Plaid Parliament of Pwning 2024 eCTF Team

Carnegie Mellon University

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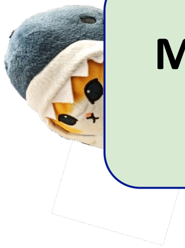
Presentation Outline

- **Design Phase**
  - Overview
  - Design Highlight: Zero-Trust Architecture
- **Attack Phase**
  - I2CBleed Exploit
  - Supply Chain I2CBleed
  - Other Attacks + Interesting Defenses
- **Project Management + Lessons Learned**

Our Design Highlights

- Encryption At-Rest of *Everything*
- Custom Hardened Physical Link Layer
- Encrypted Link Layer Wrapper
- Random Nonces to Prevent Replays
- ChaCha-Poly AEAD for encryption
- Board RNG + von-Neumann
- Minimal External Code Surface
- Avoid Interrupts & Async Code
- Random Delays + Redundant Checks



Design Highlight: Zero-Trust Architecture

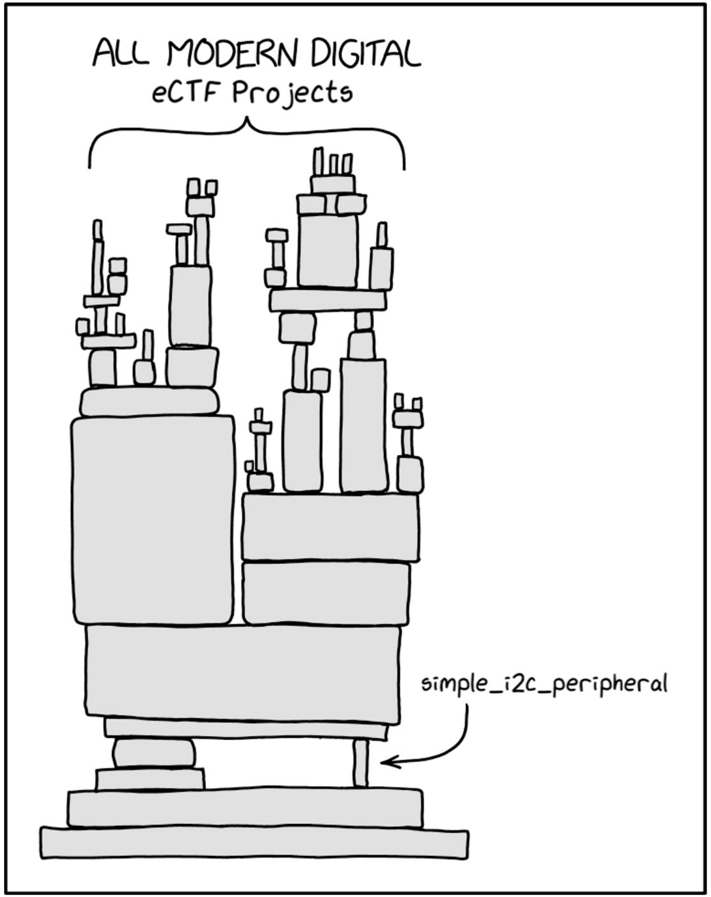
- **Thought Experiment:** Assume full hardware compromise
  - How to defend flags? Can we use fun crypto tricks?
- *BB Boot / BB Extract*: Encrypt comp. secrets w/ key stored in AP
- *Op. PIN Extract / SC Extract*: Encrypt keys inside AP w/ PIN
  - *Potential for offline brute-force if AP compromised
- *Op. Pump Swap:* Not defensible, but encrypt the code to make it harder
- *SC Boot / Damaged Boot:* ?????
  - How to require both components to be present in order to boot?

Design Highlight: Zero-Trust Architecture

- **Damaged Boot: Require all components be present in order to boot?**
- “Russian Encryption Doll”: Encrypt AP boot data with all component keys
- How to distribute component keys?
    - Comp Key = Hash(Root Key || Comp ID)
- How to do **replace component?**
    - Keep Root Key encrypted with Replace Token
    - RT is long enough to not be brute-able

Attack Highlight: I2CBleed

- **Three vulnerabilities in starter code**
  - Read/write indices not reset on repeated start
  - Read index checked for == instead of >=
  - Write index casted to unsigned (overflows)
- **Result: Arbitrary Read/Write (!!!)**
  (of anything past `I2C_REGS`)
- **Straightforward Attack Process**
  1. Write in malicious shellcode
  2. Write a bunch of padding
  3. Overwrite vector table to jump to shellcode



Attack Highlight: Fully-Automated I2CBleed

- **Q: What to do with a near-universal arbitrary-code-execution exploit?**
  - A: Make it *full auto: <u>4-5 flags in 90 seconds from ZIP download</u>*
- **Step 1: Determine I2C Address of Victim**
  - Scan all addresses, see which ones ACK (like insecure `list_components`)
- **Step 2: Determine `I2C_REGS` address (shellcode address)**
  - Use arbitrary read until the component crashes (stops ACKing)
- **Step 3: Inject shellcode**
  - Step 3.5 (SC only): Scan until we find the string “`ctf{`“
  - Locally: Dump all of flash to the UART (including keys and plaintext flags!!)
- **Step 4 (SC only): Bitbang SPI data back to malicious component**
  - Malicious component receives SPI and dumps anything transmitted over UART

Interesting Defenses

- **Defending against I2CBleed**
  - Certificate Chain: Provide each component with a ID-unique certificate signed using a deployment-time CA
  - Encrypt component attestation data / boot message with key stored in AP
  - Key pinning to assign unique component keys (bypass deployment hash check...)
- **Other unique defenses**
  - Challenge-response handshake on every message in the system
  - Custom I2C implementation (don’t trust provided libraries...)
  - Use of hardware features / PUFs to prevent emulation

Project Management + Lessons Learned

- **Design Phase**
  - Get everyone set up with insecure example in the first week
  - Design security protocol *before* starting implementation, but can start generic tasks (scripting, infra, comms, crypto library) simultaneously
  - Secure By Design: Drive out the attacker in every possible way
- **Attack Phase**
  - Balance between optimizing conventional attacks and developing novel attacks
  - Track red-team availability for executing rapid attacks for first bloods
  - Be willing to operate at strange hours (sadly)

Project Management + Lessons Learned

- **Overall**
  - Earning course credit helps offset the time investment
  - Cross-Training: EEs studied crypto, Security students studied electronics
  - If viable, hardware setup for each team member to individually play with
- **Lessons Learned**
  - Sustainability of having most of the work be done by a few team members?
  - Redundancy to avoid single points of failure (esp. for design phase timeline)
  - Novel attacks require *a lot* more human-hours than estimated, fine-tuning "standard" attacks can be better

Sponsors Acknowledgement

We acknowledge the generous support of the following sponsors to our team:

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Thank you!

Extra Slides