THE LINUX FOUNDATION
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Embedded Linux Conference

When 10,000 Screens Go Dark

Engineering Resilient Linux Drivers for Manufacturing Reality

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Background

Function

- Linux and low-level software developer in Devices team comprising of RF, Electronics, Mechanical, Production and Hardware engineers

Manufacturing

- B2B device manufacturing runs are triggered based on customer orders
- Components are procured and stocked based on future demand projections
- Manufacturing runs planned in parallel with order finalization to reduce lead time

Setup

- A new LCD vendor was selected for a fresh product line
- First several production runs went smoothly for over a year

Production lines stalled

What happened?

- None of the LCDs on one device variant initialized after firmware injection at the manufacturing facility

What was found?

- A new batch of LCDs with approximately the same part number had been installed in all affected devices
- LCD vendor had sent an email without a formal ECN, stating internal components would be slightly varied
- Vendor assured electrical and mechanical design remained unchanged
- Vendor validated new panels using their existing test box and declared compatibility

Root cause: Display Driver IC substitution

Cause:

- LCD vendor changed the Display Driver IC from HX8394F to ILI9881D
- Reason: no supply of variant HX8394F and no alternative source available to them

Why it broke everything:

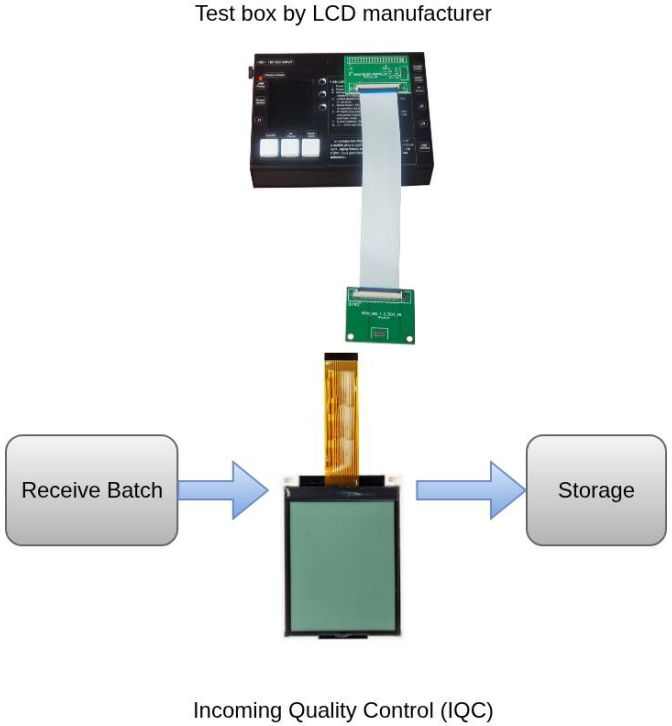
- Display Driver IC initialization sequences differ between HX8394F and ILI9881D
- Linux driver had a hardcoded init sequence written for HX8394F only
- ILI9881D received wrong commands at boot and failed to initialize the panel

No ECN = No Warning

- An Engineering Change Notice (ECN) was never formally issued
- Only an informal email notification was sent, which did not trigger any driver review

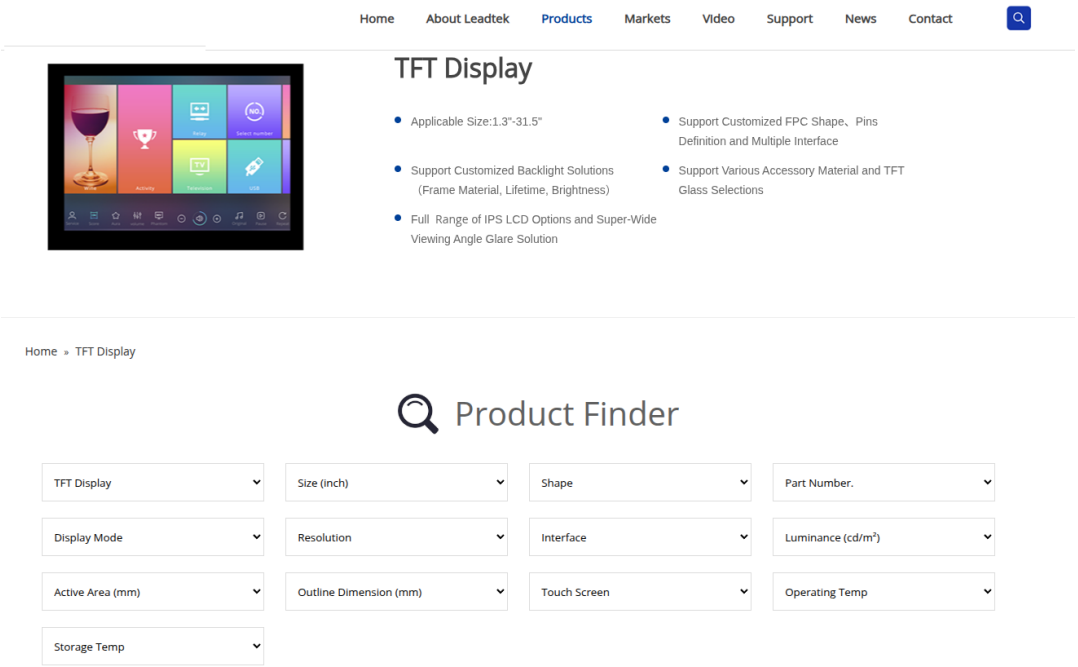
Why IQC did not catch it

- The LCD vendor and PCBA facility are in the same geographical location
- Vendor had silently updated their LCD test box to support the new Display Driver IC
- New panels passed IQC at the factory without raising any flags
- IQC validated the panel electrically and mechanically using the vendor's updated test box
- The test box passed panels that the device firmware could not drive



How LCD vendor selection and bring-up works

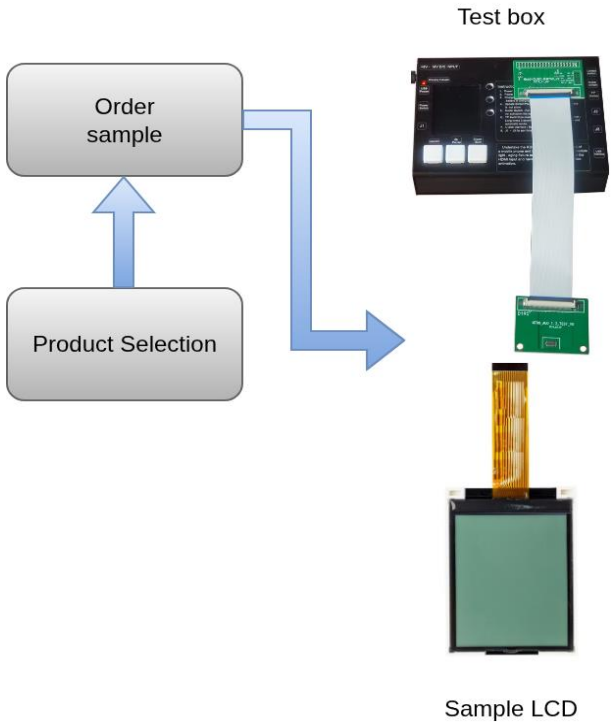
- You don’t get to choose the display driver IC



How LCD vendor selection and bring-up works

Vendor selection

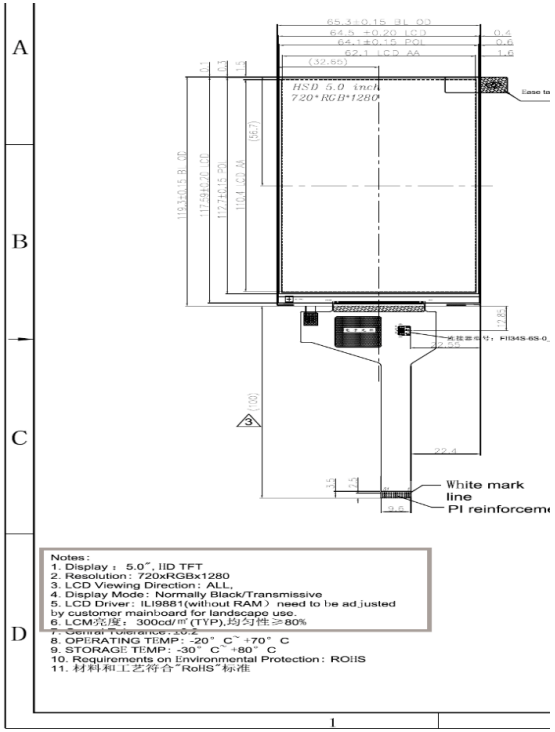
- Most LCD vendors do not offer a choice of Display Driver IC - you select based on interface, resolution, refresh rate, color depth, and lane count
- Once a panel model is selected, samples are ordered and the vendor ships a test box for validation



How LCD vendor selection and bring-up works

Electrical and mechanical fit

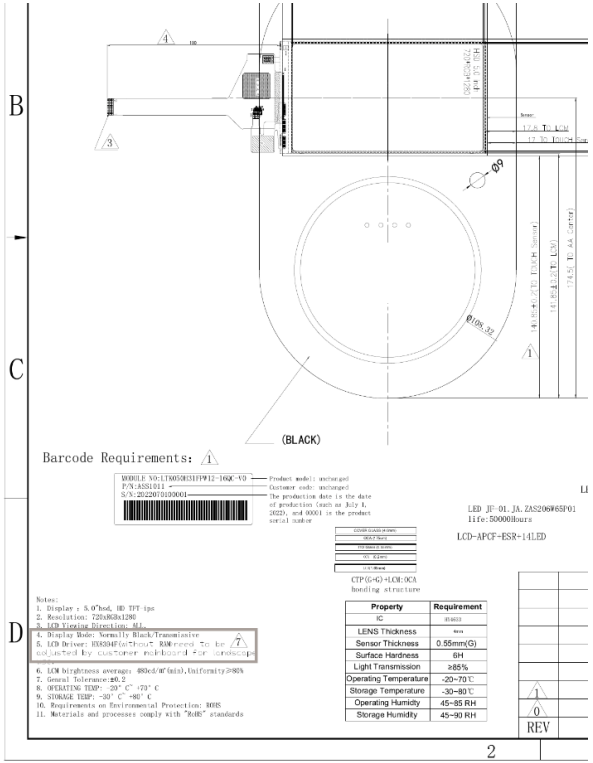
- Choice of Flexible Printed Circuit (FPC) connector, termination, length, pin-count and pitch
- Placement of Touch-screen IC, On or Off FPC.
- Backlight supply through FPC or separate cables



How LCD vendor selection and bring-up works

Product integration

- LCD vendor in this case had a broad product range and offered additional capabilities such as:
  - Bonding the panel assembly to the device glass sub-assembly
  - Supporting both plastic and metal back panels. Metal interferes with NFC designs
  - Quick turnaround times for samples and production



How LCD vendor selection and bring-up works

Software bring-up

- If a Linux kernel driver already exists for the Display Driver IC - bring-up is straightforward
- If not - roll up your sleeves: write a new MIPI DSI panel driver from scratch using vendor Application Notes and Technical Reference Manuals
- Vendor-specific initialization sequences are written as MIPI DSI command writes to Display Driver IC registers
- Software engineers may or may not get a say in panel selection - hardware teams often finalize the choice before firmware engineers are involved

Managing hardware variants in manufacturing

EOL component handling

- End-of-life and mid-lifecycle part substitutions are common in electronics - NAND flash, DDR chips, and display driver ICs are frequent examples

Existing approach in this product range

- A U-Boot menu system loaded different Device Tree Overlays at boot time
- Allowed a single firmware release to support multiple device variants
- Operator selects the appropriate overlay for the hardware present

Two approaches considered for this issue

- Approach 1: Write separate MIPI DSI panel drivers for each Display Driver IC variant
- Approach 2: Detect the Display Driver IC at runtime and load the appropriate init sequence within a single driver

Approach 1: Separate panel drivers per variant

Cleanest way

- Write two separate MIPI DSI panel drivers with corresponding Device Tree bindings and overlays - one per Display Driver IC variant
- Extend the existing U-Boot menu with additional entries to select the correct overlay at boot

This approach requires

- Updated production test plan documents
- Formal ECN issued to the factory
- A new firmware release with both drivers
- Considerably more engineering effort across software, manufacturing, and documentation

Verdict

- Clean and maintainable long-term but heavy overhead given the urgency of stalled production lines
- More work for me!

Approach 2: Runtime display driver IC detection

Key insight

- Even with the new Display Driver IC installed, MIPI DCS commands could still be sent and valid responses received
- A Manufacturer ID query over MIPI DSI could identify the Display Driver IC at runtime

DCS

- Display Command Set is a set of commands for the MIPI DSI interface
- Display driver IC manufacturers have implemented the MIPI standard and vendor-specific register interfaces

HX8394-F

720RGBx1280dots, TFT Mobile Single Chip Driver

Himax

Temporary DATA SHEET V01

5.18.51 Read ID1 (DAh)

DAH	RDID1 (Read ID1)									
	DCX	D7	D6	D5	D4	D3	D2	D1	D0	HEX
Command	0	1	1	0	1	1	0	1	0	DA
1st parameter	1	module's manufacturer[7:0]								xx
Description	This read byte identifies the LCD module's manufacturer. It is specified by display supplier and for xx is defined as xxHEX.									
Restriction	-									

ILITEK

I Love Innovation

a-Si TFT LCD Single Chip Driver
720(RGB) x 1520 Resolution and 16.7M-color

ILI9881D-03

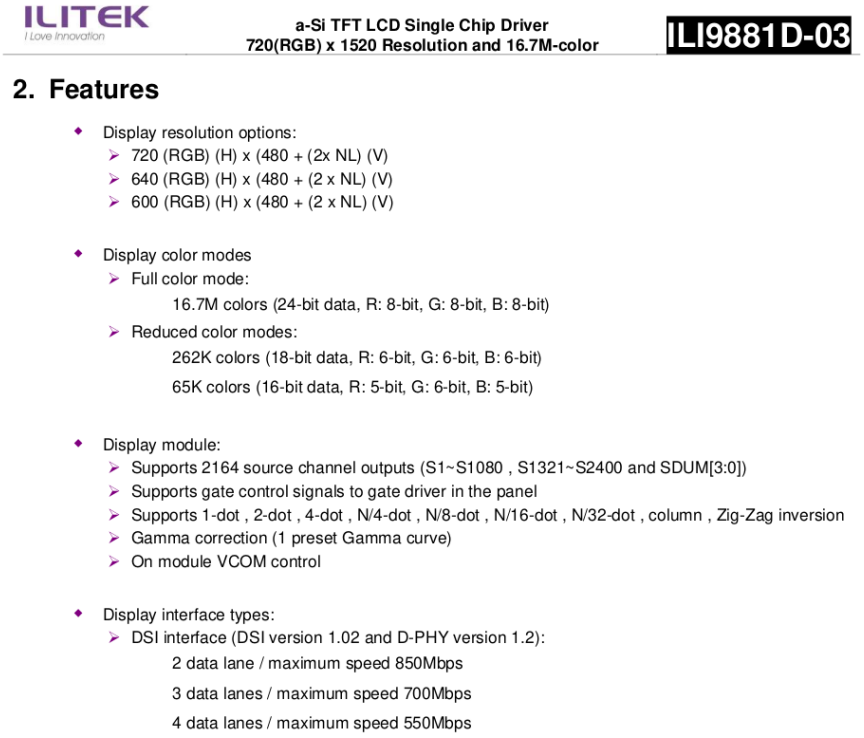
5.3.56. **Read ID1 (DAh)**

Command Page			Page 0								
Address	Parameter	W/R	D7	D6	D5	D4	D3	D2	D1	D0	Default
DAh	1st	R	ID1[7:0]								00h
Description			Dah: RDID1 (Read ID1). This read byte identifies the display module's manufacturer. The ID1[7:0] is programmed by the OTP function.								

Approach 2: Runtime display driver IC detection

Why this works

- Display Driver ICs are highly configurable, supporting multiple resolutions, lane counts, and hundreds of register-level settings
- LCD manufacturers use the same Display Driver IC across multiple panel form factors by loading different initialization configurations
- All configurations are delivered via MIPI DSI command writes to registers in the vendor Application Notes or Technical Reference Manual



ILITEK
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a-Si TFT LCD Single Chip Driver
720(RGB) x 1520 Resolution and 16.7M-color

ILI9881D-03

2. Features

- Display resolution options:
  - 720 (RGB) (H) x (480 + (2x NL) (V)
  - 640 (RGB) (H) x (480 + (2 x NL) (V)
  - 600 (RGB) (H) x (480 + (2 x NL) (V)
- Display color modes
  - Full color mode:
    16.7M colors (24-bit data, R: 8-bit, G: 8-bit, B: 8-bit)
  - Reduced color modes:
    262K colors (18-bit data, R: 6-bit, G: 6-bit, B: 6-bit)
    65K colors (16-bit data, R: 5-bit, G: 6-bit, B: 5-bit)
- Display module:
  - Supports 2164 source channel outputs (S1~S1080 , S1321~S2400 and SDUM[3:0])
  - Supports gate control signals to gate driver in the panel
  - Supports 1-dot , 2-dot , 4-dot , N/4-dot , N/8-dot , N/16-dot , N/32-dot , column , Zig-Zag inversion
  - Gamma correction (1 preset Gamma curve)
  - On module VCOM control
- Display interface types:
  - DSI interface (DSI version 1.02 and D-PHY version 1.2):
    2 data lane / maximum speed 850Mbps
    3 data lanes / maximum speed 700Mbps
    4 data lanes / maximum speed 550Mbps

How the solution works

Implementation steps

- Issue a Chip ID / Manufacturer ID query via MIPI DCS read
- Based on the returned ID, select and load the appropriate vendor-specific initialization sequence for that Display Driver IC
- Both Display Driver IC variants HX8394F and ILI9881D are handled transparently within the same firmware release

```
static int ltk05031_is_hx8394f(struct ltk05031 *ctx)
{
    u8 id[3] = {0};

    mipi_dsi_dcs_read(ctx->dsi, 0xDA, &id[0], 1);
    mipi_dsi_dcs_read(ctx->dsi, 0xDB, &id[1], 1);
    mipi_dsi_dcs_read(ctx->dsi, 0xDC, &id[2], 1);

    if ((id[0] == 0x83) && (id[1] == 0x94) && id[2] == 0xF)
        return 1;

    return 0;
}
```

```
static int ltk05031_panel_detect_configure(struct ltk05031 *ctx)
{
    ltk05031_hard_reset(ctx);

    if (ltk05031_is_ili9881d(ctx)) {
        dev_info(&ctx->dsi->dev, "Chip:ILI9881D\n");
        ctx->panel_desc = &ltk050h3123w_data;
        ltk05031_hard_reset(ctx);
    } else if (ltk05031_is_hx8394f(ctx)) {
        dev_info(&ctx->dsi->dev, "Chip:HX8394F\n");
        ctx->panel_desc = &ltk050h31fpw12_data;
        ltk05031_hard_reset(ctx);
    } else {
```

How the solution works

Implementation steps

- Chip specific init sequence and data are mapped at panel prepare stage
- Not the cleanest implementation on the planet but saves a lot of effort
- Since the LCD vendor promised electrical and mechanical compatibility, same regulator and reset pin mappings & sequence can be used

```
static const struct ltk05031_desc ltk050h3123w_data = {
    .mode = &ltk050h3123w_mode,
    .init = ltk050h3123w_init_sequence,
};
```

```
static const struct ltk05031_desc ltk050h31fpw12_data = {
    .mode = &ltk050h31fpw12_mode,
    .init = ltk050h31fpw12_init_sequence,
};
```

```
static int ltk05031_prepare(struct drm_panel *panel)
{
    struct ltk05031 *ctx = panel_to_ltk05031(panel);
    int ret;

    /* Power the panel */
    ret = regulator_enable(ctx->power);
    if (ret)
        return ret;
    msleep(5);

    ret = ltk05031_panel_detect_configure(ctx);
    if (ret)
```

How the solution works

What did not change

- No changes to the U-Boot menu or Device Tree Overlays
- No additional factory process steps or production test plan updates
- No formal ECN required - single unified firmware release deployed
- Production lines were unblocked without requiring a hardware split or multiple firmware images
- Review process and implementation confined to a single driver source
- It can address mixed fleet of devices in the field without worrying about compatibility issues

Outcome

Quick turnaround

- A single unified firmware release shipped that transparently supports both LCD variants
- No changes required to the manufacturing process, factory test plans, or U-Boot configuration
- Production lines unblocked rapidly without a formal hardware split

Broader takeaways

- Supply chain substitutions are a manufacturing reality - firmware must be resilient to component-level changes
- IQC processes must be aligned with production firmware, not just vendor test boxes
- Component changes without a formal ECN are a serious process gap that needs to be closed with vendors
- MIPI DCS read capability is a powerful tool for runtime hardware identification in Linux panel drivers

Possible improvements

Separate display driver IC configuration from driver code

- Like how Wi-Fi dongles load firmware blobs from /lib/firmware
- However, /lib/firmware is not suitable as an early splash screen may be required before the root filesystem is mounted
- Better approach is to store configuration in Device Tree, making it accessible to both U-Boot and the Linux kernel during early boot

```
/*
 * Init sequence was supplied by the panel vendor without much
 * documentation.
 */
dsi_dcs_write_seq(dsi, 0xB9, 0xFF, 0x83, 0x94);
dsi_dcs_write_seq(dsi, 0xB1, 0x50, 0x15, 0x75, 0x09, 0x32, 0x44, 0x71, 0x31, 0x55, 0x2F);
dsi_dcs_write_seq(dsi, 0xBA, 0x61, 0x03, 0x68, 0x6B, 0xB2, 0xC0);
```

```
static const struct ili9881d_instr ili9881d_init[] = {

    ILI9881D_SWITCH_PAGE_INSTR(3),
    ILI9881D_COMMAND_INSTR(0x01,0x00),
    ILI9881D_COMMAND_INSTR(0x02,0x00),
    ILI9881D_COMMAND_INSTR(0x03,0x73),
```

Possible improvements

Write panel driver against the display driver IC chip

- Rather than writing a driver tied to a specific panel model, write it against the Display Driver IC chip itself
- Expose all possible resolutions, lane counts, and configuration options as optional Device Tree properties
- Publish proper Device Tree bindings for each supported configuration
- Makes the driver reusable across any panel that uses the same Display Driver IC, regardless of the panel vendor

Thank You!
Questions?

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