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Untangling Secure Key Provisioning in U-Boot: Scalable eFuse Programming in Production

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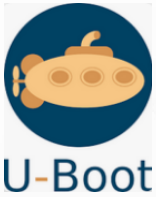
About us: TI Processors and Open Source

Upstream FIRST!

Open Source

- ✓ Upstream FIRST mentality!
- ✓ Decades of contribution and collaboration
- ✓ Focus on long term, sustainable and quality products
- ✓ Upstream & opensource ecosystem in device architecture
- ✓ Ingrained culture to give back to the community



About Speakers

Harsha Vardhan V M

Security Software Engineer, Texas Instruments

Silicon root-of-trust configuration, cryptographic key management and lifecycle state enforcement

Kavitha Malarvizhi

Security Architect, Texas Instruments

System Security, Secure boot, Cybersecurity

Texas Instruments

Why eFuse Provisioning Matters

- eFuse (Electronic Fuse) - a single non-volatile memory bit that can be blown only once.
- The programming operation is irreversible.
- eFuses control:
  - various permanent configurations and data
  - boot configurations, security settings, MAC addresses
  - secure boot enablement, silicon identity, cryptographic keys

- Factory provisioning of thousands of devices must be reliable and repeatable

How eFuses are Programmed today (in U-boot)

- Low-level, command-driven interface
- eFuses organized as:
  - **Words** - smallest group of efuses
  - **Banks** - smallest group of fuse words
- eFuses accessed via: Bank + Word addressing
- Programming flow: ***fuse prog*** – mention exact location and value
- Supports contiguous writes only
- ! No structure, no flexible non-linear batching

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U-Boot's Existing Fuse Subsystem Commands

1. fuse read
- Read fuse words from shadow cache

2. fuse readm
- Read fuse words into memory

3. fuse sense
- Read fusebox directly (bypasses shadow cache)

4. fuse cmp
- Compares the fuse value to a hex value

5. fuse override
- Modify shadow cache (non-permanent)

6. fuse prog
- Permanently program fuse words (irreversible)

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The Reality of Traditional eFuse Programming

- Most teams use long, manual U-Boot *fuse prog <bank> <word> <hexval> [<hexval>…]* cmd sequences
- Works for bring-up but breaks down in production

Typical pain points:

  - Difficulty handling **vendor-specific, non-linear** fuse maps
  - **Repititive, manual** cmd-by-cmd programming that doesn't scale
  - Increased risk of **typing mistakes or sequence errors**
  - Hard to integrate into **automated workflows**

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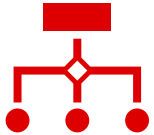
The Reality of Traditional eFuse Programming

Even a small OTP layout change -> rewrite entire command sequences



Example:

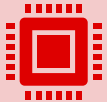
- Programming a complex non-linear OTP region.
- Run multiple fuse prog operations manually, in the right order & offsets
- One mistake can:
  - Lock a device prematurely
  - Burn the wrong lifecycle state
  - Misprogram a key region
  - Leave secure boot half-enabled

Risky and incompatible with factory automation tools

Introducing Buffer-Based Fuse Programming – fuse writebuff

Program OTP fuses using a structured buffer in memory – *fuse writebuff <addr>*

Buffer containing all necessary details for programming fuses



High-level idea:

- Construct a single buffer representing the OTP map
- Load the buffer into memory
- Let U-Boot program it
- One command, deterministic result

Fuse writebuff upstreamed into U-boot in 2025 - https://docs.u-boot.org/en/latest/usage/cmd/fuse.html

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From Imperative Commands -> Data-Driven Provisioning

- ❌ Imperative model (fuse prog):
  - “How & What to program” encoded in commands
- ✅ Declarative model (fuse writebuff):
  - “What to program” defined as structured data
  - “Consistent mechanism” to apply across platforms
- Enables:
  - Batch programming
  - Strict validation before execution
  - Automation-friendly workflows

- Changed the model and redesigned the abstraction

Towards Scalable, Production-Ready eFuse Provisioning

Solves several long-standing issues

- Makes non-linear and change in OTP maps manageable
- Eliminates manual sequencing and misalignment
- No command-scripting errors
- Reduces programming time
- Easy integration with flashing automation flows
- Enables reproducible provisioning across devices

Production Considerations

- Version-control buffers
- Validate buffer boundaries
- Always verify after programming
- Lock bits written last
- Capture failures & fallback paths

TI's AM62L Processor Case Study

Step 1: Prepare the buffer and load into memory

```
U-Boot 2026.01-ti-gee3048ee0822 (Apr 09 2026 - 00:09:07 +0000)

SoC:   AM62LX SR1.1 HS-FS
Model: Texas Instruments AM62L3 Evaluation Module
```

```
=> setenv myscript 'mw 0x82000000 0 0x400; fatload mmc 1:1 0x82000000 keywrlite_ss_tool_commit_744244f_tifs_release.bin; md 0x82000000'; run myscript
636 bytes read in 32 ms (18.6 KiB/s)
82000000: 00000001 00009045 02209012 00000100  ....E..... .....
82000010: 00000000 00000000 00000000 00004a7e  ............~J..
82000020: a5a5a55a 00000000 00000000 00000000  Z...............
82000030: 00001234 5aa5a55a b002601f b7b0d97c  4...Z..Z.`..|...
82000040: a89c7dc4 7be5aad1 a184878e 2b6b632f  .}.....{..../ck+
82000050: 987d0d76 97188fa1 f2d0df60 b10c2b3e  v.}.....`...>+..
82000060: c7edc70e 3dacedc6 e0efdf9b ff3fdced  .......=......?.
82000070: 87ade97f 7d529551 00000000 00000000  ....Q.R}........
82000080: 00009ffc 5aa5a55a 78e24b38 b20ea5a7  ....Z..Z8K.x....
82000090: acfffd5a 06d38b2e 513b2af8 05f870a7  Z........*;Q.p..
820000a0: b9de9d6c 3d0d1bf3 3e06a03e 7a12e36d  l.....=>..>m..z
820000b0: 44a1c847 0de1c73f 16b5ffad b4aeae01  G..D?...........
820000c0: e007d699 80cd7428 00000000 00000000  ....(t..........
820000d0: 00005678 5aa5a55a 00000003 00000000  xV..Z..Z........
820000e0: 00000000 000062c8 a5a5a55a 00000001  .....b..Z.......
820000f0: 00000000 00000000 00008bad a5a55a5a  ............ZZ..
=>
```

Step 2: Program using fuse writebuff

```
=> fuse writebuff -y 0x82000000
Programming fuses using a structured buffer in memory starting at addr 0x82000000
NOTICE:  Writebuff version info: 0x1
=>
```


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TI's AM62L Processor Case Study

- Secure boot enabled

```
U-Boot 2026.01-ti-gee3048ee0822 (Apr 09 2026 - 00:09:07 +0000)

SoC:   AM62LX SR1.1 HS-SE
Model: Texas Instruments AM62L3 Evaluation Module
```

- Fuse read user readable OTP data

```
=> fuse read 0 0 32
Reading bank 0:

Word 0x00000000: abcdef56 00000000 00000000 00000000
Word 0x00000004: 00000000 00000000 00000000 00000000
Word 0x00000008: 00000000 00000000 00000000 00000000
Word 0x0000000c: 00000000 00000000 00000000 00000000
Word 0x00000010: 00000000 00000000 00000000 00000000
Word 0x00000014: 00000000 00000000 00000000 00000000
Word 0x00000018: 00000000 00000000 00000000 00000000
Word 0x0000001c: 00000000 00000000 00000000 00000000
=>
```


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Q&A

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