Reverse Engineering NAND Flash

Adapted from

Josh ‘m0nk’ Thomas’s Black Hat Presentation

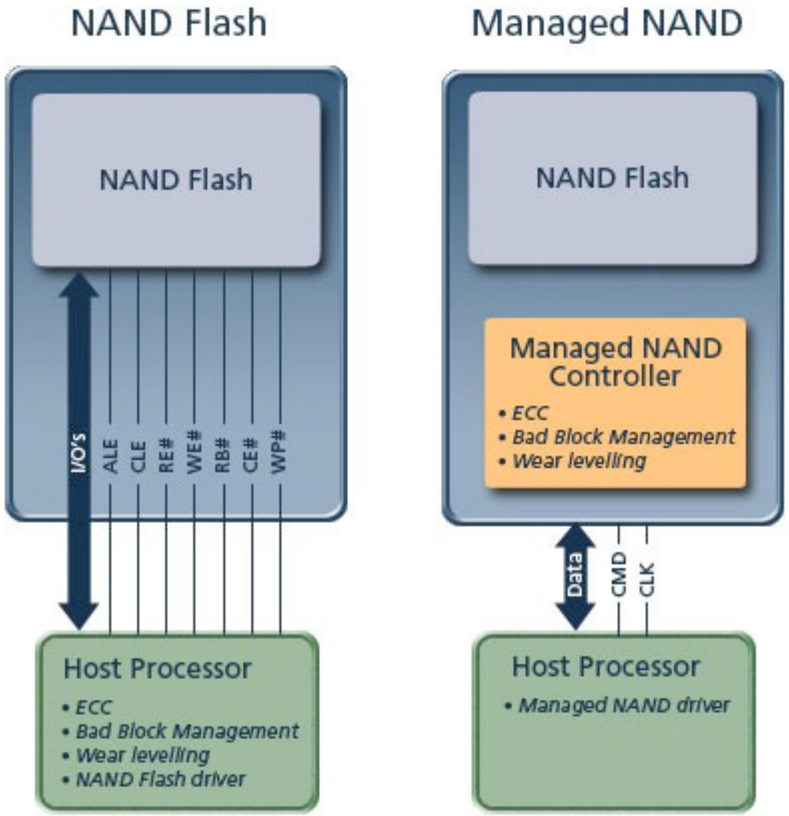
Andrew ‘bunnie’ Huang & Sean ‘xobs’ Cross 30c3 Presentation

Presented by Ben Ruktantichoke

NAND:Hard It Work

- Floating gate transistor
- Pages – Typically 512, 2048, or 4096
- Blocks – Typically 16kb – 512kb
- Shifting to 0 is easy
- Shifting to 1 is hard

NAND:Hard it Work



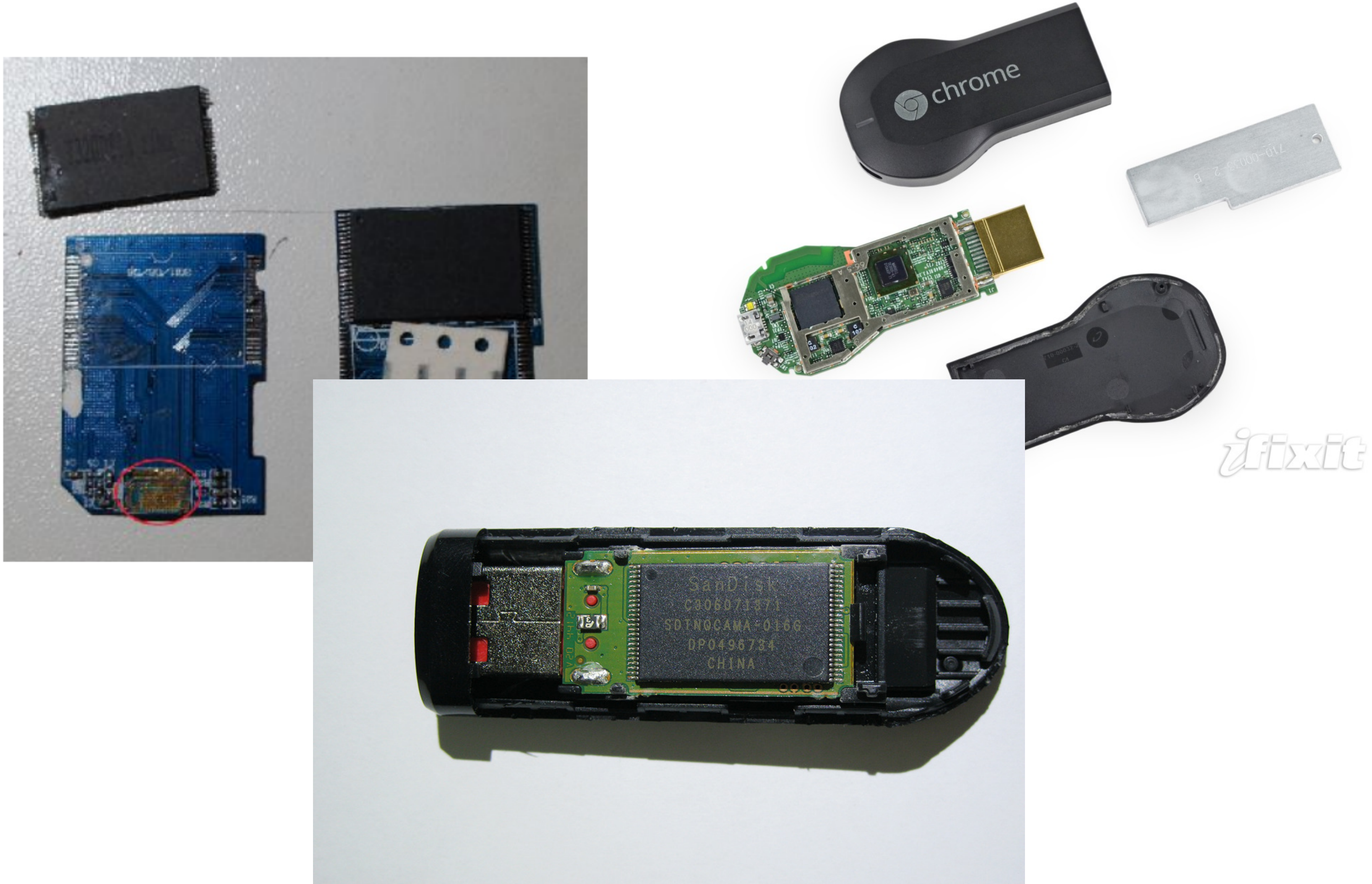
Faking Reliability

- Flash memory is “unreliable”
- You are not storing data, you are storing probabilistic approximations of your data
- Workaround: computational error correction (ECC)
- Flash geometry changes
  - New ECC rules, page size, block mapping, etc.

Also, Bad Blocks

- TLC/MLC Flash is super cheap
- Work around: bad block remapping
  - In some cases, over 80% of blocks are bad (e.g. 16GB chip sold as 2GB)
- Also, blocks go bad with P/E cycles

What’s inside

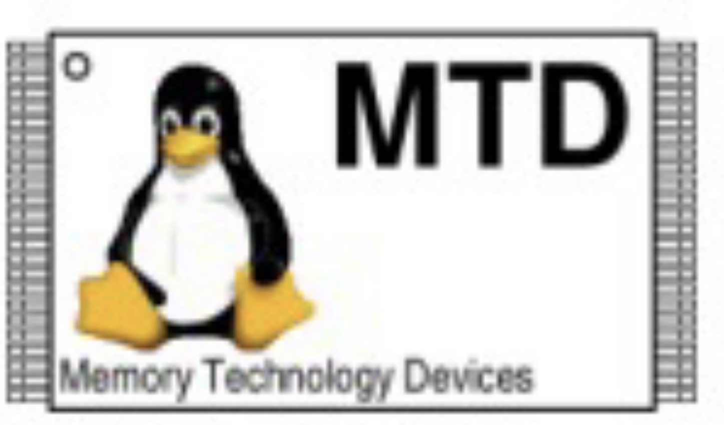


NAND:Soft it Works

- RAW NAND vs. MMC/eMMC
  - Complex Driver vs. Simple Driver
- Proprietary (closed) wear leveling algorithms are normally embedded

NAND:Soft it Works

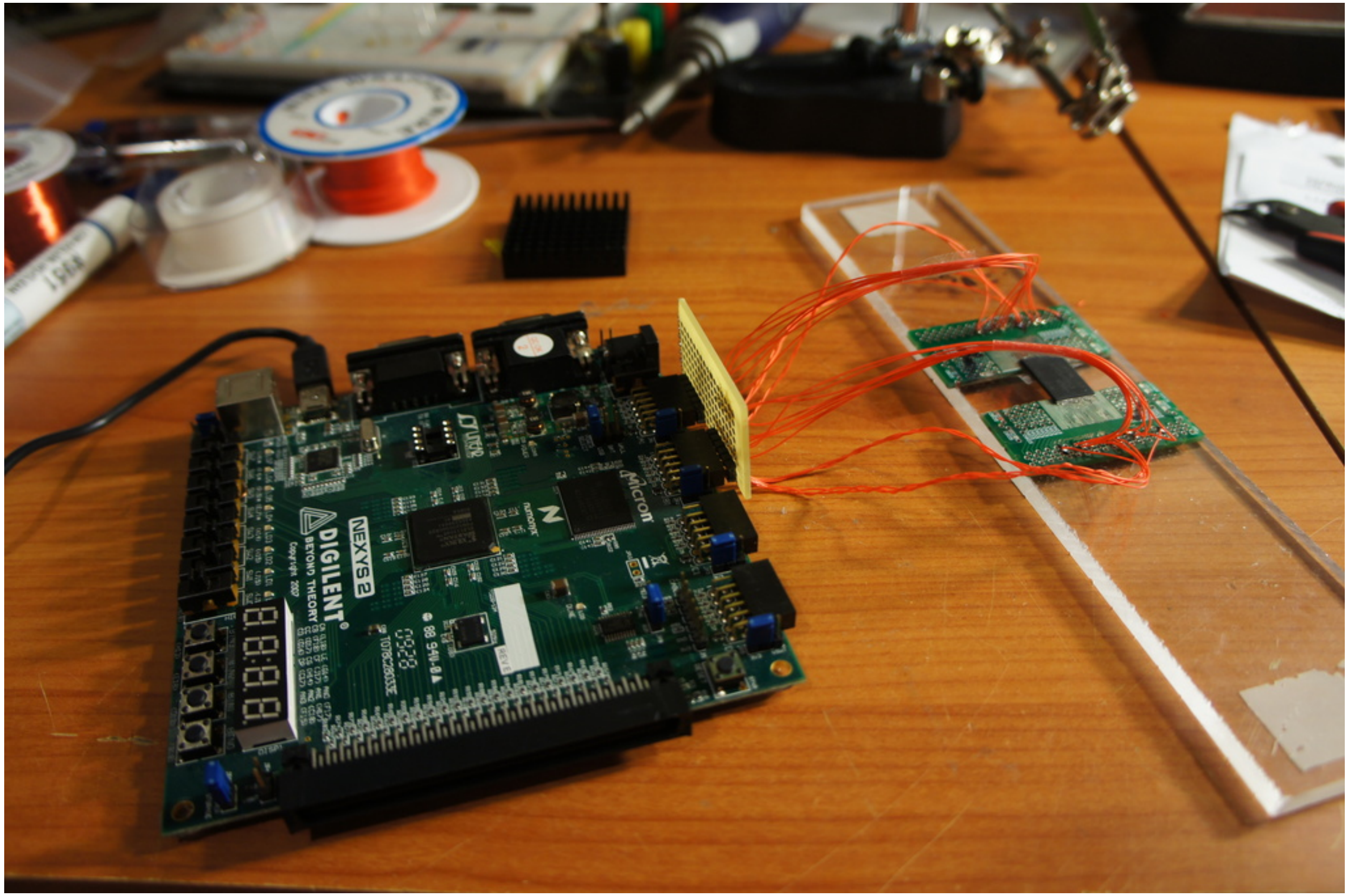
- MTD Subsystem
- Kind of a meta-driver
- Used heavily for boot partitions on Android



Related Works

- MTD at the Driver Level
- Flash Transition Layers and Reverse the Embedded Controllers

Digilient Nexys™2 Spartan-3E FPGA + Schmartboard



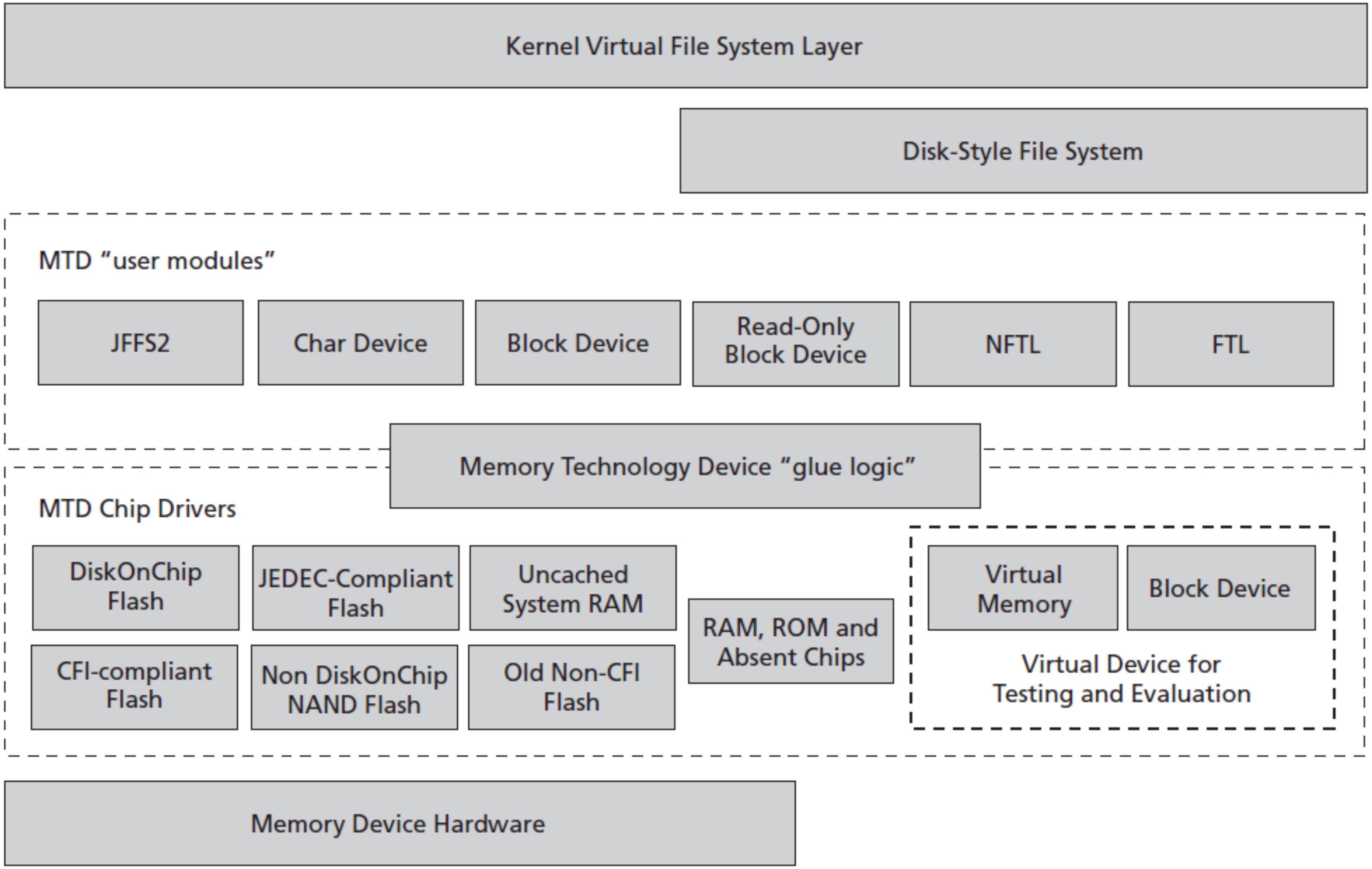
What's an initial RAM disk?

- The *initial RAM disk (initrd)* is an initial root file system that is mounted prior to when the real root file system is available. The initrd is bound to the kernel and loaded as part of the kernel boot procedure. The kernel then mounts this initrd as part of the two-stage boot process to load the modules to make the real file systems available and get at the real root file system.
- The initrd contains a minimal set of directories and executables to achieve this, such as the insmod tool to install kernel modules into the kernel.
- In the case of desktop or server Linux systems, the initrd is a transient file system. Its lifetime is short, only serving as a bridge to the real root file system. In embedded systems with no mutable storage, the initrd is the permanent root file system.

Booting with an initial RAM disk

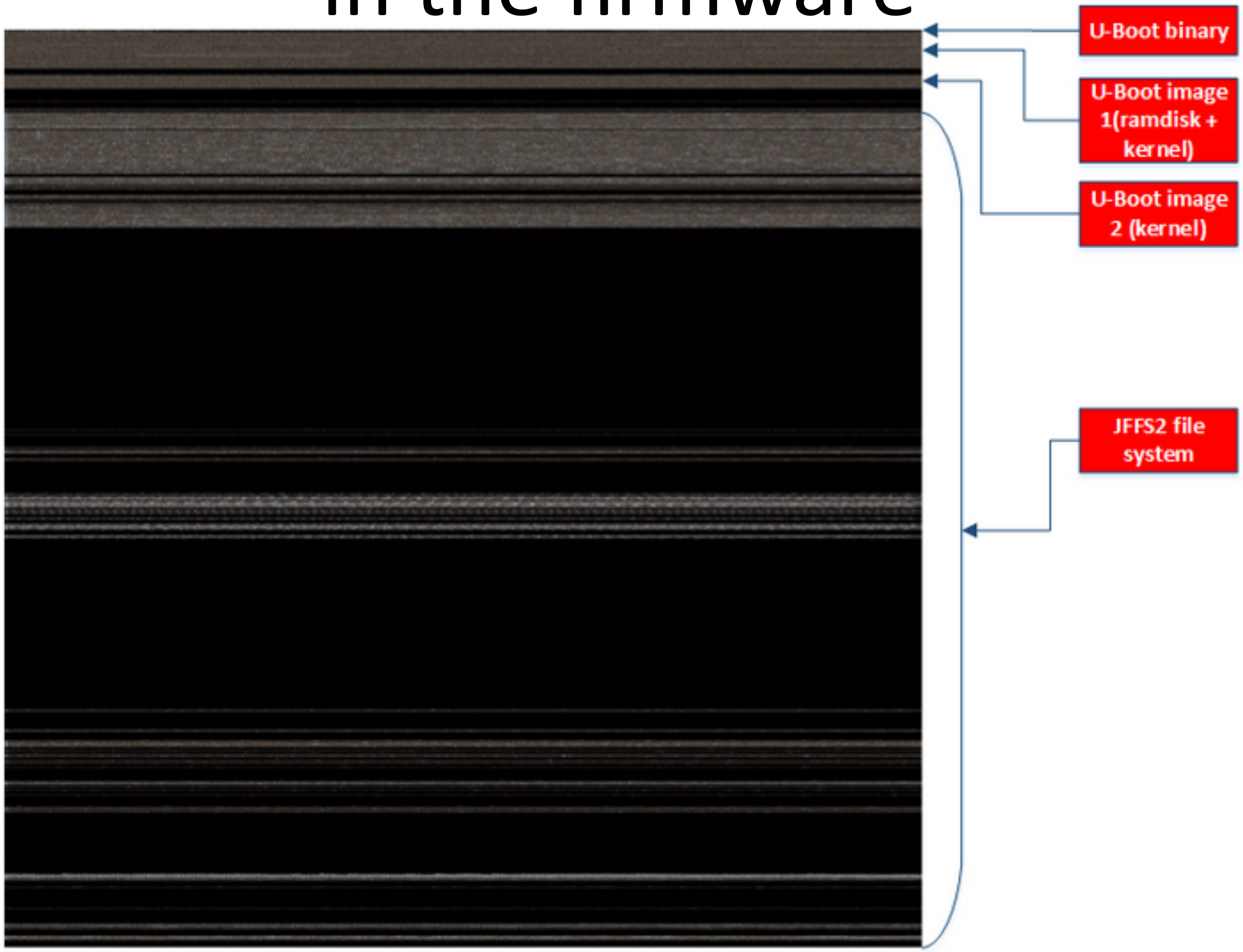
- The boot loader, such as GRUB, identifies the kernel that is to be loaded and copies this kernel image and any associated initrd into memory.
- After the kernel and initrd images are decompressed and copied into memory, the kernel is invoked. Various initialization is performed and, eventually, you find yourself in init/main.c:init() (subdir/file:function). This function performs a large amount of subsystem initialization. A call is made here to init/do_mounts.c:prepare_namespace(), which is used to prepare the namespace (mount the dev file system, RAID, or md, devices, and, finally, the initrd). Loading the initrd is done through a call to init/do_mounts_initrd.c:initrd_load().
- The initrd_load() function calls init/do_mounts_rd.c:rd_load_image(), which determines the RAM disk image to load through a call to init/do_mounts_rd.c:identify_ramdisk_image(). This function checks the magic number of the image to determine if it's a minux, etc2, romfs, cramfs, or gzip format. Upon return to initrd_load_image, a call is made to init/do_mounts_rd:crd_load(). This function allocates space for the RAM disk, calculates the cyclic redundancy check (CRC), and then uncompresses and loads the RAM disk image into memory. At this point, you have the initrd image in a block device suitable for mounting.
- Mounting the block device now as root begins with a call to init/do_mounts.c:mount_root(). The root device is created, and then a call is made to init/do_mounts.c:mount_block_root(). From here, init/do_mounts.c:do_mount_root() is called, which calls fs/namespace.c:sys_mount() to actually mount the root file system and then chdir to it. This is where you see the familiar message shown in Listing 6: VFS: Mounted root (ext2 file system).
- Finally, you return to the init function and call init/main.c:run_init_process. This results in a call to execve to start the init process (in this case /linuxrc). The linuxrc can be an executable or a script (as long as a script interpreter is available for it).

MTD Subsystem Architecture



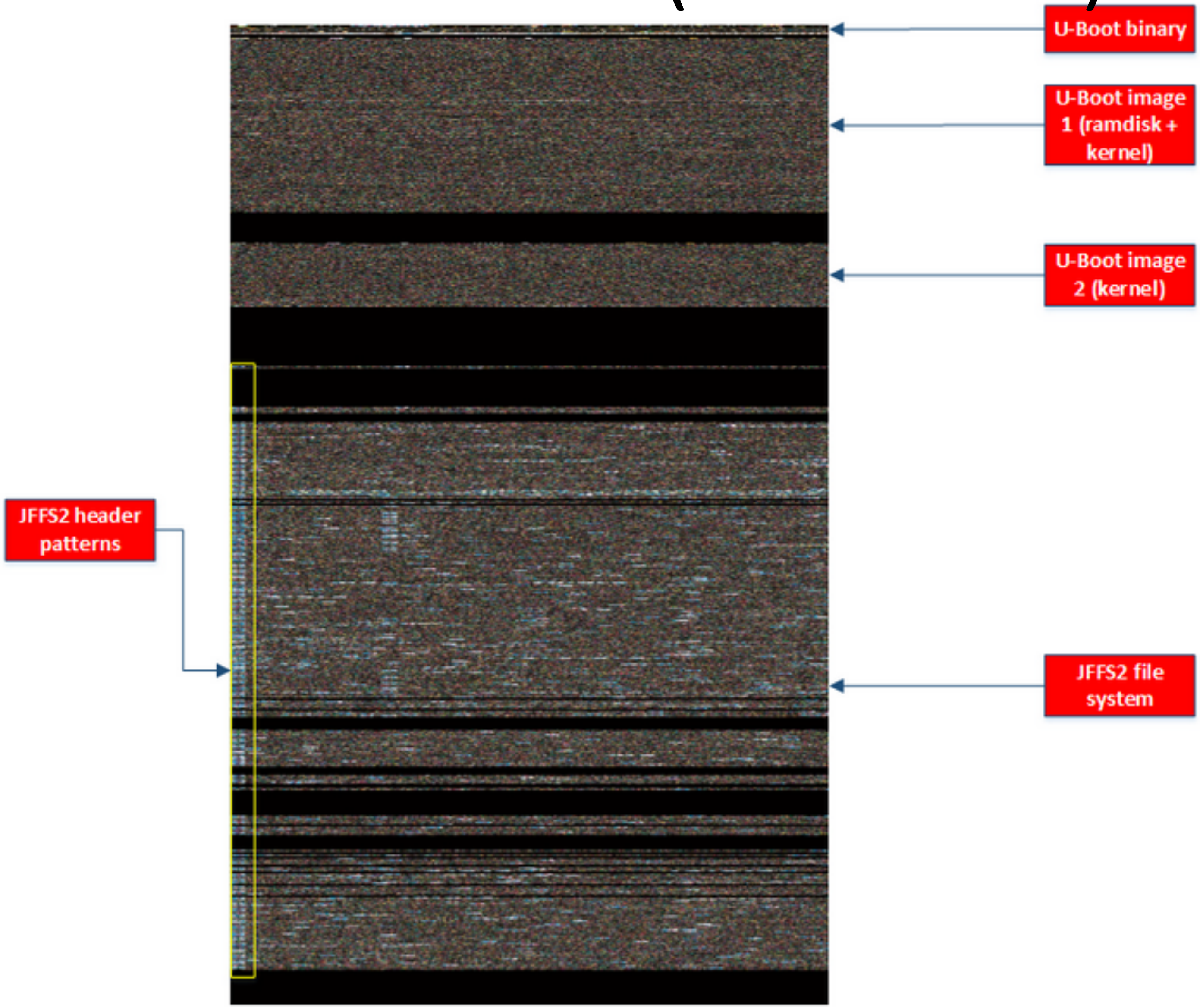
Graphical Analysis

Graphical representation of the bytes in the firmware

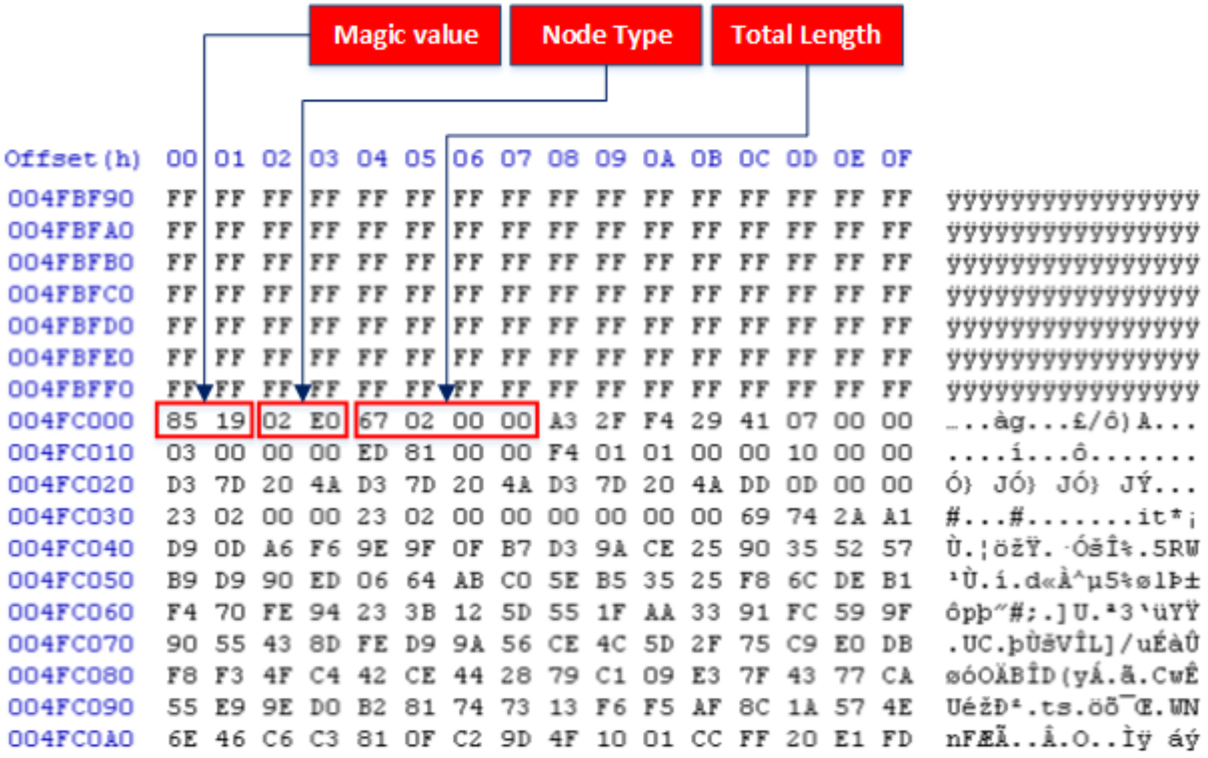


Graphical representation of the bytes in the firmware

Graphical representation of the bytes in the firmware (zoomed in)



JFFS2 Header Fields

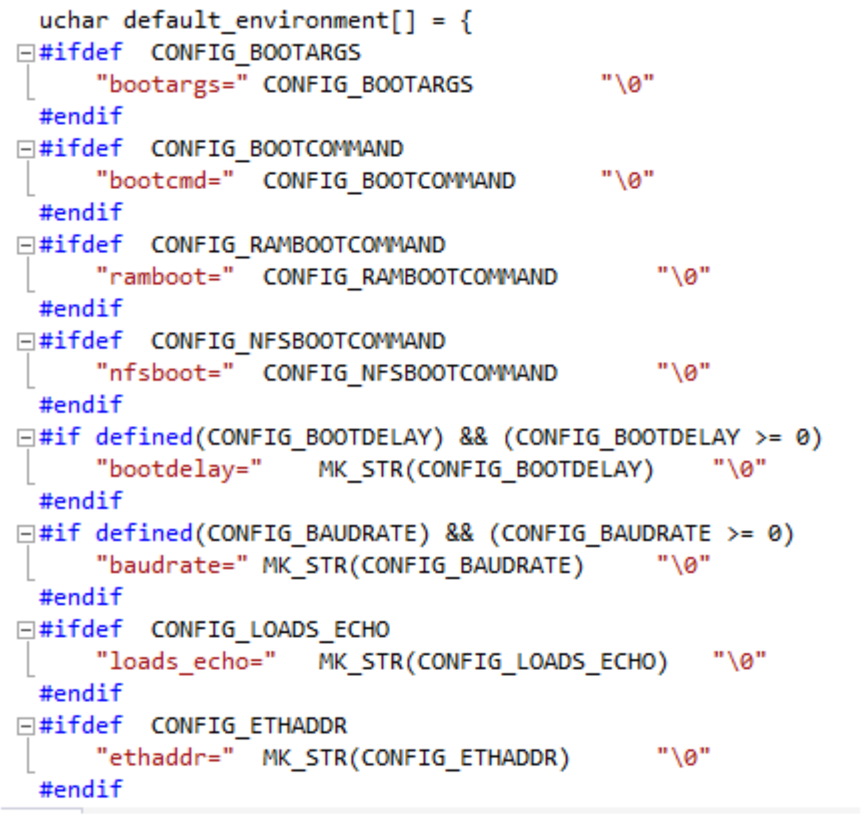


```
Offset(h) 00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F

004FBF90  FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF  ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
004FBFA0  FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF  ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
004FBFB0  FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF  ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
004FBFC0  FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF  ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
004FBFD0  FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF  ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
004FBFE0  FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF  ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
004FBFF0  FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF  ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
004FC000  85 19 02 E0 67 02 00 00 A3 2F F4 29 41 07 00 00  …..àg...£/ô)A...
004FC010  03 00 00 00 ED 81 00 00 F4 01 01 00 00 10 00 00  ....í...ô.......
004FC020  D3 7D 20 4A D3 7D 20 4A D3 7D 20 4A DD 0D 00 00  Ó} JÓ} JÓ} JÝ...
004FC030  23 02 00 00 23 02 00 00 00 00 00 00 69 74 2A A1  #...#.......it*¡
004FC040  D9 0D A6 F6 9E 9F 0F B7 D3 9A CE 25 90 35 52 57  Ù.¦öžŸ.·ÓšÎ%.5RW
004FC050  B9 D9 90 ED 06 64 AB C0 5E B5 35 25 F8 6C DE B1  ¹Ù.í.d«À^µ5%ølÞ±
004FC060  F4 70 FE 94 23 3B 12 5D 55 1F AA 33 91 FC 59 9F  ôpþ”#;.]U.ª3‘üYŸ
004FC070  90 55 43 8D FE D9 9A 56 CE 4C 5D 2F 75 C9 E0 DB  .UC.þÙšVÎL]/uÉàÛ
004FC080  F8 F3 4F C4 42 CE 44 28 79 C1 09 E3 7F 43 77 CA  øóOÄBÎD(yÁ.ã.CwÊ
004FC090  55 E9 9E D0 B2 81 74 73 13 F6 F5 AF 8C 1A 57 4E  UéžÐ².ts.öõ¯Œ.WN
004FC0A0  6E 46 C6 C3 81 0F C2 9D 4F 10 01 CC FF 20 E1 FD  nFÆÃ..Â.O..Ìÿ áý
```

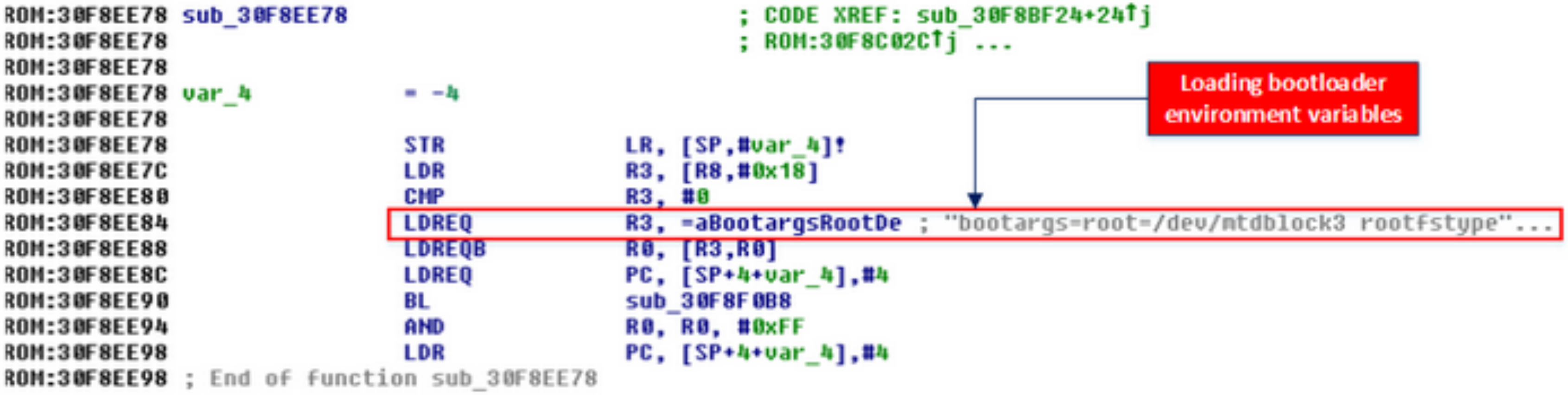
Bootloader Environemnet Variable Analysis

U-Boot code showing default_environment



```
uchar default_environment[] = {
#ifdef  CONFIG_BOOTARGS
    "bootargs=" CONFIG_BOOTARGS         "\0"
#endif
#ifdef  CONFIG_BOOTCOMMAND
    "bootcmd="  CONFIG_BOOTCOMMAND      "\0"
#endif
#ifdef  CONFIG_RAMBOOTCOMMAND
    "ramboot="  CONFIG_RAMBOOTCOMMAND       "\0"
#endif
#ifdef  CONFIG_NFSBOOTCOMMAND
    "nfsboot="  CONFIG_NFSBOOTCOMMAND       "\0"
#endif
#if defined(CONFIG_BOOTDELAY) && (CONFIG_BOOTDELAY >= 0)
    "bootdelay="    MK_STR(CONFIG_BOOTDELAY)    "\0"
#endif
#if defined(CONFIG_BAUDRATE) && (CONFIG_BAUDRATE >= 0)
    "baudrate=" MK_STR(CONFIG_BAUDRATE)     "\0"
#endif
#ifdef  CONFIG_LOADS_ECHO
    "loads_echo="   MK_STR(CONFIG_LOADS_ECHO)   "\0"
#endif
#ifdef  CONFIG_ETHADDR
    "ethaddr="  MK_STR(CONFIG_ETHADDR)      "\0"
#endif
```

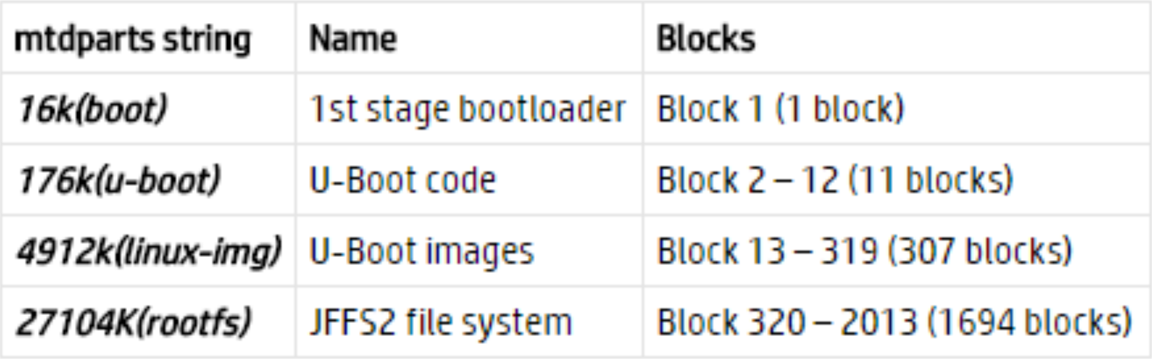
Loading default_environment variables



```
ROM:30F8EE78 sub_30F8EE78                                          ; CODE XREF: sub_30F8BF24+24↑j
ROM:30F8EE78                                                       ; ROM:30F8C02C↑j ...
ROM:30F8EE78
ROM:30F8EE78 var_4           = -4
ROM:30F8EE78
ROM:30F8EE78                 STR             LR, [SP,#var_4]!
ROM:30F8EE7C                 LDR             R3, [R8,#0x18]
ROM:30F8EE80                 CMP             R3, #0
ROM:30F8EE84                 LDREQ           R3, =aBootargsRootDe ; "bootargs=root=/dev/mtdblock3 rootfstype"...
ROM:30F8EE88                 LDREQB          R0, [R3,R0]
ROM:30F8EE8C                 LDREQ           PC, [SP+4+var_4],#4
ROM:30F8EE90                 BL              sub_30F8F0B8
ROM:30F8EE94                 AND             R0, R0, #0xFF
ROM:30F8EE98                 LDR             PC, [SP+4+var_4],#4
ROM:30F8EE98 ; End of function sub_30F8EE78
```

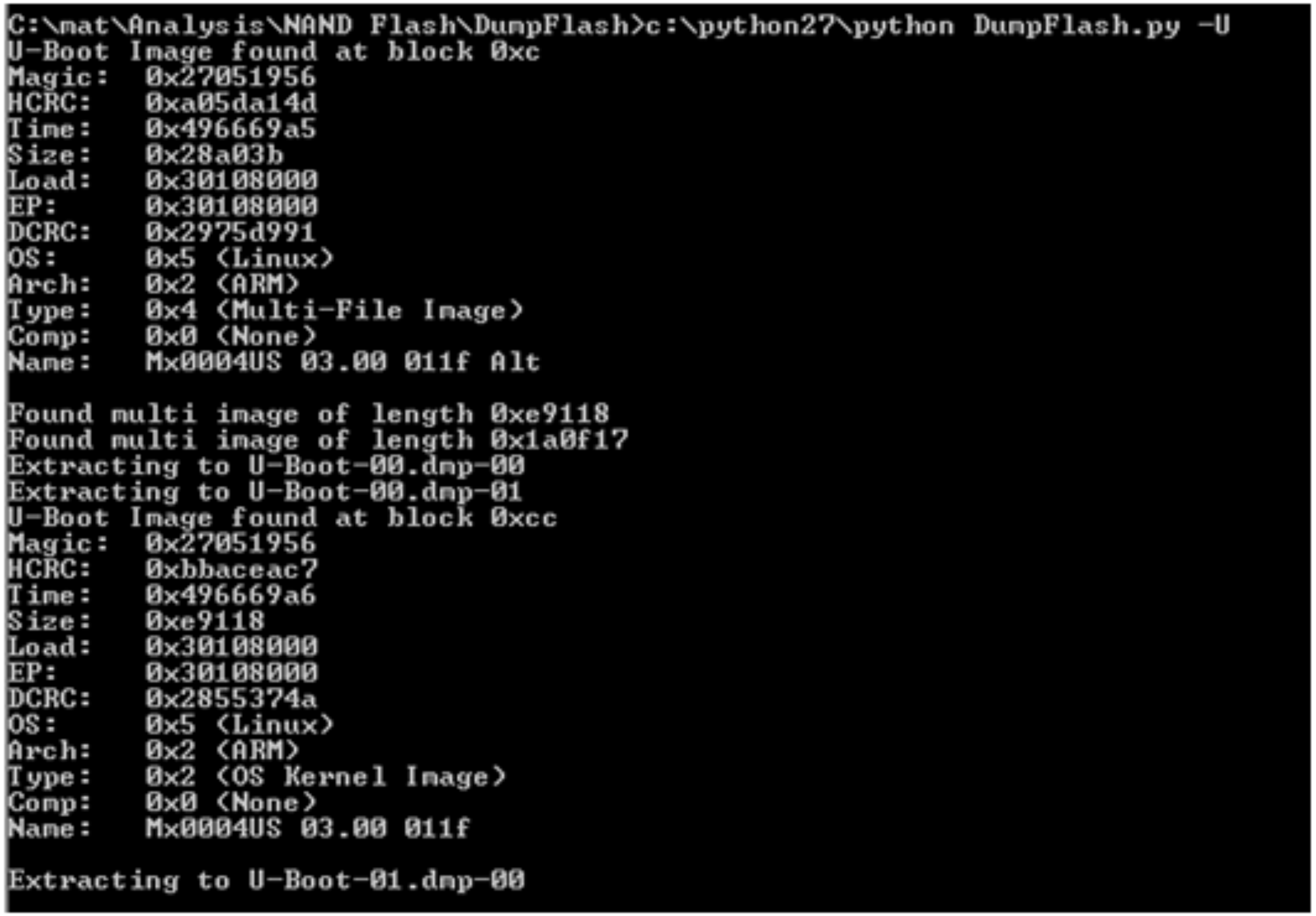
Loading bootloader environment variables

bootargs=root=/dev/mtdblock3 rootfstype=jffs2 noinitrd ramdisk_size=4096 mem=32M mtdparts=s3c2410-nand:16k(boot),176k(u-boot),4912k(linux-img), 27104K(rootfs),-(extra);phys_mapped_flash:-(all)



mtdparts string	Name	Blocks
16k(boot)	1st stage bootloader	Block 1 (1 block)
176k(u-boot)	U-Boot code	Block 2 – 12 (11 blocks)
4912k(linux-img)	U-Boot images	Block 13 – 319 (307 blocks)
27104K(rootfs)	JFFS2 file system	Block 320 – 2013 (1694 blocks)

U-boot sub-images



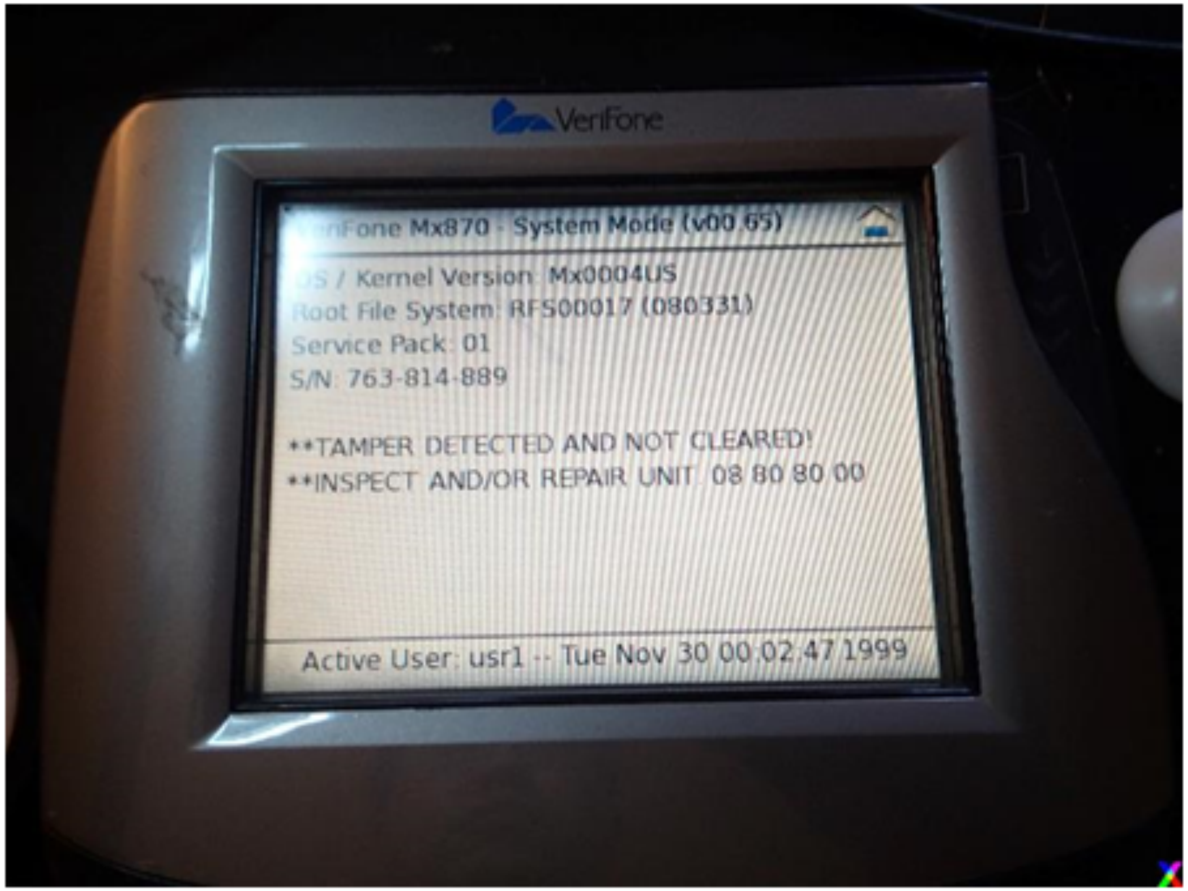
```
C:\mat\Analysis\NAND Flash\DumpFlash>c:\python27\python DumpFlash.py -U
U-Boot Image found at block 0xc
Magic:  0x27051956
HCRC:   0xa05da14d
Time:   0x496669a5
Size:   0x28a03b
Load:   0x30108000
EP:     0x30108000
DCRC:   0x2975d991
OS:     0x5 (Linux)
Arch:   0x2 (ARM)
Type:   0x4 (Multi-File Image)
Comp:   0x0 (None)
Name:   Mx0004US 03.00 011f Alt

Found multi image of length 0xe9118
Found multi image of length 0x1a0f17
Extracting to U-Boot-00.dmp-00
Extracting to U-Boot-00.dmp-01
U-Boot Image found at block 0xcc
Magic:  0x27051956
HCRC:   0xbbaceac7
Time:   0x496669a6
Size:   0xe9118
Load:   0x30108000
EP:     0x30108000
DCRC:   0x2855374a
OS:     0x5 (Linux)
Arch:   0x2 (ARM)
Type:   0x2 (OS Kernel Image)
Comp:   0x0 (None)
Name:   Mx0004US 03.00 011f

Extracting to U-Boot-01.dmp-00
```

Tamper Detection

Tamper protection in action



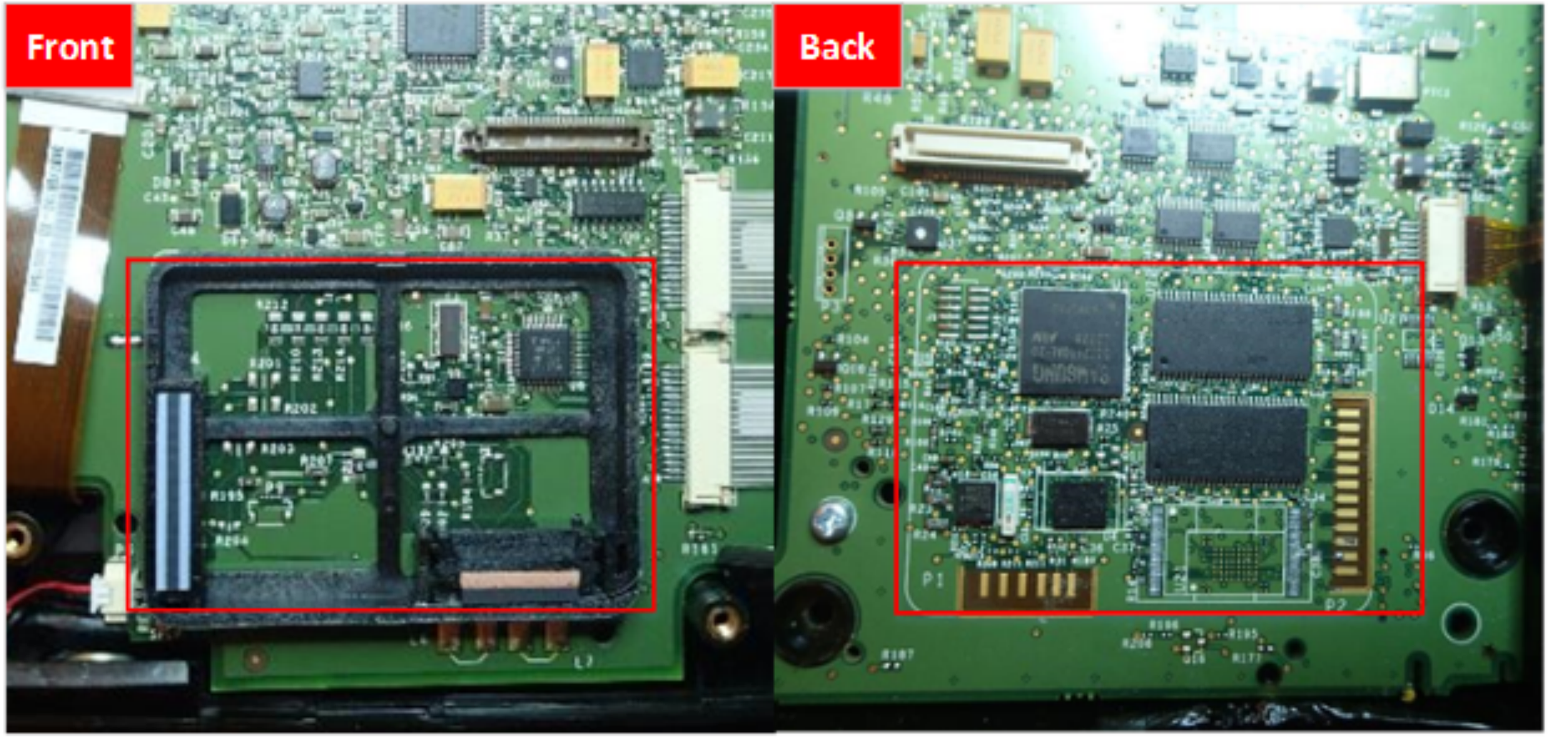
```
VeriFone Mx870 - System Mode (v00.65)

OS / Kernel Version: Mx0004US
Root File System: RFS00017 (080331)
Service Pack: 01
S/N: 763-814-889

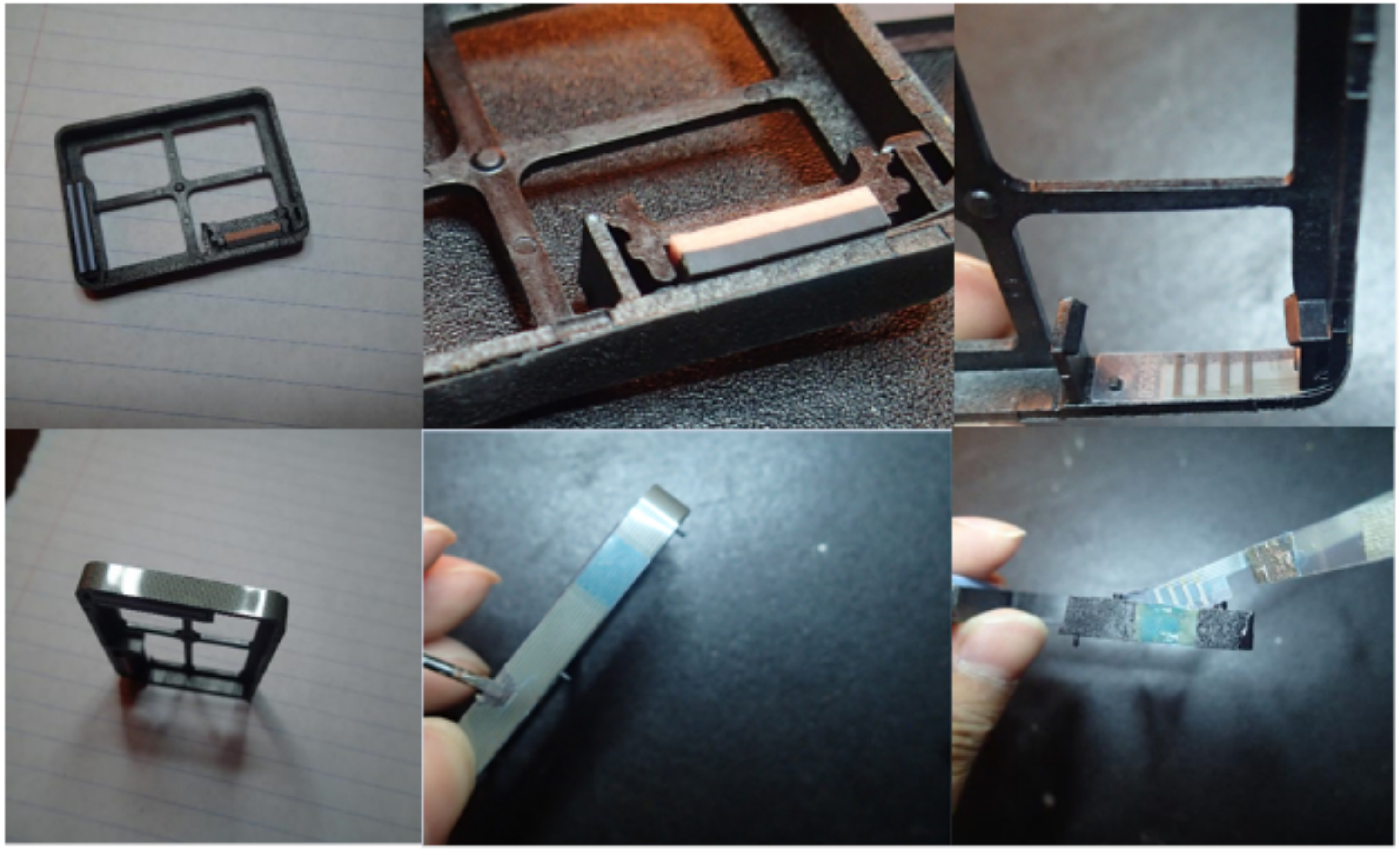
**TAMPER DETECTED AND NOT CLEARED!
**INSPECT AND/OR REPAIR UNIT: 08 80 80 00

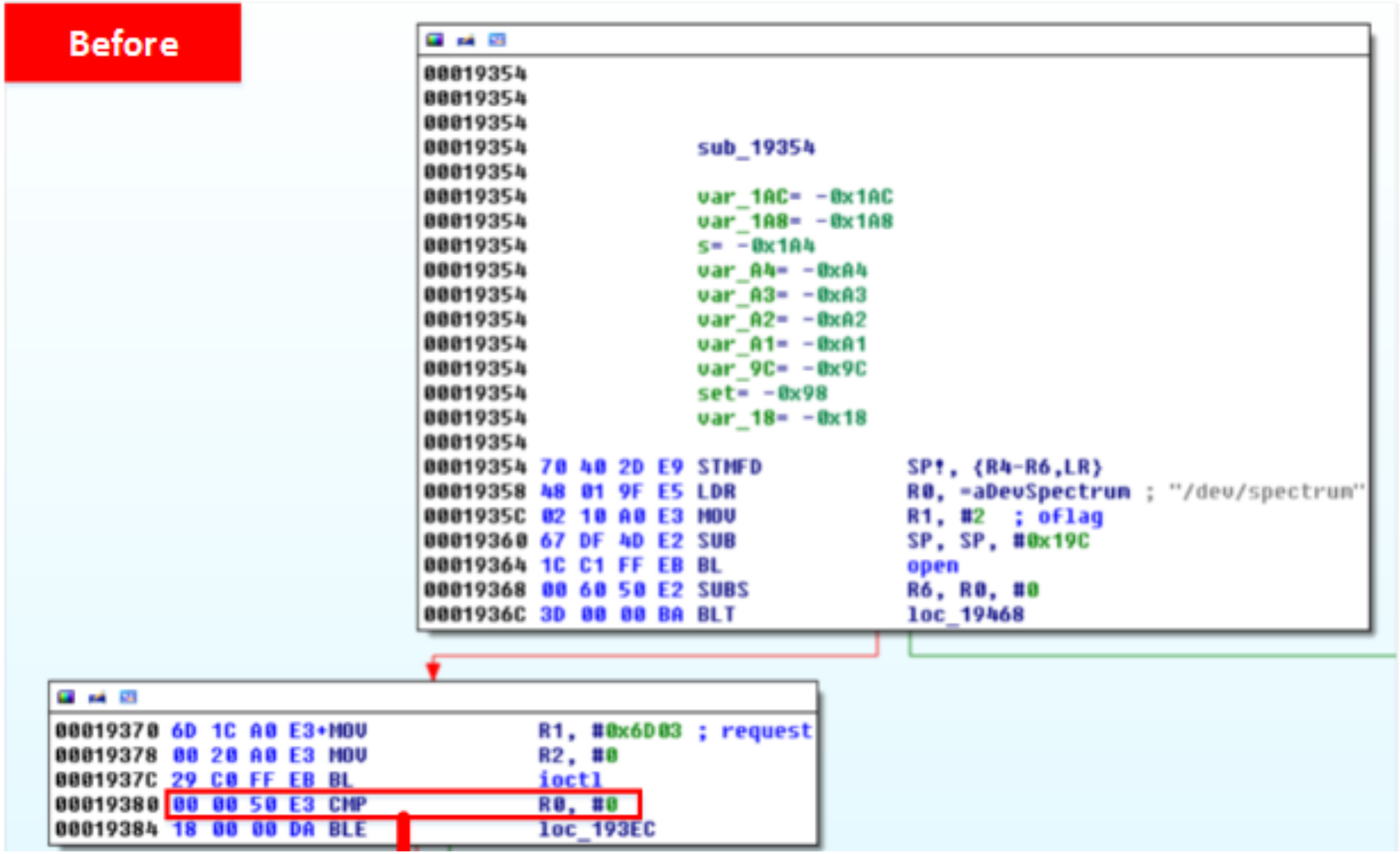
Active User: usr1 -- Tue Nov 30 00:02:47 1999
```

Front and Back panels



Circuits inside plastic padding



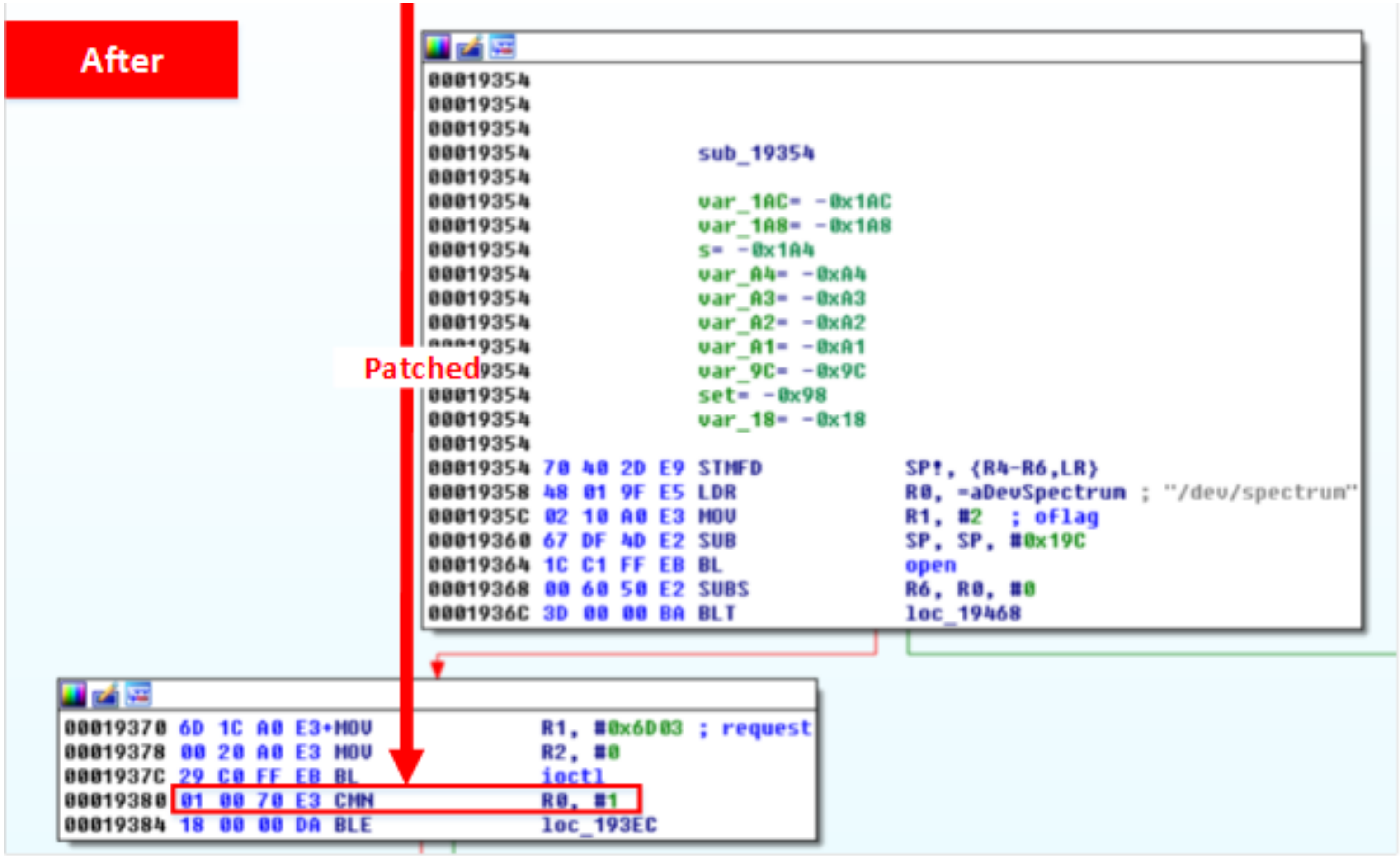


Before

```
00019354
00019354
00019354
00019354             sub_19354
00019354
00019354             var_1AC= -0x1AC
00019354             var_1A8= -0x1A8
00019354             s= -0x1A4
00019354             var_A4= -0xA4
00019354             var_A3= -0xA3
00019354             var_A2= -0xA2
00019354             var_A1= -0xA1
00019354             var_9C= -0x9C
00019354             set= -0x98
00019354             var_18= -0x18
00019354
00019354 70 40 2D E9 STMFD           SP!, {R4-R6,LR}
00019358 48 01 9F E5 LDR             R0, =aDevSpectrum ; "/dev/spectrum"
0001935C 02 10 A0 E3 MOV             R1, #2  ; oflag
00019360 67 DF 4D E2 SUB             SP, SP, #0x19C
00019364 1C C1 FF EB BL              open
00019368 00 60 50 E2 SUBS            R6, R0, #0
0001936C 3D 00 00 BA BLT             loc_19468
```

```
00019370 6D 1C A0 E3+MOV             R1, #0x6D03 ; request
00019378 00 20 A0 E3 MOV             R2, #0
0001937C 29 C0 FF EB BL              ioctl
00019380 00 00 50 E3 CMP             R0, #0
00019384 18 00 00 DA BLE             loc_193EC
```

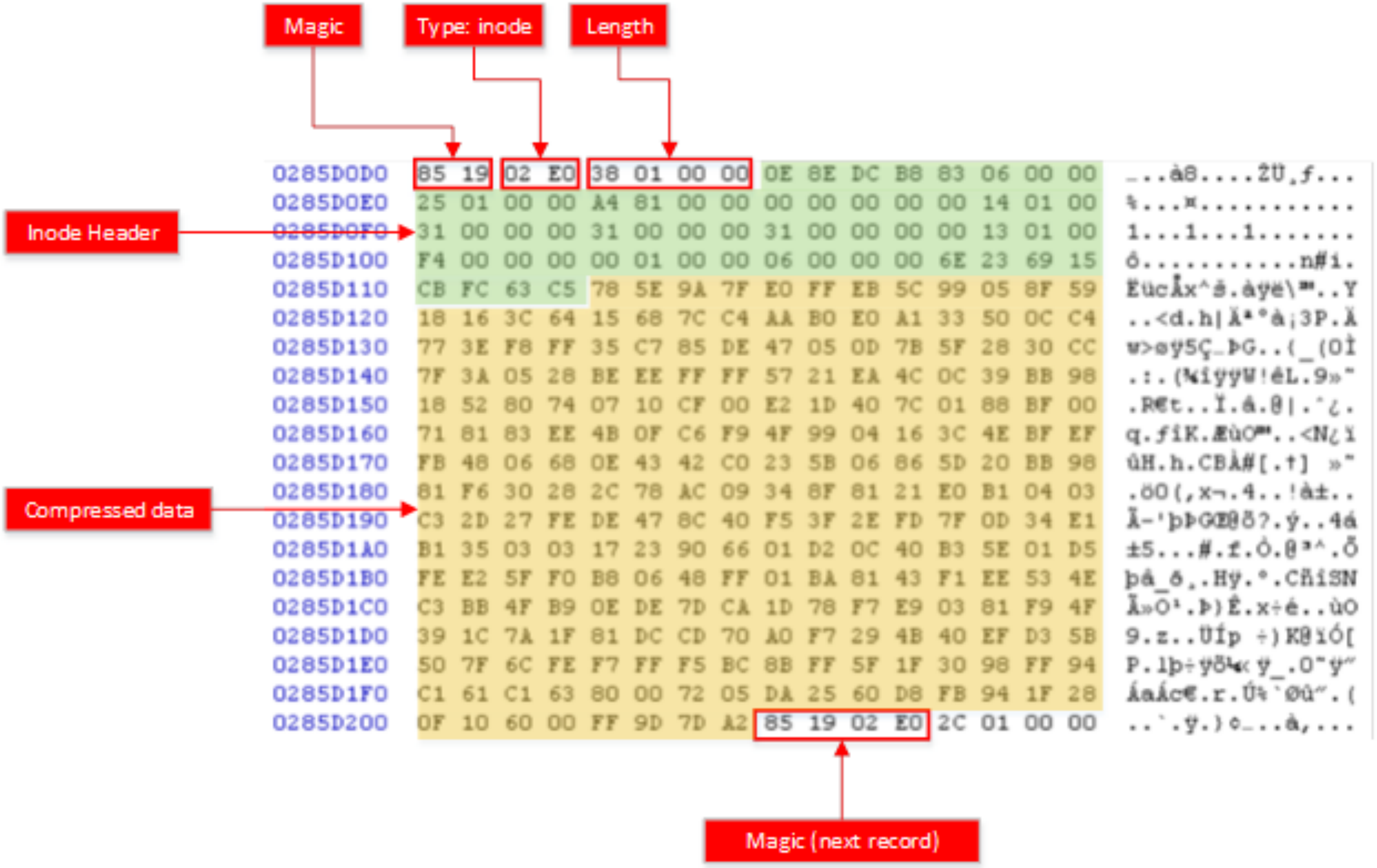
After



```
00019354
00019354
00019354
00019354                 sub_19354
00019354
00019354                 var_1AC= -0x1AC
00019354                 var_1A8= -0x1A8
00019354                 s= -0x1A4
00019354                 var_A4= -0xA4
00019354                 var_A3= -0xA3
00019354                 var_A2= -0xA2
00019354                 var_A1= -0xA1
00019354                 var_9C= -0x9C
00019354                 set= -0x98
00019354                 var_18= -0x18
00019354
00019354 70 40 2D E9 STMFD            SP!, {R4-R6,LR}
00019358 48 01 9F E5 LDR              R0, =aDevSpectrum ; "/dev/spectrum"
0001935C 02 10 A0 E3 MOV              R1, #2  ; oflag
00019360 67 DF 4D E2 SUB              SP, SP, #0x19C
00019364 1C C1 FF EB BL               open
00019368 00 60 50 E2 SUBS             R6, R0, #0
0001936C 3D 00 00 BA BLT              loc_19468
```

```
00019370 6D 1C A0 E3+MOV              R1, #0x6D03 ; request
00019378 00 20 A0 E3 MOV              R2, #0
0001937C 29 C0 FF EB BL               ioctl
00019380 01 00 70 E3 CMN              R0, #1
00019384 18 00 00 DA BLE              loc_193EC
```

Original JFFS2 Record



Magic

Type: inode

Length

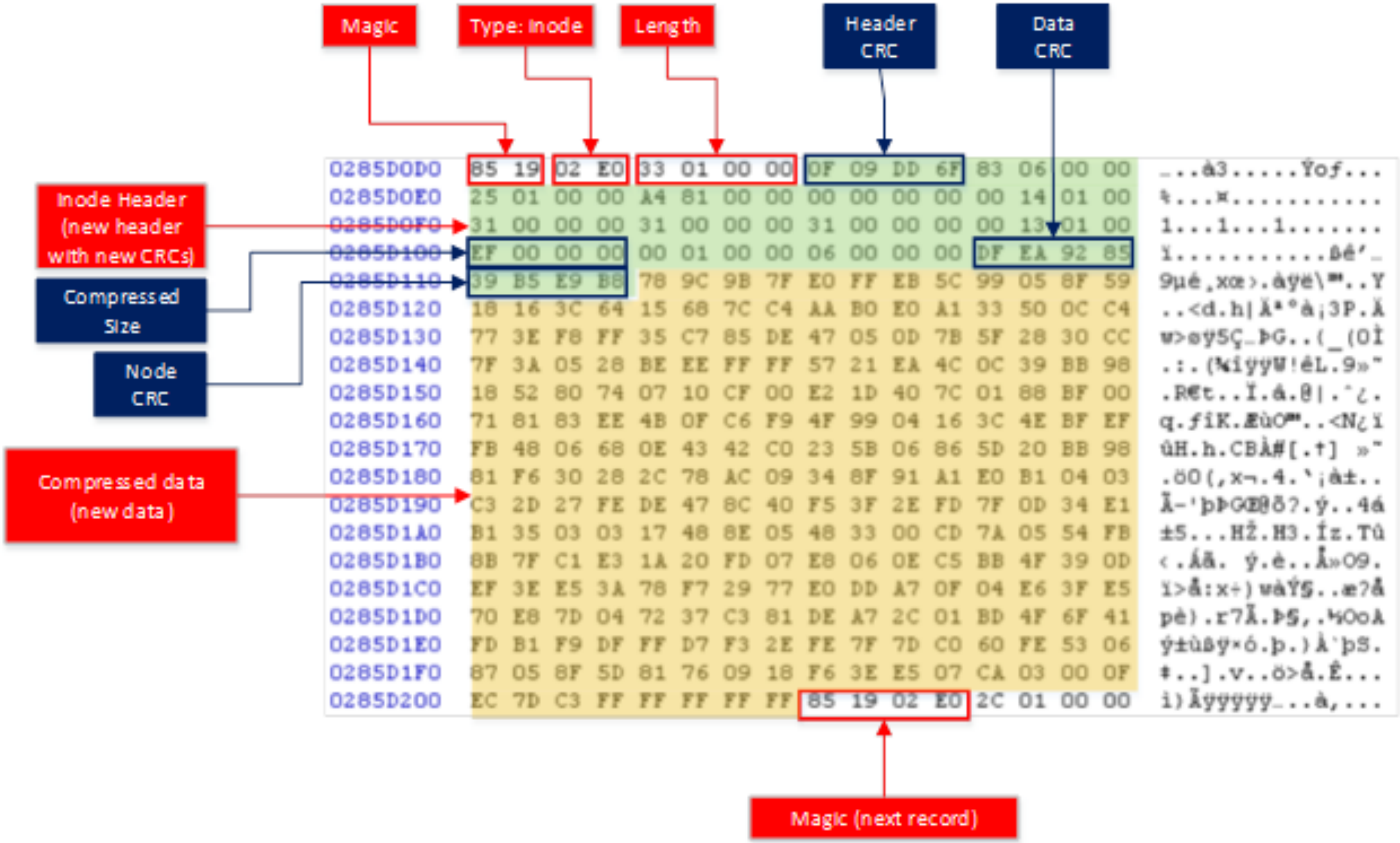
Inode Header

Compressed data

Magic (next record)

```
0285D0D0  85 19 02 E0 38 01 00 00 0E 8E DC B8 83 06 00 00   …..à8....ŽÜ¸ƒ...
0285D0E0  25 01 00 00 A4 81 00 00 00 00 00 00 00 14 01 00   %...¤...........
0285D0F0  31 00 00 00 31 00 00 00 31 00 00 00 00 13 01 00   1...1...1.......
0285D100  F4 00 00 00 00 01 00 00 06 00 00 00 6E 23 69 15   ô...........n#i.
0285D110  CB FC 63 C5 78 5E 9A 7F E0 FF EB 5C 99 05 8F 59   ËücÅx^š.àÿë\™..Y
0285D120  18 16 3C 64 15 68 7C C4 AA B0 E0 A1 33 50 0C C4   ..<d.h|Äª°à¡3P.Ä
0285D130  77 3E F8 FF 35 C7 85 DE 47 05 0D 7B 5F 28 30 CC   w>øÿ5Ç…ÞG..{_(0Ì
0285D140  7F 3A 05 28 BE EE FF FF 57 21 EA 4C 0C 39 BB 98   .:.(¾îÿÿW!êL.9»˜
0285D150  18 52 80 74 07 10 CF 00 E2 1D 40 7C 01 88 BF 00   .R€t..Ï.â.@|.ˆ¿.
0285D160  71 81 83 EE 4B 0F C6 F9 4F 99 04 16 3C 4E BF EF   q.ƒîK.ÆùO™..<N¿ï
0285D170  FB 48 06 68 0E 43 42 C0 23 5B 06 86 5D 20 BB 98   ûH.h.CBÀ#[.†] »˜
0285D180  81 F6 30 28 2C 78 AC 09 34 8F 81 21 E0 B1 04 03   .ö0(,x¬.4..!à±..
0285D190  C3 2D 27 FE DE 47 8C 40 F5 3F 2E FD 7F 0D 34 E1   Ã-'þÞGŒ@õ?.ý..4á
0285D1A0  B1 35 03 03 17 23 90 66 01 D2 0C 40 B3 5E 01 D5   ±5...#.f.Ò.@³^.Õ
0285D1B0  FE E2 5F F0 B8 06 48 FF 01 BA 81 43 F1 EE 53 4E   þâ_ð¸.Hÿ.º.CñîSN
0285D1C0  C3 BB 4F B9 0E DE 7D CA 1D 78 F7 E9 03 81 F9 4F   Ã»O¹.Þ}Ê.x÷é..ùO
0285D1D0  39 1C 7A 1F 81 DC CD 70 A0 F7 29 4B 40 EF D3 5B   9.z..ÜÍp ÷)K@ïÓ[
0285D1E0  50 7F 6C FE F7 FF F5 BC 8B FF 5F 1F 30 98 FF 94   P.lþ÷ÿõ¼‹ÿ_.0˜ÿ”
0285D1F0  C1 61 C1 63 80 00 72 05 DA 25 60 D8 FB 94 1F 28   ÁaÁc€.r.Ú%`Øû”.(
0285D200  0F 10 60 00 FF 9D 7D A2 85 19 02 E0 2C 01 00 00   ..`.ÿ.}¢…..à,...
```

Modifed JFFS2 Record



```
0285D0D0  85 19 02 E0 33 01 00 00 0F 09 DD 6F 83 06 00 00  ...à3.....Ÿof...
0285D0E0  25 01 00 00 A4 81 00 00 00 00 00 00 00 14 01 00  %...¤...........
0285D0F0  31 00 00 00 31 00 00 00 31 00 00 00 00 13 01 00  1...1...1.......
0285D100  EF 00 00 00 00 01 00 00 06 00 00 00 DF EA 92 85  ï...........ßê'…
0285D110  39 B5 E9 B8 78 9C 9B 7F E0 FF EB 5C 99 05 8F 59  9µé¸xœ›.àÿë\™..Y
0285D120  18 16 3C 64 15 68 7C C4 AA B0 E0 A1 33 50 0C C4  ..<d.h|Äª°à¡3P.Ä
0285D130  77 3E F8 FF 35 C7 85 DE 47 05 0D 7B 5F 28 30 CC  w>øÿ5Ç…ÞG..{_(0Ì
0285D140  7F 3A 05 28 BE EE FF FF 57 21 EA 4C 0C 39 BB 98  .:.(¾îÿÿW!êL.9»˜
0285D150  18 52 80 74 07 10 CF 00 E2 1D 40 7C 01 88 BF 00  .R€t..Ï.â.@|.ˆ¿.
0285D160  71 81 83 EE 4B 0F C6 F9 4F 99 04 16 3C 4E BF EF  q.ƒîK.ÆùO™..<N¿ï
0285D170  FB 48 06 68 0E 43 42 C0 23 5B 06 86 5D 20 BB 98  ûH.h.CBÀ#[.†] »˜
0285D180  81 F6 30 28 2C 78 AC 09 34 8F 91 A1 E0 B1 04 03  .ö0(,x¬.4.‘¡à±..
0285D190  C3 2D 27 FE DE 47 8C 40 F5 3F 2E FD 7F 0D 34 E1  Ã-'þÞGŒ@õ?.ý..4á
0285D1A0  B1 35 03 03 17 48 8E 05 48 33 00 CD 7A 05 54 FB  ±5...HŽ.H3.Íz.Tû
0285D1B0  8B 7F C1 E3 1A 20 FD 07 E8 06 0E C5 BB 4F 39 0D  ‹.Áã. ý.è..Å»O9.
0285D1C0  EF 3E E5 3A 78 F7 29 77 E0 DD A7 0F 04 E6 3F E5  ï>å:x÷)wàÝ§..æ?å
0285D1D0  70 E8 7D 04 72 37 C3 81 DE A7 2C 01 BD 4F 6F 41  pè}.r7Ã.Þ§,.½OoA
0285D1E0  FD B1 F9 DF FF D7 F3 2E FE 7F 7D C0 60 FE 53 06  ý±ùßÿ×ó.þ.}À`þS.
0285D1F0  87 05 8F 5D 81 76 09 18 F6 3E E5 07 CA 03 00 0F  ‡..].v..ö>å.Ê...
0285D200  EC 7D C3 FF FF FF FF FF 85 19 02 E0 2C 01 00 00  ì}Ãÿÿÿÿÿ…..à,...
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