Understanding Hardware Security

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Goals

- Learn the concepts of designing secure hardware
- Become familiar with types of attacks and attackers

General Security Concepts

- Nothing is ever 100% secure
  - Given enough time, resources, and motivation, an attacker can break any system
- Secure your product against a specific threat
  - What needs to be protected
  - Why it is being protected
  - Who you are protecting against (define the enemy)

General Security Concepts 2

Security During Product Development

- Establish a security policy as the "foundation" for design
- Treat security as an integral part of your product's development
- Minimize the elements you need to secure
- Reduce risk to an acceptable level
  - Elimination of all risk is not cost-effective

Security During Product Development 2

- Implement layered security
- Do not implement unnecessary security mechanisms
  - Each mechanism should support a defined goal
- Costs of a successful attack should outweigh potential rewards

Types of Attack

- Insider Attack
  - Significant percentage of breaches
  - Ex.: Run-on fraud, disgruntled employees
- Lunchtime Attack
  - Take place during a small window of opportunity
  - Ex.: During a lunch or coffee break
- Focused Attack
  - Time, money, and resources not an issue

Types of Attackers

- Clever Outsiders
  - Intelligent, but have limited knowledge of the product
  - Usually take advantage of a known weakness
  - Ex.: Curious kids, college students
- Knowledgeable Insiders
  - Substantial specialized technical experience
  - Highly sophisticated tools and instruments
  - Ex.: Professional engineers

Types of Attackers 2

- Funded Organizations
  - Specialists backed by great funding resources
  - In-depth analysis, sophisticated attacks, most advanced analysis tools
  - Ex.: Government, organized crime

Accessing the Product

- Purchase
  - Attacker buys the product from a retail store
- Evaluation
  - Attacker rents or borrows the product
- Active
  - Product is in operation, not owned by attacker
- Remote Access
  - No physical access to product
  - Attacks launched remotely

Threat Vectors

- Interception (or Eavesdropping)
  - Gain access to information without opening the product
- Interruption (or Fault Generation)
  - Preventing the product from functioning normally
- Modification
  - Invasive tampering of the product
- Fabrication
  - Creating counterfeit data in a product

Goals of an Attack

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

Anti-Tamper Mechanisms

- Primary area of physical security for embedded systems
- Attempts to prevent unauthorized physical or electronic tampering against the product
- Most effectively used in layers
- Possibly bypassed with knowledge of method
  - Attackers may intentionally destroy a device to determine its security mechanisms

Anti-Tamper Mechanisms 2

- Tamper Resistance
  - Specialized materials used to make tampering difficult
  - Ex.: One-way screws, epoxy encapsulation
- Tamper Evidence
  - Ensure that there is visible evidence left behind by tampering
  - Only successful if a process is in place to check for deformity
  - Ex.: Passive detectors (seals, tapes, glues), special enclosure finishes ("bleeding paint")

Anti-Tamper Mechanisms 3

- Tamper Detection
  - Enable the hardware device to be aware of tampering
  - Switches: Detect the opening of a device or breach of security boundary
  - Sensors: Detect an operational or environmental change (ex.: temperature, voltage, radiation)
  - Circuitry: Detect a puncture, break, or attempted modification of a defined security envelope (ex.: nichrome wire, W.L. Gore's D3 enclosure)

Anti-Tamper Mechanisms 4

- Tamper Response
  - Countermeasures taken upon the detection of tampering
  - Ex.: Erase memory, shutdown/disable device, enable logging
- *Physical Security Devices for Computer Subsystems* [1] provides comprehensive attacks and countermeasures

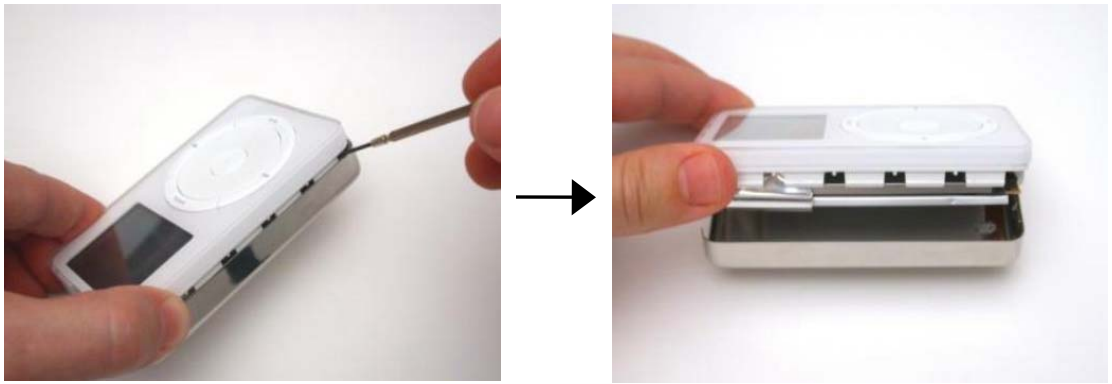
Enclosure & Mechanical

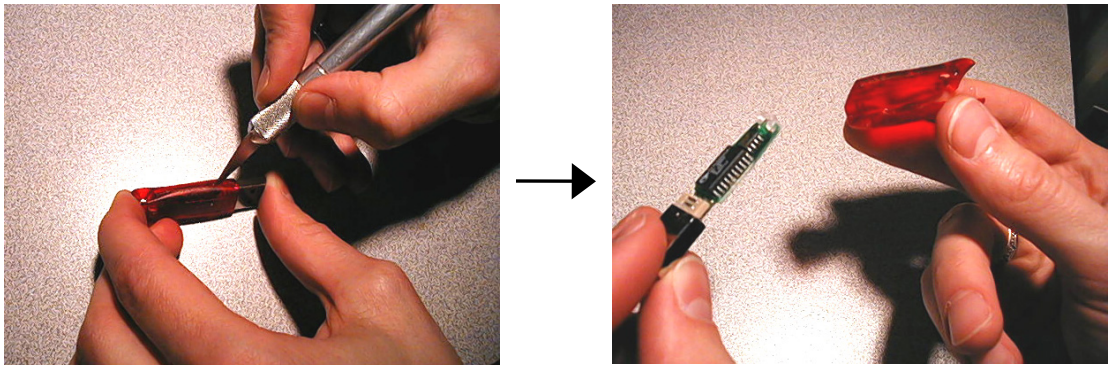
- Product Housing
- External Interfaces

Product Housing

- Attack goal of opening the product is to get access to internal circuitry
- Usually as easy as loosening some screws or prying open the device
- Designers should prevent easy access to product internals

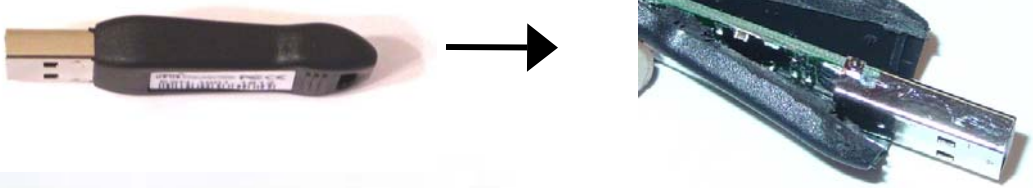
Product Housing 2





Product Housing 3

- Sealed or molded housing
  - Use a high-melting point glue
  - Use ultrasonic welding to create a one-piece outer shell
  - Will require destruction of device to open it
  - Consider service issues (if a legitimate user can open device, so can attacker)



Product Housing 4

- Security bits and one-way screws
  - Prevents housing from being easily opened
  - Ex.: 3.8mm, 4.5mm, and Tri-Wing screw for Nintendo and Sega cartridges/consoles
  - Beware: Attackers can purchase many of these special bits online

External Interfaces

- Usually connects a product to the outside world
  - Manufacturing tests, field programming/upgrading, peripheral connections
  - Ex.: RS232, USB, Firewire, Ethernet, JTAG (IEEE 1149.1)

External Interfaces 2

- Will likely be probed or monitored by attacker
- Only publicly known information should be passed
- Encrypt secret or critical components
  - If they must be sent at all...
  - Ex.: Palm OS system password decoding attack [2]

External Interfaces 3

- Don't just hide the interface
  - Will easily be discovered by an attacker
  - Ex.: Proprietary connector types, hidden access doors or holes, stickers
- Protect against malformed, bad packets
  - Intentionally sent by attacker to cause fault

External Interfaces 4

- Physically remove all diagnostic, debug, and backdoor interfaces from production units
  - Even if they are undocumented
  - Difficult to do
  - Do not just cut traces or remove resistors (which could be repaired by an attacker)
  - Ex.: Intel NetStructure crypto accelerator administrator access [3], Palm OS debug mode [4]

External Interfaces 5

- Field programmability
  - Only allow new versions of firmware to be loaded into product (so attacker can not make use of old, known security flaws)
  - Do not release firmware on your Web site (could be disassembled and analyzed by attacker)
  - If you must, use code signing (DSA) or hashes (SHA-1, MD5) to verify integrity
  - Even better, encrypt firmware images

Circuit Board

- Physical Access to Components
- EMI/ESD/RF Interference
- PCB Design and Routing
- Memory and Programmable Logic
- Power Supply
- Cryptographic Processors and Algorithms

Access to Components

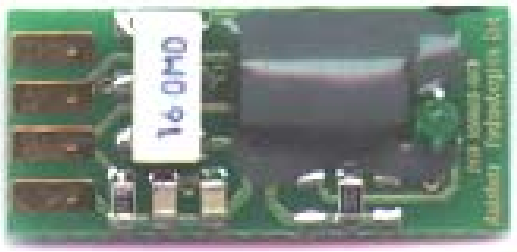
- Giving an attacker easy access to components aids in reverse engineering of the product
- Make sensitive components difficult to access
  - Ex.: Microprocessor, ROM, RAM, ASICs, FPGAs
- Remove identifiers and markings from ICs
  - Use stainless steel brush, small sander, micro-bead blast, laser etcher, or third-party
  - Easy for attacker to find data sheets online

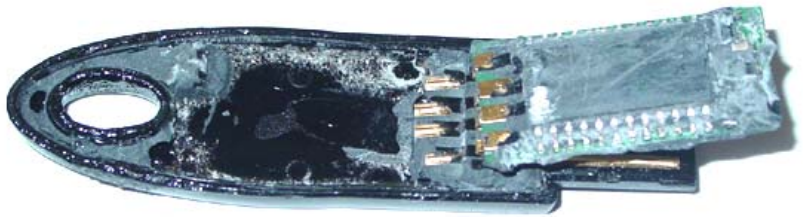
Access to Components 2

- Use advanced package types
  - Difficult to probe using standard tools
  - Ex.: BGA, Chip-on-Board (COB), Chip-in-Board (CIB)
- Use proprietary or customized ICs

Access to Components 3

- Cover critical components with epoxy or urethane encapsulation
  - Usually used to protect circuitry from moisture, dust, mold, corrosion, or arcing
  - Difficult, but not impossible, to remove with chemicals or tools





EMI/ESD/RF Interference

- All devices generate electromagnetic interference (EMI)
- Can be monitored and used by attacker to determine secret information
  - Ex.: Data on a computer monitor [5], cryptographic key from a smartcard [6]
- Devices may also be susceptible to RF or electrostatic discharge (ESD)
  - Intentionally injected to cause failure

EMI/ESD/RF Interference 2

- Install EMI shielding
  - Decrease emissions and increase immunity
  - Ex.: Coatings, tapes, sprays, housings
  - Be aware of changes in thermal characteristics that shielding may introduce (heating)
- Prevent against ESD on exposed I/O lines
  - Clamping diodes or Transient Voltage Suppressors
  - Ex.: Keypads, buttons, switches, display
- Keep circuit traces as short as possible

EMI/ESD/RF Interference 3

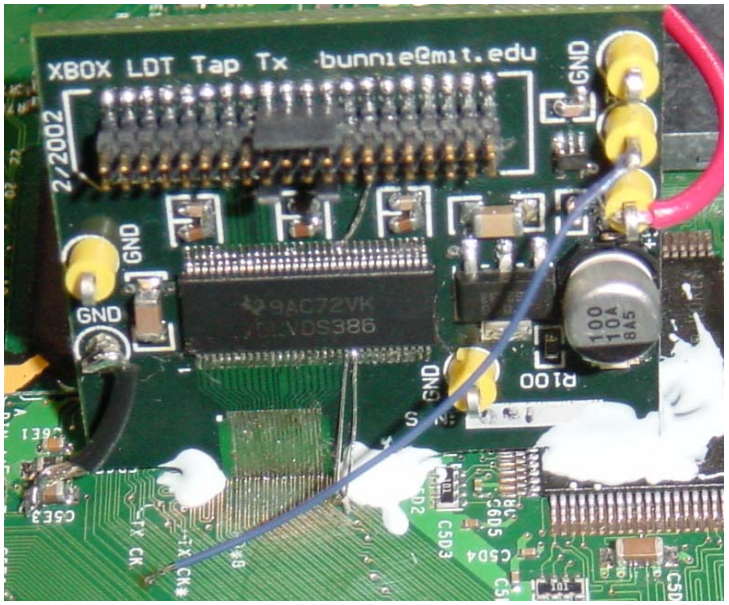
- Use properly designed power and ground planes
- Power supply circuitry as physically close as possible to power input
- Remove unnecessary test points
  - Use filled pad as opposed to through-hole, if necessary
- Unused I/O pins and modules should be disabled or set to fixed state

PCB Design and Routing

- Confuse trace paths to prevent easy reverse engineering
  - Hide critical traces on inner board layers
  - Be aware of data being transferred across exposed and/or accessible address, data, and control buses
- Use buried vias whenever possible
  - Connects between two or more inner layers but no outer layer
  - Cannot be seen from either side of the board

PCB Design and Routing 2

- Ex.: Tap board used to intercept data transfer over Xbox's HyperTransport bus [7]



Memory and Programmable Logic

- Most memory is insecure
  - Can be read with standard device programmer
  - Serial EEPROMs can be read in-circuit, usually SPI or I^2C bus (ex.: USB authentication token [8])
- Difficult to securely and totally erase data from RAM and non-volatile memory [9]
  - Remnants may exist and be retrievable from devices long after power is removed

Memory and Programmable Logic 2

- SRAM-based FPGAs most vulnerable to attack
  - Must load configuration from external memory
  - Bit stream can be monitored to retrieve data
- Protect against I/O scan attacks
  - Attacker cycles through all possible combinations of inputs to determine outputs
  - Use unused pins to detect probing

Memory and Programmable Logic 3

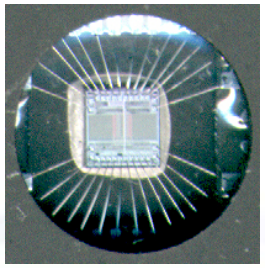
- Security fuses and boot-block protection
  - Enabled for "write-once" access to a memory area or to prevent full read back
  - Implement if available
  - Ex.: PIC16C84 attack in which security bit is removed by increasing VCC during repeated write accesses [10]

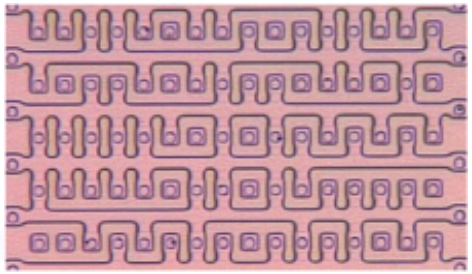
Memory and Programmable Logic 4

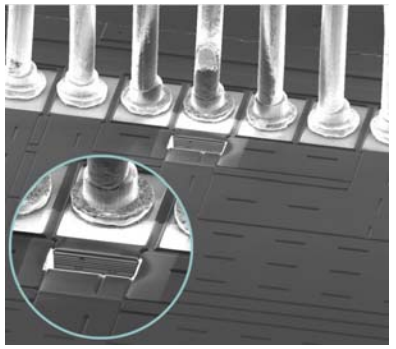
- Limit the amount of time that critical data is stored in the same region of memory
  - Periodically flip the stored bits
- If using state machine, ensure all conditions and defaults are covered
- Add digital "watermarks"
  - Features or attributes in design that can be uniquely identified as being rightfully yours

Memory and Programmable Logic 5

- Chip Decapping and Die Analysis attacks
  - 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







Power Supply

- Define minimum and maximum operating limits
  - Ex.: Comparators, watchdogs, supervisory circuits
- Do not rely on end user to supply a voltage within recommended operating conditions
  - Implement linear regulator or DC-DC converter

Power Supply 2

- Simple Power Analysis (SPA)
  - Attacker directly observes power consumption
  - Varies based on microprocessor operation
  - Easy to identify intensive functions (ex.: cryptographic)
- Differential Power Analysis (DPA)
  - Advanced mathematical methods to determine secret information on a device

Cryptographic Processors and Algorithms

- Strength of cryptography relies on secrecy of key, not the algorithm
  - Do not create your own crypto algorithms
- It is not safe to assume that large key size will guarantee security
- If algorithm implemented improperly, can be broken or bypassed by attacker
  - Test implementations in laboratory first!

Cryptographic Processors and Algorithms 2

- Move cryptographic processes out of firmware and into FPGA
  - Harder to probe than ROM devices
  - Increased performance (more efficient)
- Or, use secure cryptographic coprocessor
  - Self-contained, hardware tamper response, authentication, general-purpose processor
  - Ex.: Philips VMS747, IBM 4758

In Conclusion

- Determine what to protect, why you are protecting it, and who you are protecting against
  - No one solution fits everyone
- Do not release product with a plan to implement security later
  - It usually never happens...
- Nothing is 100% secure

In Conclusion 2

- Be aware of latest attack methodologies & trends
- As design is in progress, allocate time to analyze and break product
- Learn from mistakes
  - Study history and previous attacks

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Thank You!

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