Can You Really Trust Hardware? Exploring Security Problems in Hardware Devices

The Black Hat Briefings 2005

Joe Grand
Grand Idea Studio, Inc.
joe@grandideastudio.com

Goals

- Become familiar with classes of hardware attacks
- Learn from history
  - Explore prior attacks against hardware products
- Gain knowledge to attack/analyze new devices
- Understand and accept that hardware-based security is extremely difficult
  - Just because it's a hardware product does not mean it's secure
Threat Vectors

- Interception (or Eavesdropping)
  - Gain access to protected information without opening the product
- Interruption (or Fault Generation)
  - Preventing the product from functioning normally
- Modification
  - Tampering with the product, typically invasive
- Fabrication/Man-in-the-Middle
  - Creating counterfeit assets of a product

Attack Goals

- Competition (or Cloning)
  - Specific IP theft to gain marketplace advantage
- Theft-of-Service
  - Obtaining service for free that normally requires $$$
- User Authentication (or Spoofing)
  - Forging a user's identity to gain access to a system
- Privilege Escalation (or Feature Unlocking)
  - Gaining increased command of a system or unlocking hidden/undocumented features
Thinking Like An Attacker...

And this house is even more secure! The front door is four feet thick and made of solid titanium...

Attacks Against...

- Access control
  - Biometrics
  - Authentication tokens
  - RFID
- Network appliances
  - Cryptographic accelerators
  - Wireless access points
  - Network adapters/NICs
  - PDAs/Mobile devices
Biometrics

- Measure and analyze human body characteristics in order to authenticate identity
  - Ex.: Fingerprint, hand geometry, eye pattern (iris or retina), facial features, or voice or written signature
- Considered more secure than systems that use passwords, but physical characteristics are hard to keep secret
  - Ex.: Fingerprint lifted from keyboard, picture can be taken of a face, voice can be recorded

Biometrics 2

- Usually composed of two or three components:
  - Biometric device, application software, back-end server
- Potential problems with storage of characteristics if not implemented properly
  - Biometric data could be stolen and/or cloned
- Some characteristics can change over time
  - Ex.: Glaucoma medicine changes retina color and vein pattern, scars on a finger, etc.
- If fingerprint is stolen, you only have nine more to use...
Biometrics: Fingerprint Cloning

- Current biometric fingerprint systems (optical & capacitive) are notoriously simple to bypass
- In May 2002, Tsutomu Matsumoto presented methods to defeat scanners by using a fake finger molded out of gelatin
  - http://cryptome.org/gummy.htm
- Defeated 11 different fingerprint systems 80% of the time

Biometrics: Fingerprint Cloning 2

1. Obtained latent fingerprint from a glass
2. Enhanced with cyanoacrylate adhesive (super glue) and photographed with digital camera
3. Edited contrast in Photoshop and printed onto transparency sheet
4. Use transparency to etch fingerprint onto photosensitive printed circuit board
5. Created gelatin finger from circuit board "mold"
Biometrics: Fingerprint Cloning 3

- Gelatin finger also fools capacitive sensors due to moisture and resistance characteristics similar to a real human finger
- Unlikely that gelatin finger will work on RF fingerprint scanning technologies
  - Used to image fingerprint structure in lower layers of skin

Authentication Tokens

- Used to provide identity in order to gain access to an asset
  - How do you prove you are who you say you are?
- Typically used in combination with a password
  - Two-factor
  - Something you know and something you have
- Common security-related uses
  - Private data storage (credentials, crypto keys, certs, passwords)
  - One-time-password generation
USB Authentication Token: Rainbow iKey 1000

- All data stored in easily accessible, unprotected Serial EEPROM
- Can gain full administrator access to device by generating a new key based on weak algorithm

USB Authentication Token 2: Rainbow iKey 1000

- Extremely easy to open with X-ACTO knife
  - Under 30 seconds with no visible damage
- Can attach probes to the unpopulated footprint and read the "encapsulated" EEPROM
  - 24LC64 uses I²C bus (serial clock and data)
USB Authentication Token 3: Rainbow iKey 1000

- MKEY (Master Key) serves as administrative password (gives full access to device)
  - 256 character ASCII, default = "rainbow"
  - Hashed MKEY stored at address 0x8

```
<table>
<thead>
<tr>
<th>MKEY Password</th>
<th>MD5</th>
<th>Hashed MKEY</th>
<th>Encode</th>
<th>Obfuscated MKEY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Default: &quot;rainbow&quot;</td>
<td>0xCD13B6A6AF66FB77</td>
<td>0xD2DD960B0D0F499</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

USB Authentication Token 4: Rainbow iKey 1000

A, Hashed MKEY value, md5("rainbow") = CD13 B6A6 AF66 FB77
B, Obfuscated MKEY value in EEPROM = D2DD B960 B0D0 F499

- \( B_1 = A_1 \text{ XOR } 0x1F \)
- \( B_2 = A_2 \text{ XOR } (A_1 + 0x01) \)
- \( B_3 = A_3 \text{ XOR } 0x0F \)
- \( B_4 = A_4 \text{ XOR } (A_3 + 0x10) \)
- \( B_5 = A_5 \text{ XOR } 0x1F \)
- \( B_6 = A_6 \text{ XOR } (A_5 + 0x07) \)
- \( B_7 = A_7 \text{ XOR } 0x0F \)
- \( B_8 = A_8 \text{ XOR } (A_7 + 0xF3) \)

Example:
- \( 0xD2 = 0xCD \text{ XOR } 0x1F \)
- \( 0xDD = 0x13 \text{ XOR } (0xCD + 0x01) \)
USB Authentication Token 5: Aladdin eToken 3.3.3.x

- All data stored in easily accessible, unprotected Serial EEPROM
- Can gain full user access to device by rewriting user PIN with default PIN

USB Authentication Token 6: Aladdin eToken 3.3.3.x

- Can use heat gun to soften glue around housing and split open with X-ACTO knife
- Can attach probes to the EEPROM and read with standard device programmer
  - Atmel 25640 uses SPI bus (serial clock, data in, data out)
USB Authentication Token 7:
Aladdin eToken 3.3.3.x

- Memory map of Serial EEPROM obtained by modifying eToken data on PC and viewing content changes in EEPROM

Ranges configured by administrator with eToken tools

$0000

Common Identifier
User PIN
Administrator PIN
Default PIN
FAT / File System Header Info
Private Data (Encrypted)
Secret Data (Encrypted)
Public Data (Cleartext)

$0 - $F
$10 - $17
$18 - $1F
$20 - $27

$1FFF

USB Authentication Token 8:
Aladdin eToken 3.3.3.x

User PIN
Admin PIN

Default PIN string

Initial memory dump, User and Admin PINs set to unknown values

Memory dump, after modification, with User PIN now set to default
Dallas Semiconductor iButton

- Designed to replace barcodes, RFID tags, magnetic stripes, proximity and smart cards
- Physical features: Stainless steel, waterproof, rugged, wearable, tamper responsive
- 1-wire Interface
  - Actually, 2 wires (clock/data and ground)
  - Parasitically-powered
  - 16kbps (standard) and 142kbps (overdrive)
- Unique 64-bit ID (non-secret) for each device

iButton: DS1991 MultiKey

- 1,152 bits of non-volatile memory split into three 384-bit (48-byte) containers known as “subkeys”
- Each subkey is protected by an independent 8-byte password
- Only the correct password will grant access to the data stored within each subkey area and return the 48-bytes
  - Incorrect password supposed to return 48-bytes of "random" data
- Commonly used for cashless transactions (e.g., parking meters, public transportation) and access control
iButton: DS1991 MultiKey 2

- Initial experiments with iButton Viewer (part of free iButton-TMEX SDK) showed that "random" response is actually based on input password.

![Image](image_url)

iButton: DS1991 MultiKey 3

- Based on input password and 12kB constant block
  - Constant for all DS1991 devices
- Can precompute the 48-byte return value expected for an incorrect password
- If return value does not match, must be the correct password and subkey data.
iButton: DS1991 MultiKey 4

- For any given character (256 possibilities), a unique 48-byte response is returned from iButton
- Created application to set each single-byte password and monitor serial port for response
- Trial and error to determine how response was generated for longer length passwords

Radio Frequency Identification (RFID)

- Generic term for non-contacting technologies that use radio waves to automatically identify people or objects
- Has been available for decades, but just now becoming popular for mainstream
  - Robotics navigation, inventory (human?) tracking, access control, automatic identification, payment systems, and car immobilization
Radio Frequency Identification (RFID) 2

- Most common use is to store unique serial number (read-only) on a microchip that is attached to an antenna
  - Combined antenna and microchip called a "transponder" or "tag"
- Typical RFID system contains a reader and one or more tags
  - Each tag's unique serial number identifies a specific person or object

Radio Frequency Identification (RFID) 3

- Two major tag types:
  - Passive: No internal power source or transmitter, shorter range
  - Active: Power source (battery) and transmitter, longer range
- Four typical frequency ranges:
  - LF (Low Frequency), 125 to 134.2kHz
  - HF (High Frequency), 13.56MHz
  - UHF (Ultra-High Frequency), 868 to 928MHz
  - uW (Microwave), 2.45 and 5.8 GHz
Radio Frequency Identification (RFID) 4

1. Reader's antenna transmits RF energy
2. Energy "harvested" by tag's antenna and used to power up internal circuitry
3. Tag will modulate electromagnetic waves generated by the reader to transmit data
4. Receiver demodulates waves and converts to digital signal

Radio Frequency Identification (RFID) 5

- No security between most tag and reader transmissions
  - If you have a reader for the correct tag family and frequency, you can communicate with the tag
- Trivial to create system to read/write RFID tags
  - Parallax RFID Reader Module, www.parallax.com
  - Texas Instruments Web Page, www.tiris.com
Radio Frequency Identification (RFID) 6

- Cracked challenge/response scheme of Digital Signature Transponder (DST) tag
  - Used for Mobil SpeedPass, vehicle immobilizers, etc.
- Proprietary cipher (based on 40-bit key) reverse engineered from a single PowerPoint slide
- Over 150 million deployed devices are now at risk and could be cloned or spoofed!

Intel NetStructure 7110: Administrator Access

- SSL cryptographic accelerator
  - Offloads crypto functions from primary Web server to increase performance
- Standard PC motherboard, Pentium II 333MHz, Rainbow (now SafeNet) CryptoSwift Accelerator card
Intel NetStructure 7110: Administrator Access 2

- Serial port-based management console on front of unit
- Can be compromised to allow supervisor access

Intel NetStructure 7110: Administrator Access 3

1. Opened the unit
2. Retrieved filesystem
   - Stored on 32MB CompactFlash card
3. Examined filesystem
   - Used `strings` to determine BSD-flavor of Unix
4. Mounted filesystem on extra machine
5. Discovered password generator
   - Supervisor password based on MAC address of unit
Intel NetStructure 7110: Administrator Access 4

- Based on standard PC architecture
- Filesystem easily retrievable and mountable
- Executables compiled with debug symbols
- Homebrew crypto routines extremely weak

Cisco Router: Configuration Password

- Three types of password
  - Type 0: Plaintext
  - Type 5: MD5 hash
  - Type 7: "Encrypted"
- “Encrypted” password stored on router
  - Stored in NVRAM and can be retrieved from configuration settings
- Passwords of type 7 encoded by XOR‘ing plaintext against constant value
  - www.alcrypto.co.uk/cisco among others
Cisco Router: Configuration Password 2

- Constant
  - "tfd;kfoA,.iyewrkldJKD"
- Ex.:

```
0 8 2 0 4 E = ab
```

offset 1st char. 2nd char.

IBM 4758 Secure Cryptographic Coprocessor

- Likely the most recognized, commercially available secure coprocessor system
  - A protected hardware subsystem designed to execute sensitive functions in a trusted manner
  - FIPS-140 Level 4 tamper responsive device with hardware cryptographic support and physical tamper protection
  - Also random number generation, authentication, general-purpose processor/coprocessor, etc.
- Commonly used in financial and banking transactions
IBM 4758 Secure Cryptographic Coprocessor 2

- In 2001, First known attack against IBM 4758 by taking advantage of a flaw in the Automated Teller Machine "Common Cryptographic Architecture" support software
  
  - "Extracting a 3DES key from an IBM 4758,"
  
  www.cl.cam.ac.uk/~rnc1/descrack

- Can export all of the program's DES/3DES keys
  
  - Ex.: Communications Key, Pin Derivation Key, and Importer/Exporter Keys

IBM 4758 Secure Cryptographic Coprocessor 3

- Performed by an insider with physical access and a $995 Altera FPGA Development Board
  
  - As of February 2002, new version (2.41) of CCA fixes problems

- Even though hardware was strong, software was able to be compromised, thus breaking the whole system
Wireless Access Points: Dell TrueMobile 1184

- One of many broadband access point/routers
- Device based on vLinux distribution
  - www.onsoftwarei.com/product_vlinux.htm
  - "Hardware Hacking: Have Fun While Voiding Your Warranty" Wireless Hacks chapter
- Port scan reveals open ports 80, 333, 1863, 1864, 4443, 5190, 5566

Wireless Access Points 2: Dell TrueMobile 1184

- Can telnet into port 333 with default password to gain complete control of the device
  - username: root, password: admin
- No special hardware tools or reprogramming is necessary
- Many devices running Linux which can make hacking/experimentation easier
  - www.linuxdevices.com
  - www.ucdot.org
NIC MAC Address Cloning

- MAC (Media Access Control) Address often stored in easily reprogrammable Serial EEPROM
- Cloning could be used to bypass copy protection, gain access to MAC-filtered networks, etc.
- MAC = 6-byte value
  - First 3 bytes = Manufacturer
  - Second 3 bytes = "Unique" serial number
- Depending on the NIC, other configuration data also accessible
  - Ex.: I/O base address, interrupt type, checksum

NIC MAC Address Cloning 2

- Can sometimes be changed in software
  - No hardware tampering needed!
  - SunOS: ifconfig
  - SPARC: set in NVRAM with prom-monitor

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>EEPROM</th>
<th>MAC Address</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Semiconductor</td>
<td>NSC 7</td>
<td>91C06</td>
<td>08:09:17:03:60:EE</td>
<td>N/A</td>
</tr>
<tr>
<td>Ansol Communications</td>
<td>N2000 Plus 3</td>
<td>95C46</td>
<td>00:09:00:50:07:7E</td>
<td></td>
</tr>
<tr>
<td>Microbyte</td>
<td>NE2000 Plus 3</td>
<td>95C06</td>
<td>00:80:20:B7:C2:9C</td>
<td>N/A</td>
</tr>
<tr>
<td>Linksys</td>
<td>Ether16</td>
<td>95C46</td>
<td>00:40:05:44:17:A7</td>
<td></td>
</tr>
<tr>
<td>Genius</td>
<td>GE2000 I</td>
<td>91C46</td>
<td>00:40:33:2A:82:82</td>
<td></td>
</tr>
</tbody>
</table>
| Winbond             | HI-2003CI | 95C46  | 48:54:33:01:48:24    | 5448 0133 2448 0000 3448 0135 2448 5757 4242 0000 0000 0000 0000 0000 0020 0020
Mobile Devices: Current Risks

- Business often mixed with personal
- Most devices have no security framework
  - No access control or data/memory protection
  - Existing security mechanisms are weak and/or flawed
- "Always on" technologies leave device open to the world...all the time
  - Ex.: WiFi, Bluetooth, IR, etc.
- External memory cards
  - Some devices load apps automatically upon insertion
  - Easy to steal

Mobile Devices:
Palm OS < 4.0 Password Retrieval

- Max. 32 characters ASCII
- Reversible obfuscation method (XOR against constant)
  - “Palm OS Password Retrieval and Decoding,”
    www.grandideastudio.com/files/security/mobile/palm_password_decoding_advisory.txt
- Can retrieve password/hash:
  - During HotSync operation (IR, Serial, Network)
  - On Palm: “Unsaved Preferences” database
  - On host PC: \Palm\users.dat
  - On host Mac: Palm:Users:Palm Users
Mobile Devices: Palm OS >= 4.0 Password Retrieval

- Max. 32 characters ASCII
- Encoded block is 128-bit MD5 hash (not reversible)
- Dictionary attack still possible using common words
  - Take advantage of short passwords

Mobile Devices: Palm OS Backdoor Debug Mode

- Exists for debugging during app development
- Can install/delete/run apps, view raw memory, hard reset, export databases
- Can use to bypass “System Lockout” functionality (OS < 4.0)
  - www.grandideastudio.com/files/security/mobile/palm_backdoor_debug_advisory.txt
- No notification of activity is evident on device
- Can use pdd or PDA Seizure to create exact forensic image of data
Mobile Devices:
Pocket PC Password Retrieval

- ActiveSync used for all communication between PC and device
  - Available through serial, USB, IR, TCP/IP, Bluetooth
- Reversible obfuscation method (XOR against constant)
- Can retrieve password/hash:
  - In host PC registry: HKEY_CURRENT_USER\Software\Microsoft\Windows Ce Services\Partners

Mobile Devices:
Pocket PC Password Retrieval 2

- On some devices, 4-digit PIN used for authentication can be manually brute-forced
- Pocket PC registry accessible by any user on the device
  - PHM Registry Editor, www.phm.lu/Products/PocketPC/RegEdit
  - Ex.: PPP network passwords stored in plaintext
- Can change Control Panel Applet (cpl) entry in registry to redirect password screen
  - Microsoft "Let Me In" example, Q314989

- Exists for debugging during app development
  - Provides remote debugging and device access to Windows CE / Pocket PC
  - Developer's documentation publicly available
  - Uses ActiveSync protocol
- Can access Pocket PC registry, install/delete/run apps, export databases

Mobile Devices: Pocket PC Phone Edition

- Allows access to a device without passing any access controls
  - http://forum.xda-developers.com
- Provides a detailed debugging and diagnostics interface through sync port
- Special mode to recognize diagnostic external memory cards and can execute code directly from them
Mobile Devices: Pocket PC/XDA Bootloader

Source: "The Phone in the PDA," Job de Haas, Black Hat Amsterdam 2003

Advanced Attack Methods

- Chip Decapping and Die Analysis
  - Attacker can visually recreate contents or modify die (Ex.: to obtain crypto key or remove security bit)
  - Tools: Chip Decappers, Scanning Electron Microscope, Voltage Contrast Microscopy, Focused Ion Beam
**Advanced Attack Methods 2**

- **X-Ray**
  - Attacker can bypass any encapsulation methods to determine inner bus structures and circuit configurations
  - "How to Crack a Pac Man Plus!,”
    - [www.multigame.com/pacplus.html](http://www.multigame.com/pacplus.html)

**Common Hardware Design Problems**

- Most/many engineers not familiar with security
- No anti-tamper mechanisms used
  - Easy to open up product and probe circuitry
- Many products based on publicly-available reference designs
- Components easy to identify
  - Circuitry can easily be reverse engineered
Common Hardware Design Problems 2

- Improper protection of external memory
  - Most memory is notoriously insecure
  - Serial EEPROMs can be read in-circuit
  - SRAM-based FPGA configuration can be sniffed
- "Security through obscurity" still practiced
  - Hiding something does not make the problem go away

Conclusions

- Even though technology has advanced, same classes of problems still plague hardware
- Most, if not all, hardware solutions are open to attack
- Hardware is usually inherently trusted
  - Black box != security
- Blindly trusting hardware leads to a false sense of security
  - Hardware is not voodoo
Thanks!

Joe Grand
Grand Idea Studio, Inc.

www.grandideastudio.com