

# bso2 Monitor Reference

Target: W65C02EDU | Source: SRC/bso2.asm | Generated: 2026-02-23

## 0) Naming

bso2 is the preferred written form in this manual.

It is intentionally dual-meaning and retro-styled:

- b = 6 = Basic
- s = 5 = System
- o = 0 = Operations
- 2 = 2 = /2 (homage to IBM System/36)

That makes 6502 a visual shorthand for bso2.

Expanded meaning: Basic System Operations/2.

Release marker format: R#M#V#I## where I means INTERNAL.

## 1) Startup / Prompt Behavior

On reset with valid reset cookie, boot choices are C/W/M:

C = clear RAM (confirm Y/N)

W = warm start

M = enter monitor

Power-on prompt uses C/M with a 6-second wait and > tick markers; timeout defaults to C.

Reset-cookie prompt uses C/W/M with a 6-second wait and < tick markers; LEDs blink every ~333ms while waiting and timeout defaults to M.

Boot-choice and clear-confirm prompts echo keypresses in uppercase.

### C/W/M Decision Truth Table

Condition	Input	Result
Power-on (no valid reset cookie)	C	Enter clear path.
Power-on (no valid reset cookie)	M	Enter monitor path.
Power-on (no valid reset cookie)	Timeout	Default to clear path (C).
Power-on (no valid reset cookie)	Invalid key	Ignored; prompt/countdown continues.
Reset with valid cookie	C	Enter clear confirmation prompt Y/N.
Clear confirmation	Y	Run clear-memory path.
Clear confirmation	N	Abort clear and continue warm path (W-equivalent branch).
Reset with valid cookie	W	Warm-recovery monitor path (no clear); may print terse restart hints.
Reset with valid cookie	M	Clean monitor path.

Reset with valid cookie	Invalid key	Ignored; prompt/countdown continues.
Reset with valid cookie	Timeout	Default to monitor path (M).

Note: this is the default behavior for the currently installed vector trampolines/handlers; future trampolines or handlers may implement different startup policy.

Warm-recovery hints are advisory only; they do not auto-resume execution.

Default terminal width is 80 columns at reset.

Default runtime policy enables both I T0 1 and I I 1 at boot (Timer1 free-run on, CPU IRQ enabled).

EDU LED heartbeat timing from Timer1: base 122.0703125 Hz (period 8.192 ms), overlay toggle 0.476837158 Hz (~2.097 s per edge), full blink cycle 0.238418579 Hz (~4.194 s period).

Runtime terminal control is via T: T/T C clears viewport; T 20|40|80|132 sets wrap width.

Legacy width-prompt timeout byte remains pinned at \$007B (TERM\_WIDTH\_TIMEOUT) for compatibility.

After clear/startup, the sign-on banner (BS02\_INIT) is printed:

```
**** basic system operations/2 ****
****   b s o / 2  R0M0V2I01 ****
****       6 5 0 2          ****
```

Monitor prompt is a single - character on a new line.

## 2) Command Summary

Cmd	Syntax	Behavior / Output	Flags / Notes
?	?	Short help line.	Quick command list only.
H	H [A P M S]	Help index or scoped help sections.	H=index, H A=all, H P=protection, H M=memory/tools, H S=steering.
Z	Z	Clear RAM after Y/N confirmation.	Zeroes \$0200-\$7EFF. Does not zero \$0000-\$01FF (ZP/stack) or \$7F00-\$7FFF (I/O area).
T	T, T C, T 20 40 80 132	Terminal clear and width control.	T/T C: emits CR then LF x127. Width applies to global output wrapping.
D	D [START [END]]	Hex+ASCII dump. END is inclusive.	D alone repeats last span from next address. Hex/ASCII fields show an 8+8 split.
U	U [START END]	Disassemble as 65C02 mnemonics and operands.	END is inclusive. Bare U repeats from saved next-instruction address. Emits

			ADDR: MNM OPERAND .
A	A START [INSN]	Tiny 65C02 assembler, interactive at next address.	Example: A 1000 LDA #FF then prompt A 1002: . . exits. No labels/forward refs. Relative branches accept absolute hex targets and are range-checked. Explicit accumulator form like INC A is supported.
X	X	Reserved for future command family.	No active behavior in current firmware.
I	I, I A, I T0 [0 1], I I [0 1], I C <RPN...> or IC <RPN...>	Info root, about text, timer heartbeat toggle/query, IRQ mask toggle/query, or 16-bit hex RPN evaluation.	I T0=show Timer1 heartbeat state, I T0 1=enable, I T0 0=disable. I I=show CPU IRQ mask state, I I 1=enable IRQ, I I 0=disable IRQ. Boot defaults are I T0 1 and I I 1. RPN values are 1..4 hex digits (optional \$), operators: + - * / &   ^ ~, output I C = \$HHHH .
R	R START, R [A=HH] [X=HH] [Y=HH], or !R START	Run or resume based on debug- context state.	If no debug context exists, R START executes from address. If debug context exists, bare R resumes via RTI with optional A/X/Y overrides; address-form prints R CTX ACTIVE, R [A/X/Y=] or !R START unless forced with !R START .
N	N	Run to next sequential instruction.	Implements next- stop by patching a temporary BRK at PC+len(opcode) . RAM only; ROM/I/O patch targets are

			rejected. Debug output restores and displays the original stepped-to instruction in CURR: .
M	M [START [B0..B15]]	Modify/deposit memory. Inline deposit supports up to 16 bytes.	Interactive mode: CR/LF = next , . ends. CRLF pair counts as one next.
F	F START END B0[..B15]	Fill inclusive range with repeating 1..16 byte pattern.	No interactive mode. Verifies each write.
C	C SRC_START SRC_END DST_START	Copy inclusive source range to destination.	Overlap-safe (forward/backward selection). Verifies each write.
S	S B START END ... or S C START END TEXT	Search memory for byte patterns or text.	Prints hit address plus aligned row base context.
L	L S   L G S   L B ADDR LEN	Load Motorola S-records or raw bytes.	L G S / LGS auto-jumps to the S7/S8/S9 start address after successful load.
!	!F ..., !M ..., !C ..., !A ..., !N, !R START	Force-prefix for protected commands and explicit run override.	Allows access to protected low RAM ( \$0000-\$0FFF ). For R with active context, !R START force-runs from address and drops old context.
Q	Q	Enter WAI halt loop.	IRQ masked. Resume by NMI (or Reset). NMI latch returns cleanly to monitor.
V	V	Show vector jump chains.	Spaced format: RST: FFFC > F818 > 8004 > A8CB > [0080] > 800D . IRQ appends sub-dispatch lines: BRK: XXXX <name> and HW: YYYY <name> . Bracketed links use [addr16] and indicate a patchable 16-bit

## 2.1) Reading V Output

Example chain output:

```
RST: FFFC > F818 > 8004 > A8CB > [0080] > 800D **RST_PLACEHOLDER**
NMI: FFFA > 8007 > [0083] > A8E8 **NMI_PLACEHOLDER**
IRQ: FFFE > 800A > [0086] > A941 > BSO2_IRQ_BRK_HW_DISPATCH
      BRK: [0089] > A952 **BRK_PLACEHOLDER**
      HW: [008C] > A980 **HW_PLACEHOLDER**
```

- Each > is one control-transfer hop in the chain as traced by the monitor.
- FFFC, FFFA, and FFFE are fixed hardware vector locations (RST/NMI/IRQ+BRK).
- F818 is the WDC ROM reset bridge; 8004/8007/800A are monitor-side vector entry stubs.
- Bracketed entries like [0080], [0083], [0086], [0089], [008C] are patchable RAM JMP trampolines in zero page.
- Unbracketed high addresses (for example A8CB, A8E8, A941, A952, A980) are current resolved code targets and can move between builds.
- The IRQ main line ends with BSO2\_IRQ\_BRK\_HW\_DISPATCH because IRQ first lands in a common front-end, then runtime-dispatches to BRK or hardware IRQ sub-hooks.
- Design takeaway: high flexibility by design: one stable IRQ entry, two independently patchable sub-dispatch paths (BRK/HW).
- The \*\*...\_PLACEHOLDER\*\* suffixes are handler-name slots printed with each chain/sub-chain; in a fully named build they identify the currently bound handler symbol/name.

## 3) Interactive Caveats

- M interactive: two hex digits are required per byte write (00..FF).
- A interactive: type one mnemonic/operand per prompt, . exits assembler mode.
- . exits interactive modify and retains next-address state for subsequent M.
- CR or lone LF advances to next address.
- CRLF pair is consumed as a single next-step.
- F does not support interactive mode.
- At an empty monitor prompt, Up Arrow (ESC [ A) repeats and executes the previous command.
- Special repeat behavior: if the previous command was a D ... or U ... form, up-arrow replays bare D/U; D continues by saved span, U by saved next-instruction address.
- F/M/C/A/N/L block access to \$0000-\$0FFF unless prefixed with !. D is always allowed.
- Direct vector-hook edits with !M are non-atomic and debug-only. Writing live bytes at \$0080-\$0088 (especially \$0083-\$0085) can produce mixed-byte jumps, wrong dispatch, hangs/crashes, or temporary vector-name mismatch while patching.
- Game ask hook (GAME ASK, older text: POST ASK) is sticky: when set, it prints at each prompt until cleared.
- Hook flag is fixed/reserved at \$0078 (GAME\_ASK\_PENDING). Manual control: !M 78 01 sets pending; !M 78 00 clears pending.
- GAME\_ASK\_PENDING defaults to 01 only on power-on/invalid-cookie path; reset warm paths preserve current \$0078 value.
- Terminal width byte is fixed/reserved at \$007A (TERM\_COLS): 14/28/50/84 for 20/40/80/132 columns.
- Terminal-width prompt timeout byte is fixed/reserved at \$007B (TERM\_WIDTH\_TIMEOUT): 00=wait forever, 01-FF=seconds, default 08.
- User ZP range is reserved at \$0090-\$00FF.
- User-program origin policy: avoid \$0000-\$0FFF in normal operation (protected by default for write/execute-adjacent commands).
- Input ring overflow is handled by dropping the in-flight line to end-of-line; monitor prints INPUT OVERFLOW; LINE DROPPED once after resync.
- Minimum practical user-program origin is \$0800.
- Preferred default user-program origin is \$1000 (recommended for demos and monitor interoperability).

## 4) Verify / Error Outputs

Operation	Message / Behavior
Modify verify fail	M VERIFY FAILED AT ADDR + failing address.
Fill verify fail	F VERIFY FAILED AT ADDR + failing address.
Copy verify fail	C VERIFY FAILED AT ADDR + failing address.
Dump range error	D RANGE ERROR .
Unassemble range error	U RANGE ERROR .
Assembler branch range error	A BRANCH RANGE ERROR .
BRK debug context	Printed as two lines: CURR: and NEXT: on one line, then STATE: on the next line. For N-generated temporary breaks, CURR: shows the restored original instruction.
R START while context active	R CTX ACTIVE, R [A/X/Y=] or !R START .
Bad syntax	Per-command usage lines (e.g. USAGE: M [START [B0..B15]] ).

## 5) API Reference (Macros and Functions)

Use this section when calling monitor functionality from your own assembly code.

Include model: prefer INCLUDE EQUATES.INC for monitor builds; EQUATES.INC automatically includes MACROS.INC .

### 5.1) Macro Reference (macros.inc)

Macro	Parameters	Behavior / Notes
PUSH	PUSH p1 [,p2] [,p3] [,p4]	Pushes listed registers in given order. Supported tokens: A/X/Y/P (case-insensitive).
PULL	PULL p1 [,p2] [,p3] [,p4]	Pops listed registers in given order. Keep ordering compatible with prior PUSH .
REPEAT	REPEAT Routine, Count	Calls JSR Routine repeatedly Count times. Preserves X via push/pull.
PRT_CSTRING	PRT_CSTRING Label	Prints null-terminated string at Label via PRT_C_STRING .
DUMP	DUMP Start, EndExclusive	Convenience wrapper for MEM_DUMP with explicit exclusive end.
FILL	FILL Start, EndInclusive, B0 [,B1] [,B2] [,B3] [,B4]	Loads pattern bytes (1..5) and calls MEM_FILL_PATTERN . End is inclusive in macro syntax.
COPY	COPY SrcStart, SrcEndInclusive, DstStart	Calls overlap-safe MEM_COPY_RANGE . Source end is inclusive in macro syntax.
COPY_BLOCK	COPY_BLOCK SrcStart, Length, DstStart	Compatibility wrapper that expands to COPY SrcStart,(SrcStart+Length-1),DstStart .

CMP_CSTRING	CMP_CSTRING AddrA, AddrB	Wrapper for project-specific string compare symbols/routine (STRCMP_PTR*, STR_COMPARE). Use only when those symbols are provided by your build.
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## 5.2) Callable Function Reference

Practical entry points for extensions and integration.

Routine	Input	Output	Flags	ZP / Memory Use
INIT_SERIAL	None	UART initialized	Unchanged	None
WRITE_BYTE	A =char	Char sent to UART, LED updated	Unchanged	None
READ_BYTE	None	A=received char (ROM read)	ROM-defined	None
CHECK_BYTE	None	A=status	C=1 if RX empty	None
RBUF_INIT	None	Input ring reset	Unchanged	Uses generic buffer descriptor core
BUF_INIT	Active descriptor pointers set	Head/Tail/Count zeroed	Unchanged	Uses BUF_*_PTR
BUF_PUT_A	A=byte	Byte queued	C=0 stored, C=1 full	Uses BUF_*_PTR, BUF_SIZE
BUF_GET_A	None	A=byte	C=0 byte, C=1 empty	Uses BUF_*_PTR, BUF_SIZE
CMD_DISPATCH	A=command letter	Handler called from table	C=0 handled, C=1 unknown	Uses CMD_TABLE, CMD_POST_ACTION
MEM_DUMP	PTR_DUMP_CUR=start (inc), PTR_TEMP=end (exc)	Formatted hex+ASCII dump with 8+8 separator	Unchanged	Uses PTR_DUMP_CUR, PTR_DUMP_END, PTR_LEG, MEM_DUMP_CNT
MEM_DISASM_65C02	PTR_DUMP_CUR=start (inc), PTR_TEMP=end (inc)	65C02 disassembly output (ADDR: MNM OPERAND)	Unchanged	Uses PTR_DUMP_CUR, PTR_DUMP_END, PTR_TEMP, PTR_LEG, DIS_*
MEM_FILL_PATTERN	PTR_DUMP_CUR=start (inc), PTR_DUMP_END=end (exc), F_COUNT=pattern length, F_PATTERN=pattern bytes	Fills range with repeating pattern	C=0 complete, C=1 aborted (verify/protect)	Uses PTR_DUMP_CUR, PTR_DUMP_END, F_COUNT,

				F_PATTERN , F_PAT_IDX
MEM_COPY_RANGE	PTR_LEG=src start (inc), PTR_DUMP_END=src end (exc), PTR_TEMP=dst start	Copies source to destination (overlap-safe)	C=0 complete, C=1 aborted (verify/protect)	Uses PTR_LEG , PTR_DUMP_CUR , PTR_DUMP_END , PTR_TEMP , CMD_PARSE_VAL
CMD_DO_ASM	CMD_LINE = A START [INSN]	Interactive tiny assembler	. exits	Uses CMD_LINE , PTR_TEMP , opcode tables, and ASM_* / DIS_* scratch

## 6) Parser and Buffer Limits

- CMD\_MAX\_LEN = 64 characters (excluding null terminator).
- RBUF\_SIZE = 32 bytes.
- On ring overflow, input is resynchronized to CR/LF and the partial line is dropped.
- One-command history is kept for up-arrow repeat (CMD\_LAST\_LINE).
- Hex token parser accepts 1..4 hex digits, optional \$ prefix.
- M and F inline byte lists: max 16 bytes each.
- ! is consumed as a command prefix, then normal parsing continues.

## 7) Memory Usage

### Build Section Usage (current)

Section	ORG	Size (hex)	Size (dec)
PAGE0	\$0030	\$60	96
CODE	\$8000	\$32BF	12991
KDATA	\$B2BF	\$15EE	5614
UDATA	\$0200	\$EC	236
Total	-	\$49F9	18937

### RAM Layout Highlights

- PAGE0 starts at \$0030. Includes parser state, dump state, debug snapshot, vector hooks, and active buffer descriptor pointers.
- Guard policy reserves monitor PAGE0 through \$008F; user ZP is reserved at \$0090-\$00FF.
- KDATA floats directly behind CODE (current build start: \$B2BF).
- Fixed/pinned bytes: GAME\_ASK\_PENDING=\$0078, BRK\_FLAG=\$0079, TERM\_COLS=\$007A, TERM\_WIDTH\_TIMEOUT=\$007B, RST\_HOOK=\$0080, NMI\_HOOK=\$0083, IRQ\_HOOK=\$0086, BRK\_HOOK=\$0089, HW\_HOOK=\$008C.
- Hardware vectors are fixed at the top page: NMI=\$FFFA, RST=\$FFFC, IRQ/BRK=\$FFFE.
- Detailed zero-page map: [zero-page-usage.md](#) and [zero-page-usage.pdf](#).
- UDATA starts at \$0200:

```

RBUF_DATA      32 bytes
CMD_LINE       65 bytes (64 + NUL)
CMD_LAST_LINE  65 bytes (64 + NUL)
RESET_COOKIE   4 bytes

```



```
RNG_STATE      1 byte
F_PATTERN      16 bytes
DBG_TAG_BUF    6 bytes
```

8) Notes for Integrators

- Command parser uppercases incoming command bytes before parse/dispatch.
- Command execution is table-driven via `CMD_TABLE`.
- Input buffering now uses a generic descriptor-based core bound to the ring buffer.
- `Q` path relies on NMI latch (`SYSF_NMI_FLAG_M`) and then re-enters monitor cleanly.

9) Planned Commands (Appendix, Provisional)

This appendix documents planned command architecture and roadmap intent only.  
**Proviso:** change is constant. These plans are not stable API and may change before publish.

9.1) Grammar Direction

- Primary model: `noun verb [args...]` (namespace first, action second).
- Direct-action commands may still exist where practical (for example `jump/execute` style flow).
- Parser should accept both spaced and fused forms for operator speed.

9.2) Canonical Input Compatibility

- Parser policy: token 1 selects namespace and remains locked for that line (no cross-namespace fallback).
- `X S` and `XS` should map to the same internal command key.
- `X R` and `XR` should map to the same internal command key.
- `M D` and `MD` should map to the same internal command key.
- `I O V` and `IOV` should map to the same internal command key.
- `I C` and `IC` should map to the same internal command key.
- One canonical dispatch representation is preferred to avoid duplicate handlers.
- Aliases are spelling variants only (same meaning); command override behavior is intentionally avoided.

9.3) Namespace Plan

Root	Planned Role	Notes
B	Bank / FLASH	Reserved for FLASH-related operations (read/program/erase/verify family).
I	Info root	Carries nested subfamilies such as time and I/O.
I T	Time	Time remains planned under Info; top-level T is active for terminal operations (clear + width).
I C	Calculator	Implemented baseline (I C / IC) with 16-bit hex RPN tokens; future expansion remains planned.
T	Terminal	Repurposed top-level namespace for terminal-related operations.
I O P	PIA	Top-level P is freed; PIA moves under Info/IO.
I O V	VIA	Top-level V is freed; VIA moves under Info/IO.
I O V T	VIA timers	Hardware timers are expected under VIA tree.
J	Jump / Execute	Preferred home for execute flow if top-level execute letter changes.

X	Transfer / XMODEM	At minimum: send and receive support.
S	Search	Text and binary search families.
M	Memory family	Supports compact forms such as MD/MM as aliases.
O	Deferred decision	Candidate: chained execution wrapper; decision postponed.

## 9.4) Search Family Detail

- Planned base forms: `S C START END <text>` and `S B START END <pattern...>`.
- Current hit display format is `<HIT_ADDR>{ |*}<ROW_BASE>: ...`; `HIT_ADDR` is exact match start, and `ROW_BASE = HIT_ADDR & $FFF0`.
- Separator marker: `*` means the match continues into the next 16-byte row (for example `$B8AF*$B8A0` implies continuation at `$B8B0`).
- `S C` mode: unquoted text stops at first whitespace.
- `S C` mode: quoted delimiters can include `"`, `'`, and ```.
- `S C` mode: delimiter escape by doubling delimiter character.
- `S C` mode wildcards: `?` matches exactly one character, `*` matches zero or more characters.
- `S C` mode literals: `??` matches literal `?`, and `**` matches literal `*`.
- `S B` mode tokens: `HH` byte, `HHHH` little-endian word, nibble wildcard (`?A/A?/??`), and `*` byte wildcard.
- Candidate extensions: Pascal strings and high-bit-set text search modes.

## 9.5) XMODEM Requirement

- Before publish, provide both XMODEM receive and send paths.
- Preferred forms: `X R ...` and `X S ...` with fused aliases (`XR`, `XS`).

## 9.6) Vector + Safety Direction (Pre-Publish Requirement)

- Vector updates must support dynamic atomic update behavior.
- Handler-name contract direction: every patchable target exports `<HANDLER>` and `<HANDLER>_NAME` (ASCIIIZ); retarget operations update target address and name pointer together.
- Critical windows include vector commit and FLASH routines.
- During critical windows, all EDU LEDs should flash to signal that NMI should not be pressed.
- NMI path should be guarded/deferred during critical windows instead of normal debug flow.
- Staged-update plus atomic-commit behavior is the intended implementation pattern.
- NMI retargeting direction: patch inactive slot fully, then commit via single-byte active-slot selector flip (no in-place live NMI hook rewrite).
- Direct `!M` edits to live vector hook bytes are allowed for bring-up/debug but are intentionally outside the production-safe retarget path.
- Mandate (non-changing requirement): any operation that mutates FLASH state or vector state must assert critical indication/guard behavior, including module/transient load paths; implementation detail may change, requirement does not.

## 9.7) Deferred Item

- `O` command semantics are intentionally deferred.
- If adopted as an operation chain wrapper, error policy and guard policy must be defined explicitly.

## 9.8) Active TODO (Pressing)

### Now

- TODO: rework `bso2` wrapper/trampoline entry points for `WDCMONv2` FLASH routines; current `WDCMONv2` FLASH programming flow is tied to Python tooling and needs a rethink for this project.
- TODO: add a post-link map check that enforces `END_KDATA < $F000`.

**Soon**

- TODO: get the ACIA port on the EDU board running.

**Before Publish**

- TODO: provide XMODEM receive and send paths before publish (X R/XR, X S/XS).
- TODO: implement staged vector update plus atomic commit flow for runtime retargeting.
- TODO: enforce critical-window behavior for FLASH/vector mutation paths (LED warning plus NMI guard/defer).
- TODO: enforce dangerous B operation policy (! required, explicit confirmation, and fail-closed behavior without mutation).
- TODO: add deterministic status reporting for dangerous operations (status code byte plus OK / ABORTED / VERIFY\_FAIL / FLASH\_FAIL / DENIED).
- Deferred (not current TODO): text compression/decompression, tokenization/RLE, and TX ring architecture while 32K FLASH headroom is sufficient.

**9.9) Flash / Bank Safety Policy (Critical, Non-Negotiable)**

- B must not execute dangerous operations by default.
- bso2 plans to use WDCMONv2 FLASH routines through wrappers/trampolines, but current WDCMONv2 FLASH programming flow is tied to Python tooling and requires a rethink.
- Integration intent is behavioral/protocol compatibility via wrapper entry points, not direct source-text copy.
- Any dangerous B operation requires both force-prefix ! and explicit user confirmation.
- Dangerous operations include at minimum erase, program/write, monitor self-update, vector commit, and bank activation/commit transitions.
- If ! is absent, dangerous operations fail closed with no side effects.
- Confirmation must be operation-specific (typed intent token), not an implicit continue.
- During dangerous operations: enter critical guard mode before mutation starts, flash all LEDs, and guard/defer NMI debug flow until critical mode exits.
- On verify/check failure: abort mutation, exit critical mode cleanly, and report explicit status.
- Required output for dangerous operations: status code byte plus textual result (OK, ABORTED, VERIFY\_FAIL, FLASH\_FAIL, DENIED).

**9.10) Board Self-Update Policy**

- Board self-update is always dangerous and always requires ! plus explicit confirmation.
- Before final commit, display target region, byte count, and integrity value (checksum/hash when available).
- Preferred execution shape: preflight validation, stage payload, erase/program, verify, then commit/activate.
- Avoid in-place blind overwrite as the only strategy; preserve a recovery path.
- Self-update is fully covered by the non-changing mandate: any FLASH/vector mutation path (including module/transient load/activation) must assert critical indication and guard behavior.

**9.11) Host Tooling Direction (Linux GNU C)**

- Critical FLASH workflows are expected to have a Linux GNU C host path.
- Python helpers may exist for convenience, but they are not the required path for critical FLASH operations.
- Preferred host model: raw serial protocol wrappers in C with explicit timeout/error handling and deterministic status reporting.

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