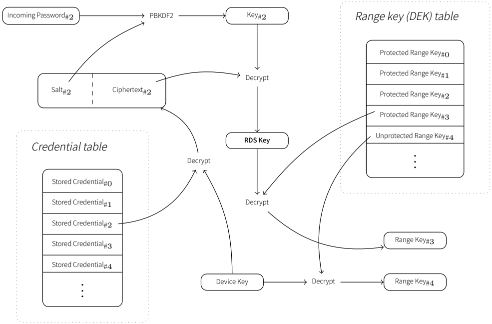
- RDS-key allows access to **all protected ranges**
  - Prevented by firmware, though not cryptographically enforced



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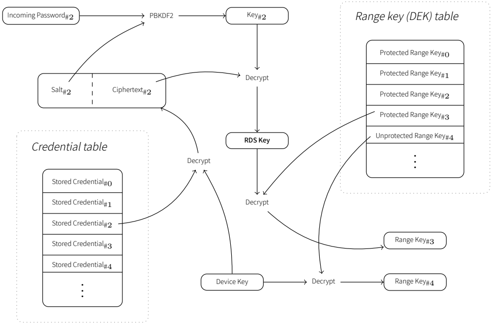

Scheme used to obtain a range key (DEK) from the user-supplied password. In this example, credential #2 is used to unlock range #3.

Thus, everything is accessible with a single valid password. But it's even worse (next)

Crucial MX300 (4)

Consider the password protection function

```
int __fastcall ProtectPwd_Impl(unsigned __int8 *lpPassword, int dwPasswordLength, int bStoreRdsKey, unsigned __int8 *lpOutput)
{
  int dwPasswordLength_; // r8
  unsigned __int8 *lpPassword_; // r9
  unsigned __int8 *lpOutput_; // r7
  int bStoreRdsKey_; // r4
  ProtectedPassword stProtectedPassword; // [sp+Ch] [bp-C4h]
  unsigned __int8 abRandomSalt[32]; // [sp+54h] [bp-7Ch]
  unsigned __int8 abRdsKeyInput[32]; // [sp+74h] [bp-5Ch]
  unsigned __int8 abHmacKey[32]; // [sp+94h] [bp-3Ch]

  dwPasswordLength_ = dwPasswordLength;
  lpPassword_ = lpPassword;
  lpOutput_ = lpOutput;
  bStoreRdsKey_ = bStoreRdsKey;
  bzero(abRdsKeyInput, 32);
  GenerateRandom(abRandomSalt, 32);
  PBKDF2_HMAC_SHA256(lpPassword_, dwPasswordLength_, abRandomSalt, 32, 100, 32, abHmacKey);
  if ( !bStoreRdsKey_ )
    goto LABEL_4;
  if ( IsRdsKeyValid() )
  {
    memcpy(abRdsKeyInput, g_abRdsKey, 32);
LABEL_4:
    AesEncrypt(abRdsKeyInput, 32, abHmacKey, stProtectedPassword.abCipherText);
    memcpy(stProtectedPassword.abSalt, abRandomSalt, 32);
    return AesEncrypt(stProtectedPassword.abCipherText, 72, g_abDeviceKey, lpOutput_);
  }
  return printf_0("!! Protect Pwd: RDSKEY is not valid !!\n");
}
```

- “Protect Pwd” does more than just password hashing

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  dwPasswordLength_ = dwPasswordLength;
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- Output contains encrypted **RDS-key**

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```

- “Protect Pwd” does more than just password hashing
- Output contains encrypted **RDS-key**
- They shouldn’t be throwing its output around

Crucial MX300 (5)

Consider this trace captured during BitLocker provisioning

```
VerifyPasswd(szPasswd="AEGIS_ACADIA_MSID_12456789012345", bExtractRdsKey=true, dwSlotNo=2)
VerifyPasswd(szPasswd="AEGIS_ACADIA_MSID_12456789012345", bExtractRdsKey=true, dwSlotNo=2)
CopyCredential(dwSourceSlot=2, dwDestinationSlot=10)
ProtectPasswd(szPasswd=[0x00 × 32], bStoreRdsKey=true, dwSlotNo=11)          ▹ szPasswd is zero buffer
CopyCredential(dwSourceSlot=11, dwDestinationSlot=12)
CopyCredential(dwSourceSlot=11, dwDestinationSlot=13)
CopyCredential(dwSourceSlot=11, dwDestinationSlot=14)
        .
        .
        .
CopyCredential(dwSourceSlot=11, dwDestinationSlot=29)
StoreCryptoContextInSpiFlash()
VerifyPasswd(szPasswd="AEGIS_ACADIA_MSID_12456789012345", bExtractRdsKey=true, dwSlotNo=2)
VerifyPasswd(szPasswd="AEGIS_ACADIA_MSID_12456789012345", bExtractRdsKey=true, dwSlotNo=10)
VerifyPasswd(szPasswd="AEGIS_ACADIA_MSID_12456789012345", bExtractRdsKey=true, dwSlotNo=2)
ProtectPasswd(szPasswd=«BitLocker SID password», bStoreRdsKey=true, dwSlotNo=2))
StoreCryptoContextInSpiFlash()
VerifyPasswd(szPasswd="AEGIS_ACADIA_MSID_12456789012345", bExtractRdsKey=true, dwSlotNo=10)
ProtectPasswd(szPasswd=«BitLocker SID password», bStoreRdsKey=true, dwSlotNo=10)
StoreCryptoContextInSpiFlash()
VerifyPasswd(szPasswd=[0x00 × 32], bExtractRdsKey=true, dwSlotNo=15)
GenerateRandomDekAndWrap(dwRangeNo=1, bIsProtectedRange=false)
VerifyPasswd(szPasswd=[0x00 × 32], bExtractRdsKey=true, dwSlotNo=15)
StoreCryptoContextInSpiFlash()
UnwrapDek(dwRangeNo=1, bIsProtectedRange=false)
VerifyPasswd(szPasswd=[0x00 × 32], bExtractRdsKey=true, dwSlotNo=15)
VerifyPasswd(szPasswd=[0x00 × 32], bExtractRdsKey=true, dwSlotNo=15)
VerifyPasswd(szPasswd=[0x00 × 32], bExtractRdsKey=true, dwSlotNo=15)
UnwrapDek(dwRangeNo=1, bIsProtectedRange=false)
WrapDek(dwRangeNo=1, bIsProtectedRange=true)
VerifyPasswd(szPasswd=[0x00 × 32], bExtractRdsKey=true, dwSlotNo=15)
ProtectPasswd(szPasswd=«BitLocker user password», bStoreRdsKey=true, dwSlotNo=15)
StoreCryptoContextInSpiFlash()
VerifyPasswd(szPasswd=«BitLocker user password», bExtractRdsKey=true, dwSlotNo=15)
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```

- RDS key ends up in all slots 11-29 (except 15)
- Decryption key is a **zero buffer**

Crucial MX300 (6)

Attack strategy

(i) Flash modified firmware image (before)

Crucial MX300 (6)

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RDS key is now recovered

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RDS key is now recovered

(iv) Modify the password verification routine so that it accepts any password

(v) Unlock any desired range with an arbitrary password

Demo

Crucial MX300 (7)

Get best-in-class hardware encryption.
Keep personal files and sensitive information secure from hackers and thieves with AES 256-bit encryption—the same grade used by banks and hospitals. The Crucial MX100 is one of the only drives available that meets Microsoft® eDrive®, IEEE-1667, *and* TCG Opal 2.0 standards of encryption.

https://www.crucial.com/wcsstore/CrucialSAS/pdf/product-flyer/ssd/productflyer-crucial-mx100-ssd-en.pdf

Crucial MX300 (8)

ATA Security

- The crucial MX300 has an empty (“”) factory-set master password

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Crucial MX300 (8)

ATA Security

- The crucial MX300 has an empty (“”) factory-set master password
- Recall: *change* the Master password or set MASTER PASSWORD CAPABILITY to *Maximum* (1)
- For the MX300, latter is **insufficient**
- Can use the arbitrary write to patch it back to High (0), unlock with empty string

Samsung 840 EVO

- First Samsung drive to support TCG Opal

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- Tri-core Cortex-R4, 400 Mhz

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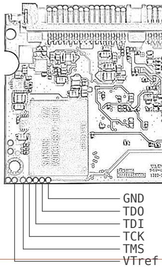
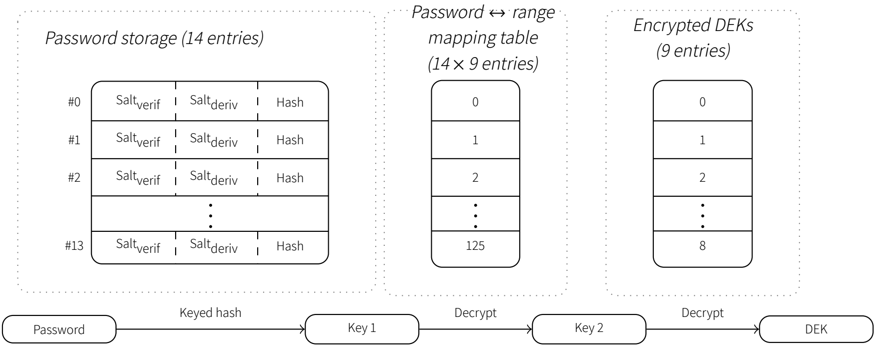


Samsung 840 EVO (2)

From Opal password to DEK



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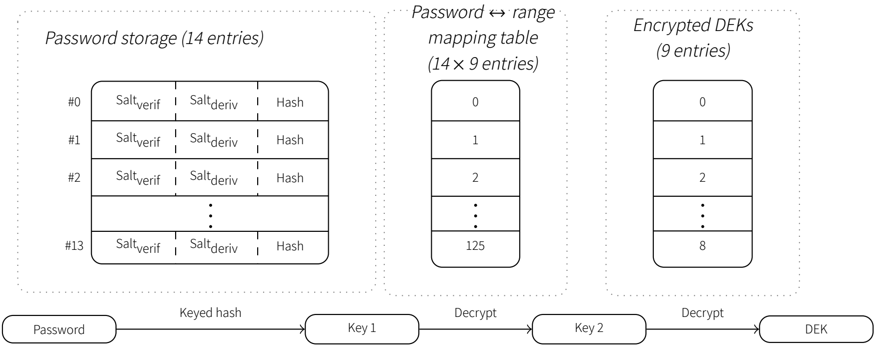

- Sound Opal implementation

Samsung 840 EVO (2)

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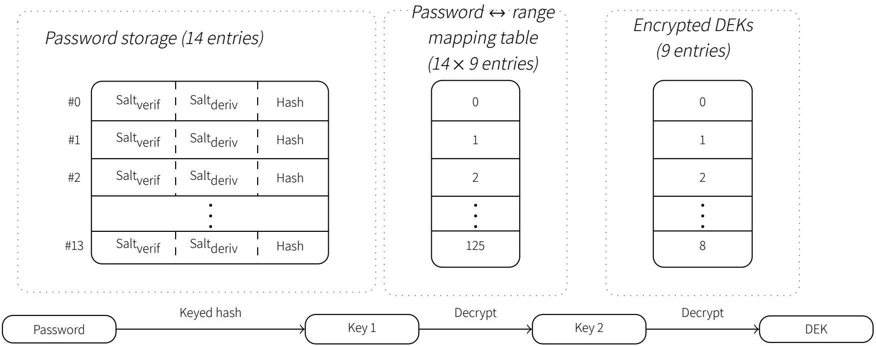

- Sound Opal implementation
- All properties cryptographically enforced

Samsung 840 EVO (3)

ATA Security feature set

Samsung 840 EVO (3)

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- DEK depends on password **only** in *Maximum* mode

Samsung 840 EVO (3)

ATA Security feature set

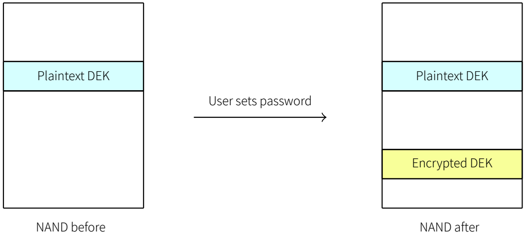
- DEK depends on password **only** in *Maximum* mode
- Otherwise, **no dependency** on password whatsoever
  - Removal of hash comparison allows access

Samsung 840 EVO (4)

Crypto data structure storage

Samsung 840 EVO (4)

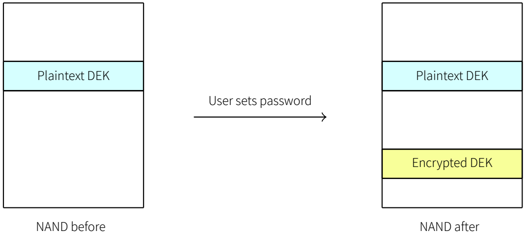
Crypto data structure storage



- All crypto related data is stored in NAND, wear leveled

Samsung 840 EVO (4)

Crypto data structure storage



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- Thus, can scan through NAND for unprotected keys

Samsung 840 EVO (4)

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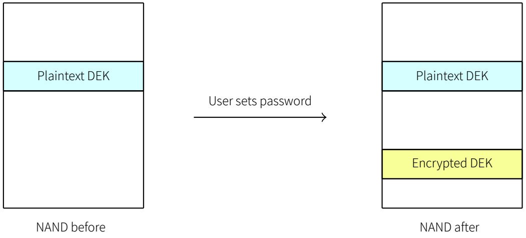

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- If found, completely compromises encryption

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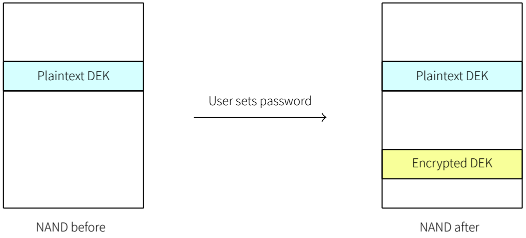

- All crypto related data is stored in NAND, wear leveled
- Thus, can scan through NAND for unprotected keys
- If found, completely compromises encryption
- Affects both ATA security and TCG Opal

Samsung 850 EVO

- Successor to 840 EVO

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- Samsung MGX controller

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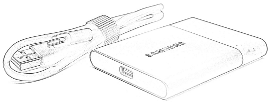
- Very similar encryption implementation

Samsung 850 EVO

- Successor to 840 EVO
- Samsung MGX controller
- Different firmware obfuscation
    - de-obfuscation still performed on the host pc
- Supports DEVSLP
- Very similar encryption implementation
- Thus, **same vulnerability**, except the wear-leveling issue

Samsung T3 Portable

- Essentially a 850 EVO with USB↔mSATA adapter
  (with T3-specific firmware, not available for download)



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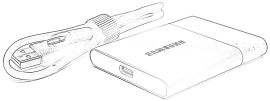

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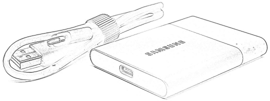

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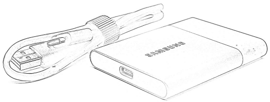

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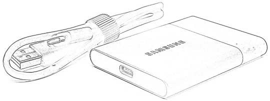

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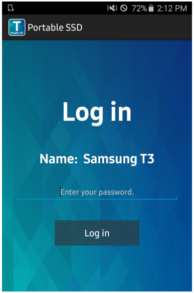

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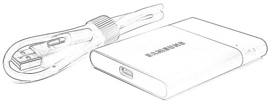

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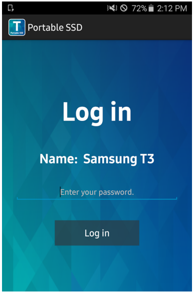

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- Built on the ATA security implementation
  With MASTER PASSWORD CAPABILITY set to **High**

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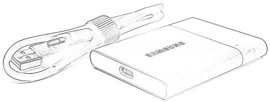

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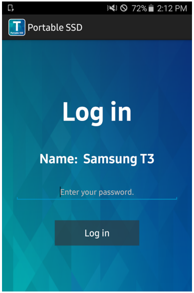


- Configuration tool for Windows, MacOS and Android
- Built on the ATA security implementation
  With MASTER PASSWORD CAPABILITY set to **High**
- Thus, password and DEK **not** linked, equivalent to **no encryption**

Demo

Midnight Blue

Radboud University

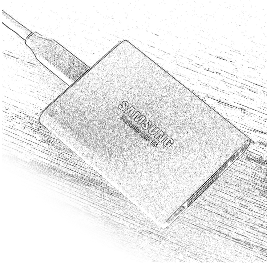
Samsung T3 Portable (2)

Tough to Crack

A trifecta of protection, the shock-resistant T3 has a strong exterior metal body, internal support frame and optional AES 256-bit hardware encryption prepared for demands of life.

https://www.samsung.com/semiconductor/minisite/ssd/product/portable/t3/

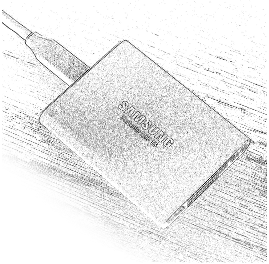
Samsung T5 Portable



Key differences with T3

- USB 3.1 Gen2 instead of Gen1

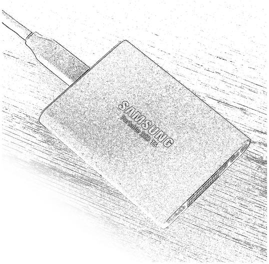
Samsung T5 Portable



Key differences with T3

- USB 3.1 Gen2 instead of Gen1
- JTAG switched off

Samsung T5 Portable



Key differences with T3

- USB 3.1 Gen2 instead of Gen1
- JTAG switched off
- Equally vulnerable

    Just harder to exploit

Conclusion

Conclusion

- Most SEDs have severe weaknesses

Drive	1	2	3	4	5	6	7	8	9	Impact
Crucial MX100 (all form factors)	✗	✗	✗							✗ Compromised
Crucial MX200 (all form factors)	✗	✗	✗							✗ Compromised
Crucial MX300 (all form factors)	✓	✓	✓		✗	✓	✓	✓	✓	✗ Compromised
Samsung 840 EVO (SATA)	✗	✓	✓		✓	✓	✓	✗	✓	~ Depends
Samsung 850 EVO (SATA)	✗	✓	✓		✓	✓	✓	✓	✓	~ Depends
Samsung T3 (USB)				✗						✗ Compromised
Samsung T5 (USB)				✗						✗ Compromised

[1] Cryptographic binding in ATA Security (High mode)
[2] Cryptographic binding in ATA Security (Max mode)
[3] Cryptographic binding in TCG Opal
[4] Cryptographic binding in proprietary standard
[5] No single key for entire disk
[6] Randomized DEK on sanitize
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Overview of case study findings.

Conclusion

- Most SEDs have severe weaknesses
- Best case scenario: security guarantees are equivalent to software FDE

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Samsung 840 EVO (SATA)	✗	✓	✓		✓	✓	✓	✗	✓	~ Depends
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Conclusion

- Most SEDs have severe weaknesses
- Best case scenario: security guarantees are equivalent to software FDE
- Worst case: confidentiality relies on an **if-statement**
- TCG Opal is terrible
  - Over-engineered
  - Security goals not clear
  - No reference implementation exists
  - Implementation is not even part of complience tests
  - Structural changes needed

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Overview of case study findings.

Questions

See the draft paper 'Self-Encrypting Deception'

Carlo Meijer

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https://cs.ru.nl/~cmeijer/

https://midnightbluelabs.com/

Midnight Blue

Radboud University