The challenges in designing a secure hard drive

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Outline

Introduction

Presentation goal:

- describe the world of consumer encrypted HDD enclosures
- analyze the design challenges
- present an overview of attacks and possible solutions

All based on practical experience:

- thorough analysis of several enclosures
- analysis of several encrypted USB flash drives

Outline

Features

User features:

- should use standard SATA HDD
- authentication mean could be
  - hardware keyboard to enter PIN
  - could be fingerprint reader
  - could be RFID
- optional LCD display
- good confidentiality (!!)
- good performance

Vocabulary

Some definitions:

- µC: micro-controller
- "secrets": needed to decrypt on-disk data (NOT user files on disk)
- DEK: disk encryption key: key used to encrypt on-disk user data
- class break: break one drive $\Longrightarrow$ break all drives

Security needs

Security features:

- multiple PINs to allow multiple users
- good data encryption algorithm (AES-XTS?)
- should warn user on bad PIN (for usability)
- anti bruteforce:
  - incremental delay
  - auto destroy after X tries
- independent security: breaking a drive should not lead to class-break

Attacker model:

- moderately motivated attacker
- offline attacks only (drive is acquired locked)
- evil-maid attacks off scope
- no advanced hardware attacks capabilities (FIB, etc.)

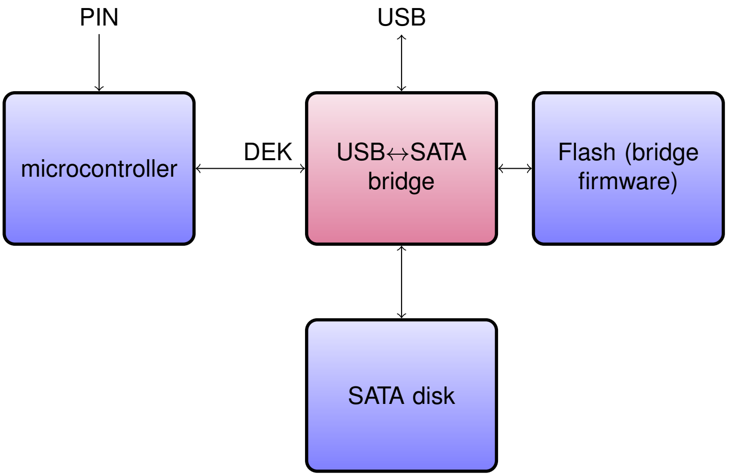
Outline

Components

PCB with several components:

- USB↔SATA bridge with encryption support. E.g.:
  - Initio INIC-3607E
  - Fujitsu MB86C31
  - Symwave SW6316
  - etc.
- most of them include a CPU (ARM, ARC, etc.)
- microcontroller for:
  - keyboard handling
  - PIN verification
- Optional SPI flash for firmware/data storage
- and of course: SATA port, USB port

Classical design



µC sends DEK to bridge to allow user data access

Crypto design / secrets storage

Tradeoff:

- we must be able to check for correct PIN
- even with access to the stored secrets, the attacker must be slowed down

Do's

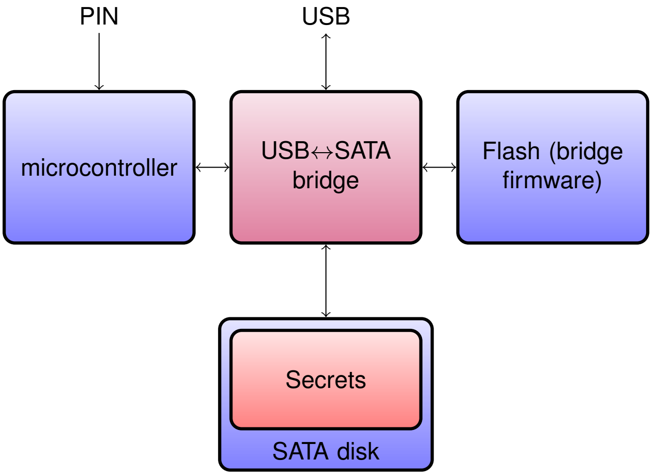
- generate disk encryption key with cryptographically secure RNG
- hash PIN securely (slow, with salt) before use
- encrypt disk encryption key with each PIN hash

Storing secrets

- must be stored on board, not on disk !
- should not be accessible without hardware (decapping) attacks

$\Longrightarrow$ the main goal is to force the attacker to use expensive attacks

Example design: 1



Design analysis

Fail

Secret are stored on HDD. Potential consequences:

- if disk encryption key (DEK) is in cleartext on disk $\Longrightarrow$ game over
- DEK is encrypted with fixed key on board $\Longrightarrow$ class break
- DEK is encrypted with PIN $\Longrightarrow$ PIN bruteforce $\Longrightarrow$ class break
- DEK is encrypted with key stored on board $\Longrightarrow$ better store DEK on board

Outline

Overview

Attackers goal:

- access data of stolen/found disk without PIN code
- *ideal* case:
    - class break: break one drive $\Longrightarrow$ break all drives

Methods:

- from “obvious and cheap” to “complex and expensive”
- software first, hardware last
- as seen from a software reverser point of view

Basic testing (1)

Basic crypto testing:

1. configure encryption
2. write zeros on the drive
3. remove drive from enclosure
4. read encrypted data directly from the disk (use a normal USB/SATA bridge)
5. verify that the entropy is very high and that ECB is not used

Verify the key (and IV) is not fixed or derived directly (without salt) from the PIN:

1. using the same enclosure, *reset* and *reconfigure* encryption with the same PIN
2. write zeros again
3. ensure that the (raw) encrypted data is different from the previous read

Basic testing (2)

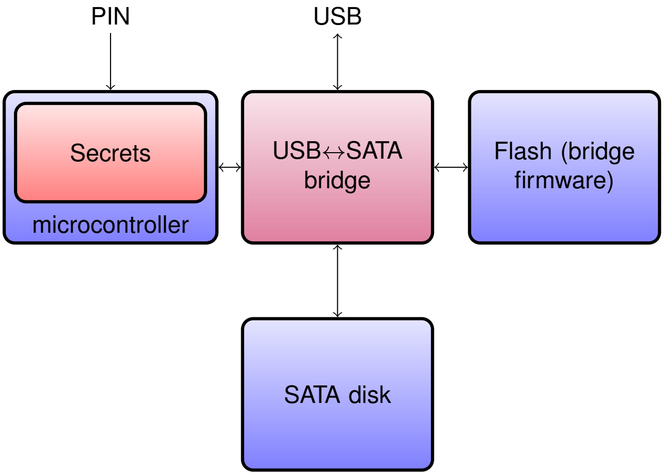
Verify the disk is tied to a specific enclosure (i.e. some secrets in hardware):

1. put drive in enclosure A
2. configure encryption with non default PIN P, write data
3. put drive in (new, out of the box) enclosure B
4. verify it doesn't work:
   - drive should not be recognized as encrypted
   - OR PIN P should not work
   - AND data should never be accessible

If data can be accessed with PIN P, secrets are stored on the drive:

- class break probable (no difference between enclosure)
- check where the data is stored: end of drive ?
- and how: encrypted, etc. ?

Example design: 2



Design analysis

Better design !

Secret are stored on µC. Accessing secrets is (probably) equivalent to accessing firmware:

- unprotected µC $\Longrightarrow$ game over
- protected µC $\Longrightarrow$ known problem

Accessing data on a protected µC

Rather well studied problem, example research:

- RAM access [1]
- bootloader rewrite attacks [2, 3]
- hardware attacks [4, 5]

Firmware recovery

Obvious goal: read the code, understand what is needed to attack.

- easiest: cleartext code in firmware update:)
- easy: cleartext code on SPI flash: dump SPI
- medium: cleartext code on unprotected µC: use documented methods to read code
- hard: encrypted code on SPI flash
- hard: code on protected but insecure µC
- hardest: code on protected, secure µC

Firmware reversing

Goals

- look for backdoors !
- identify crypto mechanisms:
  - potential key recovery schemes
  - PIN change handling
- identify secrets storage
- reverse RNG
- reverse “anti-bruteforce” protection
- bindiffing different versions

RNG analysis

- verify it is used for first configuration (manufacturer generated key ?)
- verify its quality. If flawed (predictable):
  - manufacturer backdoor with plausible deniability ?
  - construct RNG bruteforce attack

Bus sniffing

Goal

if firmware cannot be extracted: understand interactions between components

Means

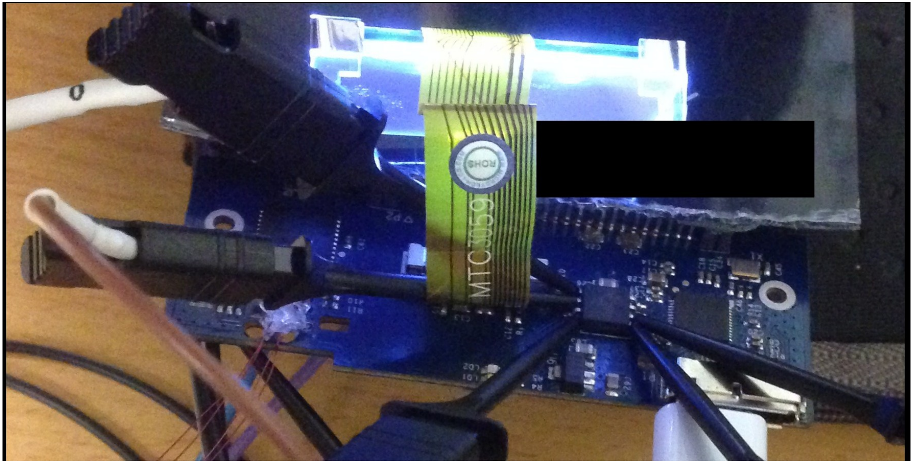
Logic analyzer

Practical example

- drive with “hard to dump” components
- shared bus with:
  - bridge $\leftrightarrow$ µC communications
  - bridge $\leftrightarrow$ SPI flash comms

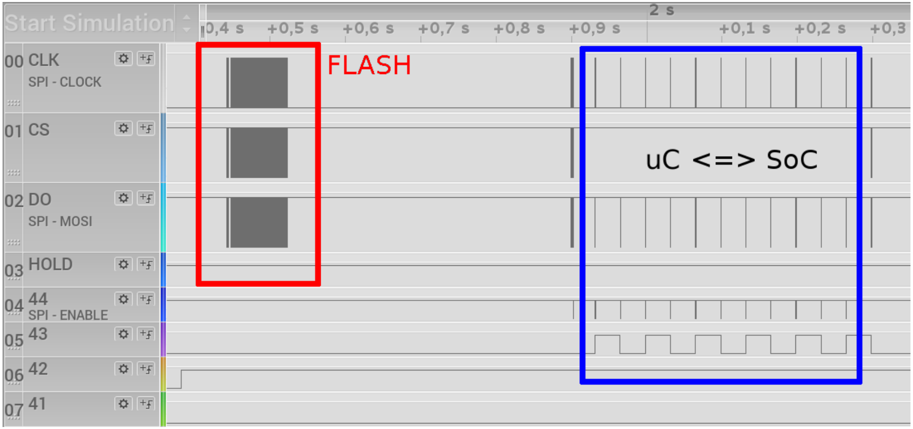
Placing the probes

Using the (awesome) Saleae Logic Pro 16:



[redacted]

Sniffing results



Analysing traces

High level results

- proprietary protocol between bridge and µC
- rather easy to analyze: preambles, classical TLV scheme
- PIN handling:
  - bridge requests PIN
  - µC reads PIN
  - µC sends *hashed* PIN to bridge
  - bridge returns result

Security analysis

- bridge checks the PIN
- hash function is non standard

$\Longrightarrow$ not bruteforcable, must break bridge

Brute forcing, timing attacks and glitching

Spritesmods.com [6] has an awesome analysis that shows:

- how “PIN errors” count is handled
- a method to reset “bad tries” count in EEPROM
- a *bad PIN* detection to allow infinite bruteforce

Other possible attacks include:

- if DEK is not encrypted by PIN: inject fault during compare [7]
- replacing physical keyboard by µC to automate bruteforce

Chip decapping: the ultimate solution

Principle [5]

1. remove chip plastic capping (hot $\mathrm{HNO_3}$; dangerous!)
2. remove protective metal layers over fuses (HF extremely dangerous!)
3. reset protection fuses
4. dump chip content: secrets, code

In practice

- use internal lab (complex)
- pay Chinese lab [8, 9], price varies:
    - $2000 for “easy” chip
    - $7500 for a more modern chip with some protections

Outline

A good design ?

Proposal

- a secure µC (Atmel, ST, etc.) with hardware RNG and HW countermeasures
- secure firmware update mechanism to be able to fix bugs
- a validated/certified USB-SATA controller
- good crypto
- all in epoxy, to slow down the attacker

Crypto

- disk encryption key (DEK) is based on secure µC RNG with output hashing
- PIN is hashed with salt
- DEK is encrypted with each PIN
- PIN validation is done either by:
  - ideally, the USB-SATA chip by reading and checking a magic sector, decrypted with DEK
  - verifying a magic in the decrypted DEK (easier to implement, easier to attack)

A good design ? (2)

Remaining challenges

µC CPUs are slow: how can we hash the PIN ?
Slow hashes like *scrypt* are out of question, but fast hashes help the attacker brute-force the PIN

Going further (but at which cost ?)

- use own ASIC/FPGA to make reversing more difficult
- use tamper detection to erase secrets in case of intrusion

End

Questions?

References

[1] http://www.proxclone.com/pdfs/iClass_Key_Extraction.pdf

[2] http://blog.lanka.sk/2013/11/hacking-apc-back-ups-hs-500.html

[3] http://www.openpcd.org/images/HID-iCLASS-security.pdf

[4] http://www.cl.cam.ac.uk/~sps32/index.html

[5] http://www.bunniestudios.com/blog/?page_id=40

[6] http://spritesmods.com/?art=diskgenie

[7] http://www.t4f.org/articles/
fault-injection-attacks-clock-glitching-tutorial/

[8] http://www.break-ic.com/

[9] http://www.epplos-mcu.com/