Zephyr-friendly Embedded Display Shopping Guide

Eve Redero, Electronics & Embedded Engineer

About me

Eve Redero – redero.fr

Freelance electronics and embedded engineer

~10 years XP in consumer electronics

~3 year Zephyr user

Project story

Designing a fully-Zephyr compatible board

Looking for a display

Got lost in catalogues

- Lots of different technologies
- Lots of references
- Minimalist datasheets

Summary

I- Characters or graphics

What should the display do?

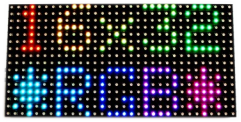
II- Display technologies

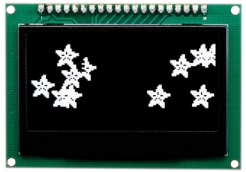
III- Display controllers

IV- Display interfaces

I- Characters or graphics?

Pixel Matrix





Alphanumeric

14-segment LED

Alphanumeric LCD

7-segment LED

Alphanumeric VFD

7-segment LCD

Managing too many pixels

Display code:

- Memory intensive
- Resource intensive
- Code intensive

Zephyr driver API:

- Implements low-level drivers

Graphics libraries:

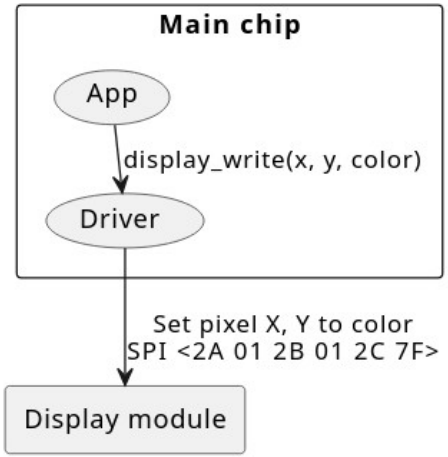
- Create objects to display

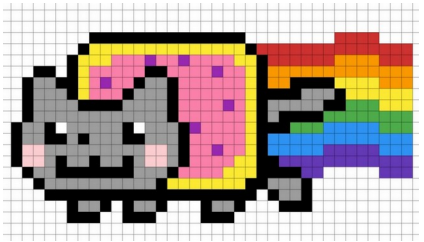
Display driver API

drivers/display

Per-pixel abstraction

```
static int display_write (
    const struct device *dev,
    const uint16_t x,
    const uint16_t y,
    const struct display_buffer_descriptor *desc,
    const void *buf)
```



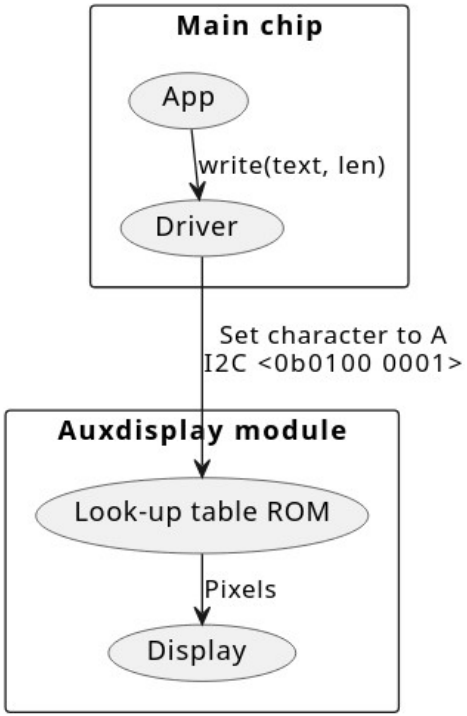


Auxdisplay driver API

drivers/auxdisplay

Alphanumeric devices abstraction

```
static int write (
    const struct device *dev,
    const uint8_t *text,
    uint16_t len)
```



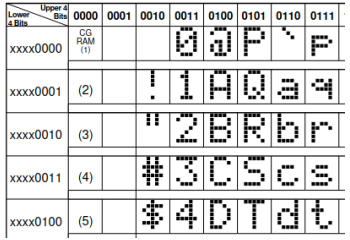


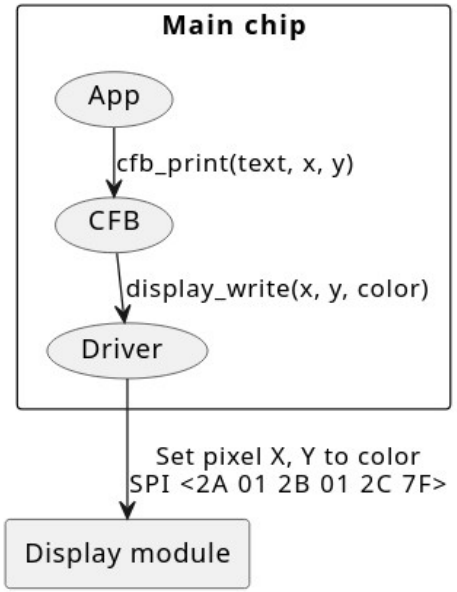
Image source: https://cdn.sparkfun.com/assets/9/5/f/7/b/HD44780.pdf

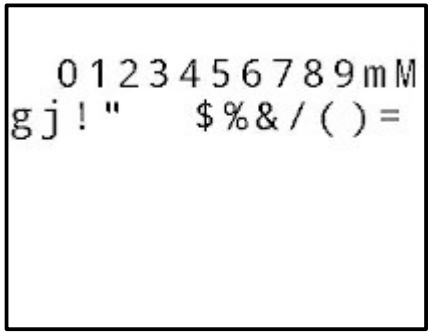
CFB library

CFB: Character Frame Buffer

Library to draw text on pixel displays

```
int cfb_print (
    const struct device *dev,
    const char *const str,
    uint16_t x,
    uint16_t y)
```





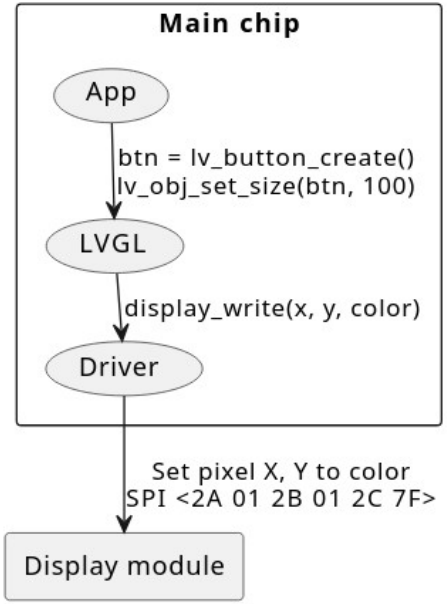
LVGL library

LVGL: Light and Versatile Graphics Library

Advanced graphics library

```
lv_obt_t * lv_button_create (
   lv_obt_t  * parent)

void lv_textarea_add_text (
   lv_obt_t  * obt,
    const char  * txt)
```



Smart displays

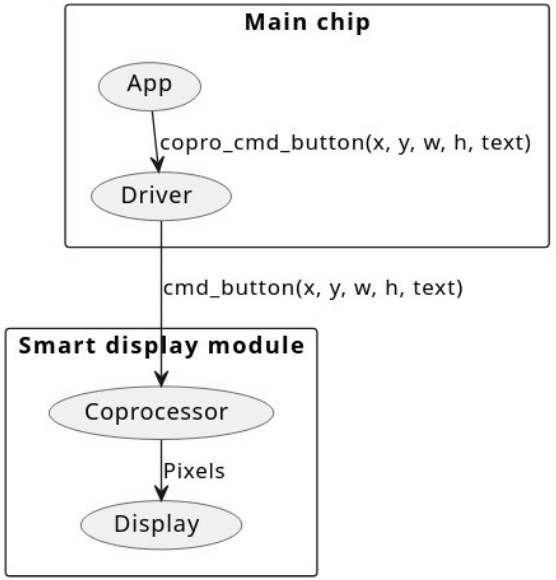
drivers/misc/ft8xx

Graphics library embedded in the display

Device-specific API

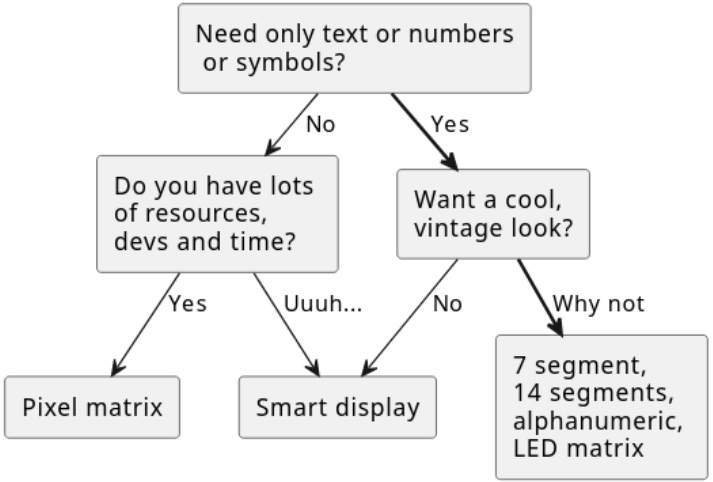
FTDI FT80x, FT81x series

```
void ft8xx_copro_cmd_text(
    const struct device *dev,
    int16_t x,
    int16_t y,
    int16_t font,
    uint16_t options,
    const char *string)
```

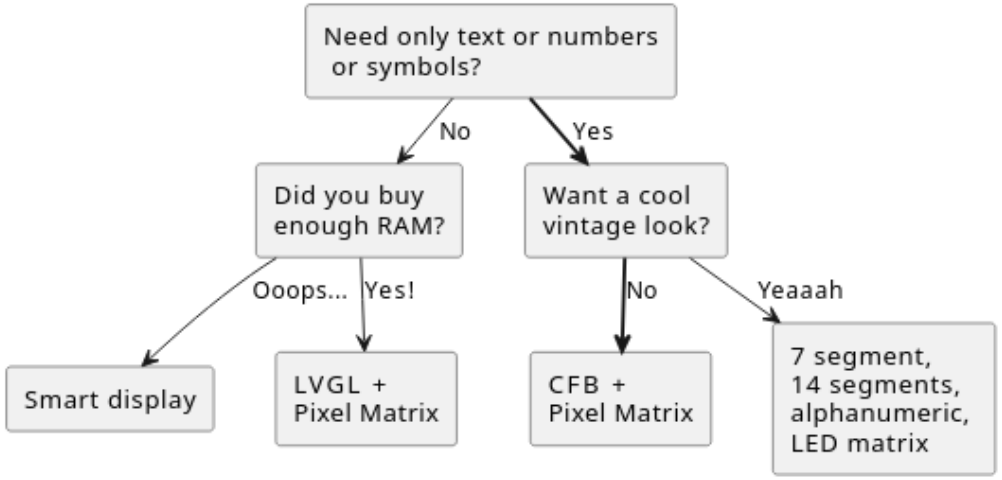


Which display type should I choose?

Without Zephyr



With Zephyr



Summary

I- Characters or graphics

II- Display technologies

FSTN? IPS? VFD? EPD? AMOLED?

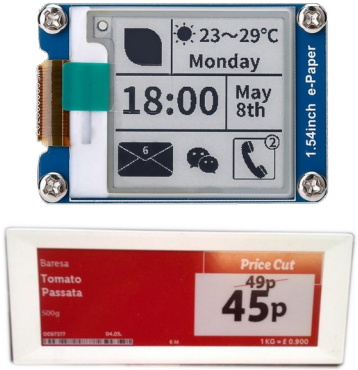
III- Display controllers

IV- Display interfaces

II- Display technologies

1. LCD

2. E-Paper



3. LED - OLED

1. LCD - TFT LCD vs Classic LCD

Catalogue name	Meaning
LCD	Classic TN LCD display
TN, STN, FSTN	Classic TN LCD display
TFT, TFT LCD	TFT TN LCD
IPS, IPS LCD	TFT IPS LCD

Physics of LCD displays

Liquid Crystal: polarization properties

Polarization changed by electric field

+ Liquid crystal

+ Polarization filters

+ Capacitors for electric fields

= Controlled opacity

Analog control

Requires a backlight (LED)

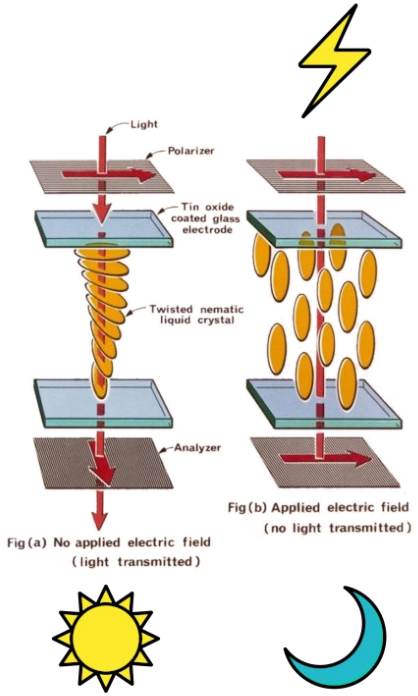


Image source: http://www.scifun.org/CHEMWEEK/LCD/LCDs2019.html

TN vs IPS

2 ways to use the Liquid Crystal phases

TN: ~ 1970

Twisted Nematics

Default: transparent

IPS: ~ 2000

In-Plane Switching

Default: opaque

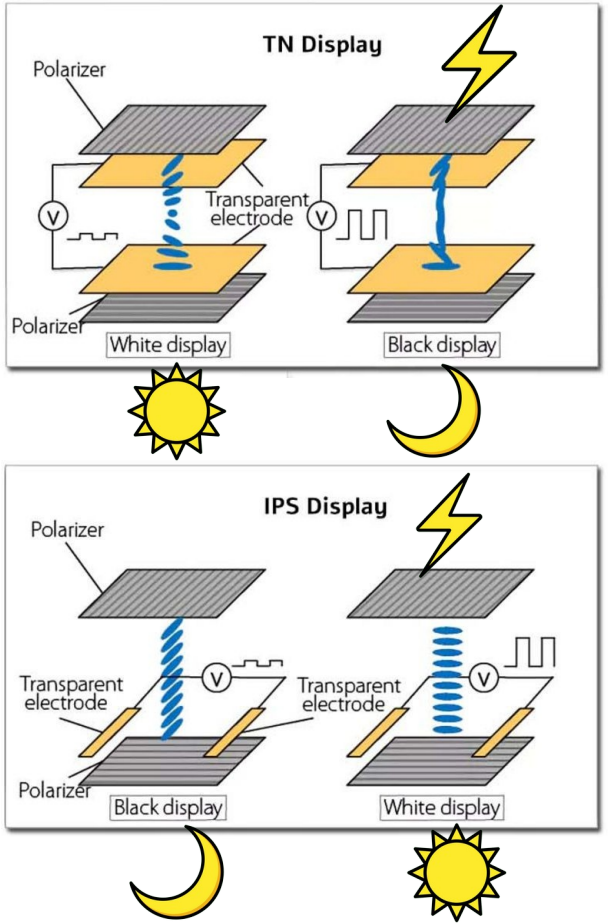


Image source: https://www.orientdisplay.com/fr/knowledge-base/tft-basics/how-does-tft-displays-work/

What is TFT?

Problem:

- Each pixel needs its own tiny electrical field
- Silicon wafers can't help: they are opaque

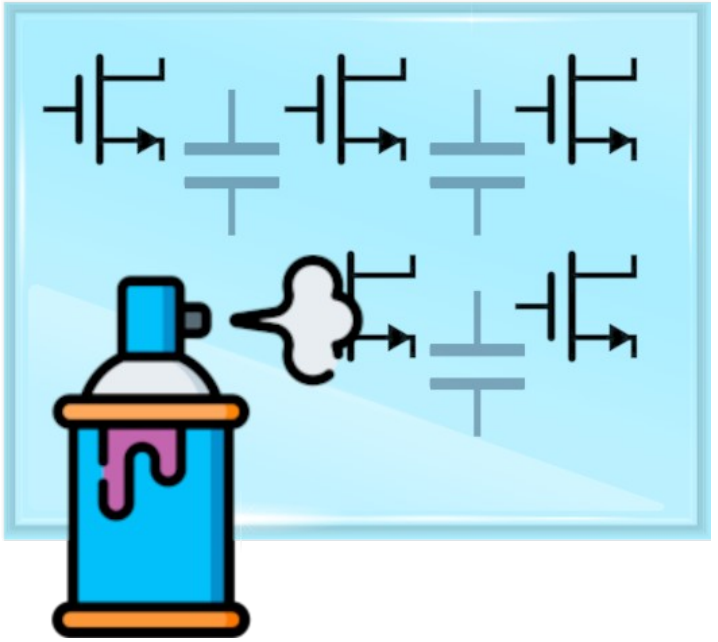
TFT: Thin-Film Transistor

- Miniaturized transistor
- Deposited on glass

ITO: Indium Tin Oxyde

- Transparent conductor
- Indium is rare

TFT transistors + ITO capacitors => TFT backplanes



TFT LCD vs Classic LCD

Catalogue name	Meaning
LCD	Classic TN LCD display
TN, STN, FSTN HTN, DSTN, DFSTN, FRSTN, FFSTN, MSTN, EBTN...	Classic TN LCD display
TFT, TFT LCD	TFT TN LCD
IPS, IPS LCD	TFT IPS LCD

LCD: Liquid Crystal Display

TN: Twisted Nematics

STN: Super Twisted Nematics

IPS: In-Plane Switching

TFT: Thin Film Transistor

ITO: Indium Tin Oxyde

2- Physics of E-Paper displays

Bubbles of charged ink

Driven by TFT backplane

Electric field toggles the charge side

Bistable

- Once changed, a pixel stays the same color

Exists in 3 pigments or more

- Only monochromes supported by Zephyr

Also named:

- ESL: Electronic Shelf Label
- EPD: Electronic Paper Display or ElectroPhoretic Display
- E-Ink ®

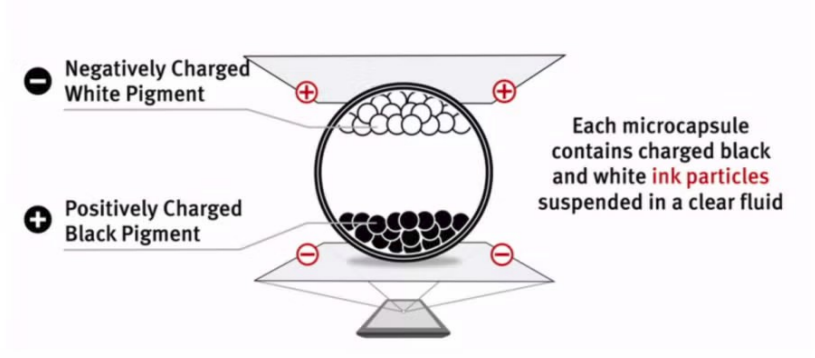
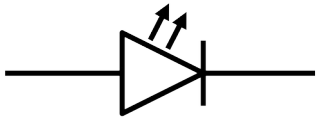


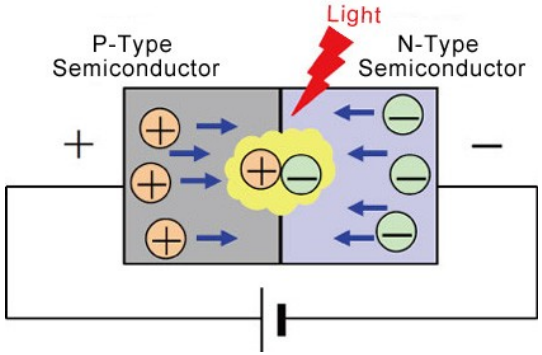
Image source: https://www.eink.com/tech/detail/How_it_works

3- Physics of OLED displays

Miniaturized LED matrix display

- Diode: P-N junction
- LED: special P-N junction producing light





OLED display:

- P-N sandwich
- Vertical mini-diodes
- One side is transparent (ITO)
- Grid pattern, pixels = intersections

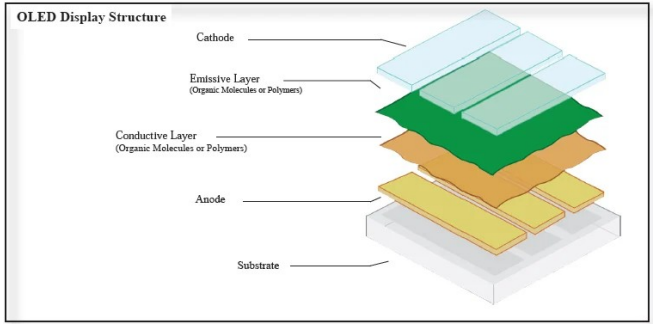
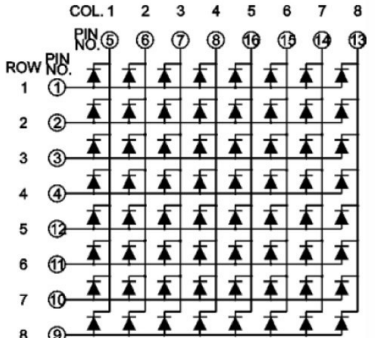


Image source: https://www.mouser.fr/new/newhaven-display/newhavenoleddisplay/

Driving a Passive Matrix OLED display

LED only have two pins:

- Updating one single row at a time
- Other rows are floated (disconnected)
- Pixels holding state until next refresh



How to display text '9'

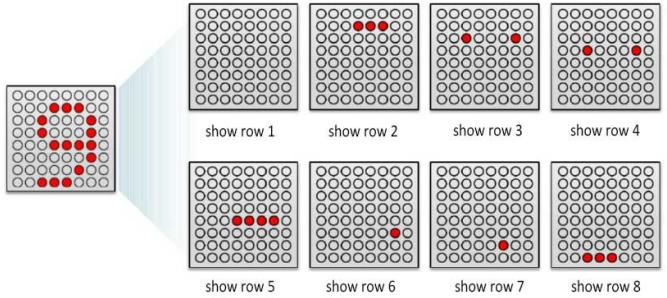


Image source: https://seengreat.com/blog/64/dot-matrix-led-display-panel
https://tronixstuff.com/2013/10/11/tutorial-arduino-max7219-led-display-driver-ic/

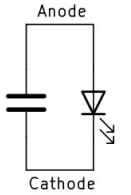
PMOLED VS AMOLED

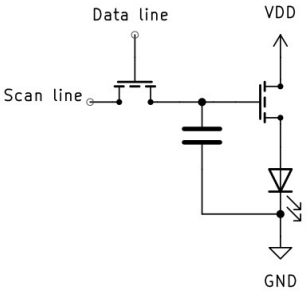
Passive Matrix OLED

- No TFT backplane
- Common anode or cathode
- One row updated at a time
- Small, monochrome embedded displays

Active Matrix OLED

- OLED + TFT backplane
- Higher range displays





4. VFD

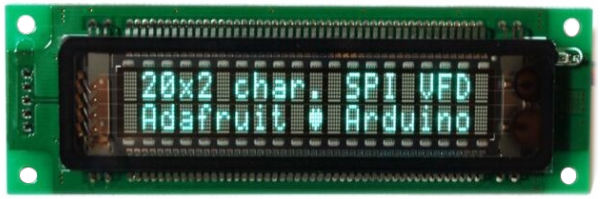
VFD: Vacuum Fluorescent Display

Mostly legacy

Works like neon lights

Drivers in auxdisplay:

- PTC PT6314
- Noritake Itron CU-TE, CU-Y, GU series



Display technologies cheat sheet

Catalogue name	Meaning	
LCD, TN, STN, FSTN HTN, DSTN, DFSTN, FRSTN, FFSTN, MSTN, EBTN...	Classic TN LCD	
TFT, IPS	TFT LCD (TN or IPS)	
EPD, ESL, E-Ink	E-Paper	
AMOLED	"Big" OLED	
PMOLED	"Small" OLED	
VFD	80's neon	

Summary

I- Characters or graphics

II- Display technologies

III- Display controllers

How to control 560 pins?

IV- Display interfaces

III- Display controllers

Displays:

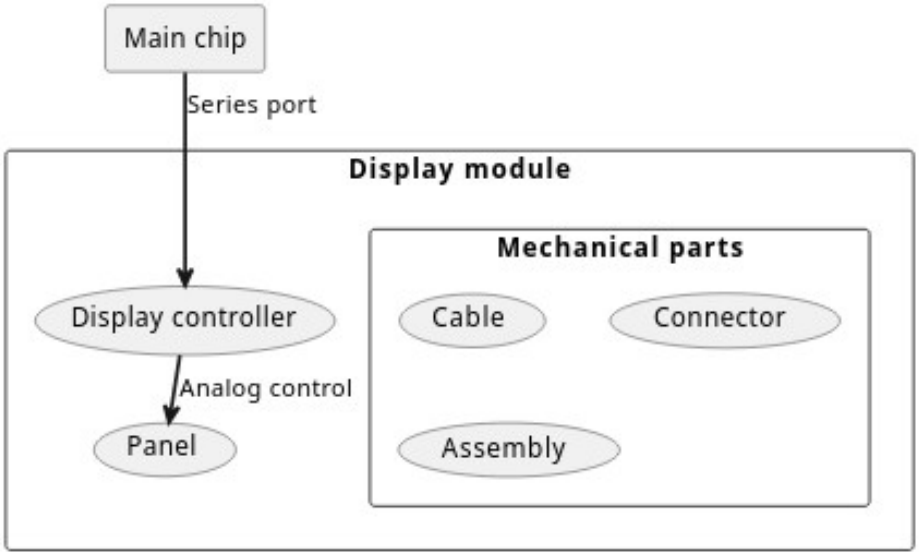
- Require lots of pins
  - 240+320 = 560
- Require memory to refresh pixels
- Require analog control

Controllers:

- Specialized chip to drive panels
- Built inside modules

Modules:

- Controller + panel + mechanical parts
- Mostly tailored, small runs



What does a display controller look like?

COG: Chip On Glass

Soldered directly on glass

No plastic package

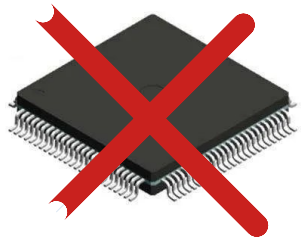
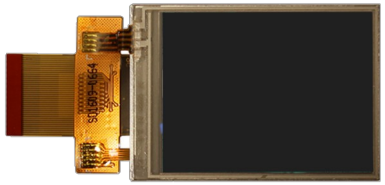


Image source: https://www.nxp.com/docs/en/white-paper/LCD_WhitePaper_D3.pdf

Display modules

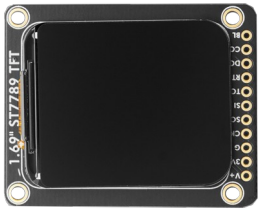


NewHaven
NHD-2.4-240320CF-CSXN#-FT
240x320

HanSheng
HS20HS072RX
240x320

NewVision
N114-2413THBIG01-H13
135x240

Sitronix ST7789(Vx)
sitronix_st7789v



Adafruit
1.69" IPS TFT
280x240

Adafruit
1.9" IPS TFT
320x170

Waveshare
1.14" IPS TFT
240x135

Sparkfun
2.0" TFT LCD
240x320
ZhongJingYuan
ZJY200S0800TG01

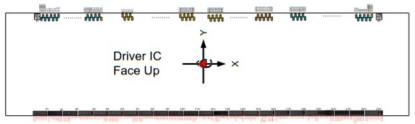
Display controllers and modules in software

Display controllers:

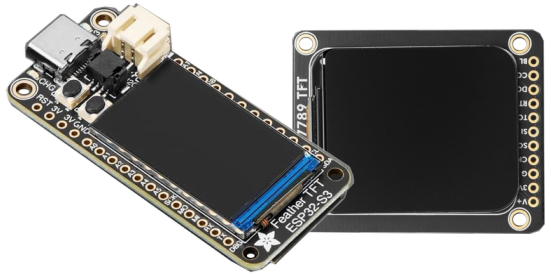
- Zephyr drivers
- Described in the controller datasheet

Display module specifics:

- Device-tree properties
- Display size, orientation, offsets, inversions...
- Described in the module datasheet



ST7789.pdf
drivers/display/display_st7789v.c



Display modules in software

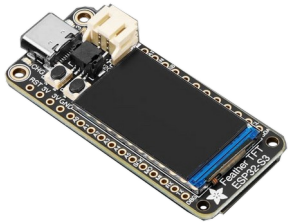
Can be found as shields or in board device trees

boards/shields/waveshare_pico_lcd_1_14/
waveshare_pico_lcd_1_14_display.overlay


```
st7789v_waveshare_pico_lcd_1_14: st7789v@0 {
        compatible = "sitronix,st7789v";
        reg = <0>;
        mipi-max-frequency = <20000000>;

        width = <240>;
        height = <135>;
        x-offset = <40>;
        y-offset = <53>;
```

boards/adafruit/feather_esp32s3_tft/
adafruit_feather_esp32s3_tft_procpu.dts



```
st7789v_tft: st7789v_tft@0 {
        compatible = "sitronix,st7789v";
        power-domains = <&i2c_reg>;
        mipi-max-frequency = <DT_FREQ_M(20)>;

        reg = <0>;
        width = <135>;
        height = <240>;
        x-offset = <52>;
        y-offset = <40>;
```

Zephyr-supported references cheat sheet 1/2
Auxdisplay API

Hitachi HD44780

7-segments GPIO

JHD JHD1313

Sparkfun Qwiic SerLCD

PTC PT6314

Noritake Itron

Legend

LCD

LED

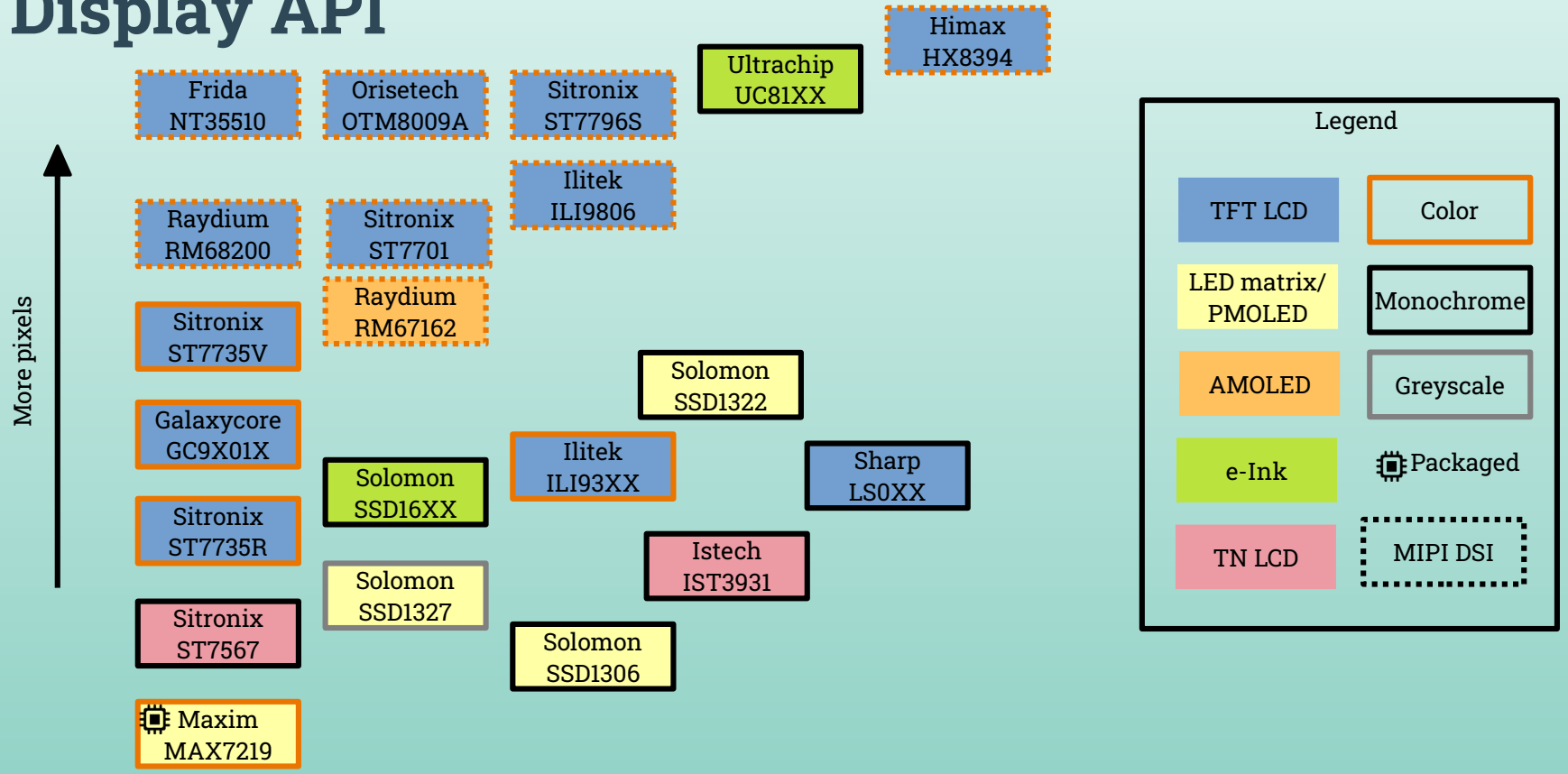
VFD

Monochrome

Packaged

Zephyr-supported references cheat sheet 2/2

Display API



Summary

I- Characters or graphics

II- Display technologies

III- Display controllers

IV- Display interfaces

How do I connect my display module to my board?

IV- Display controllers interfaces

2 ingredients:

- Interfaces on which they talk
  - SPI, I2C, MIPI DSI...
- Controller drivers, implementing protocols
  - Bunch of hex values, depends on your display

Not all MCU to controller interfaces supported by all Zephyr controller drivers

Ilitek ILI9341 Zephyr driver:

- 8080-I parallel
- 8080-II parallel
- 3 lines serial (SPI)
- 4 lines serial (SPI + D/C)

1. Serial interfaces

Serial interfaces commonly used:

- I2C
- SPI (MIPI DBI type C):
  - 3-wires (normal SPI)
  - 4-wires (SPI with D/C line)

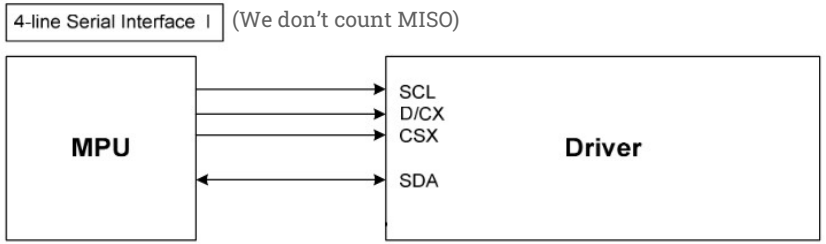


Image source: https://cdn-shop.adafruit.com/datasheets/ILI9341.pdf

Serial interface example architecture

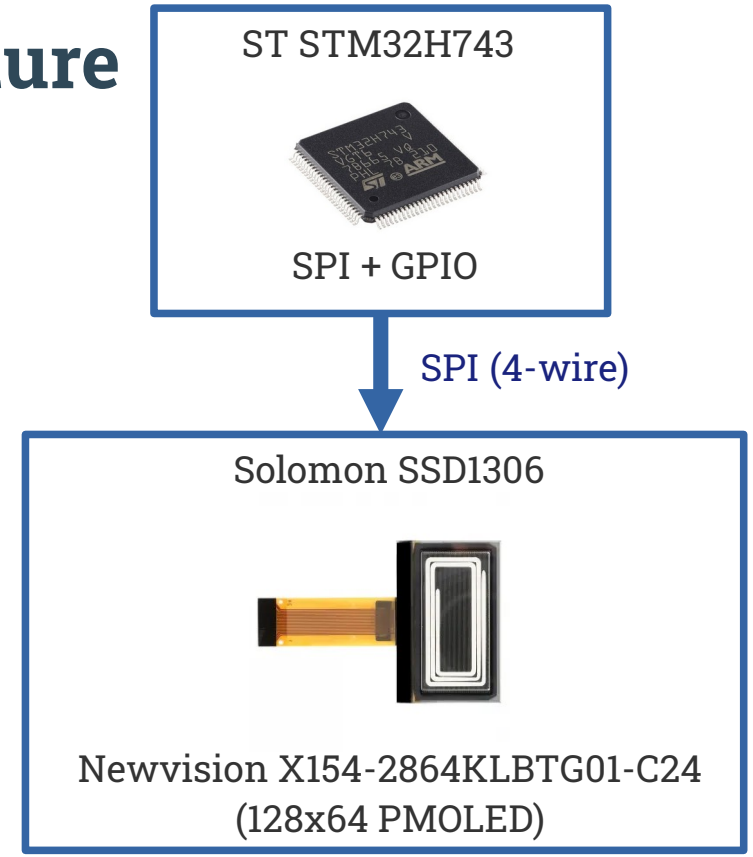
Solomon SSD1306:

Has I2C and SPI interface with Zephyr support

```
compatible = "solomon,ssd1306fb";
```

Exemple commands:

0xae	Set display off
0x81	Set contrast control
0x32	-- 50 %
0xa8	Set multiplex ratio
0x3f	-- 1/64
0xd3	Set display offset
0x00	-- 0
0xaf	Set display on



2. LCD RGB Interface

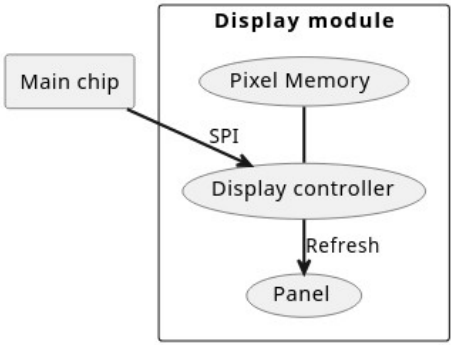
TFT LCD with direct LCD drivers

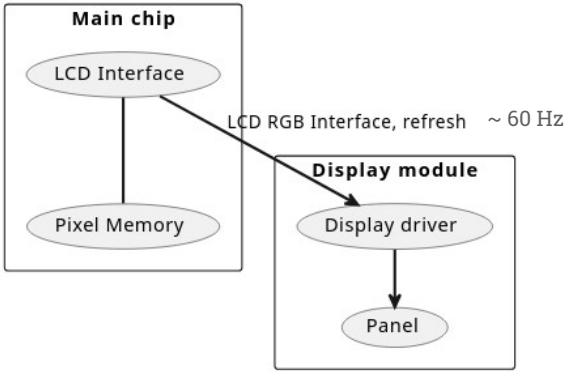
- MCU transmits clocks and data for each pixel at each refresh
- No protocol – no software driver required
- Requires hardware block in microcontroller

Interface sometimes called "Parallel RGB", "Standard RGB" or "DotClock RGB", "TTL RGB", "MIPI DPI" or just "RGB"

Zephyr supported LCD RGB interfaces:
- STM32 LTDC
- NXP MCUX ELCDIF & DCNano LCDIF
- Renesas LCDC & RA GLCDC

TFT LCD controllers usually backward compatible to RGB interface
- ex: Sitronix ST7789





How to spot a LCD RGB interface?

LCD RGB interface uses HSYNC, VSYNC, RED[N], GREEN[N], BLUE[N] and a pixel clock

Different pixel depths

RGB888: 8-bit colors

- 24 colors bits + 3 clocks
- Total 27 lines

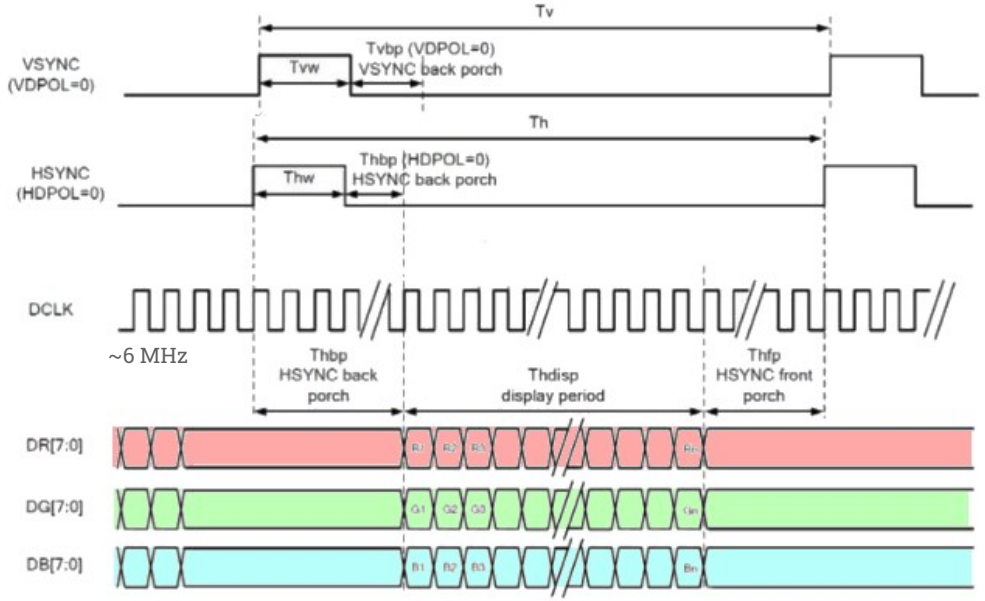


Image source: https://download.riverdi.com/RVT35HHTNWN00/DS_RVT35HHTNWN00_Rev.1.1.pdf

RGB interface example architecture

Sitronix ST7262:

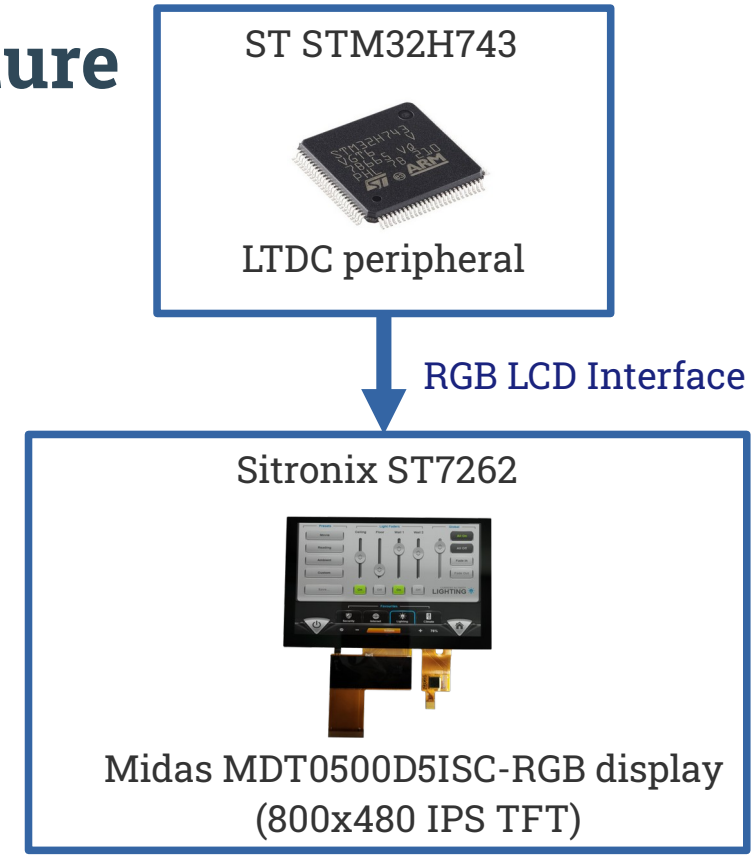
Has I2C interface with no Zephyr support

~~`compatible = "sitronix,st7262";`~~

Has RGB LCD interface

```
compatible = "st,stm32-ltdc";
```

No need for controller driver

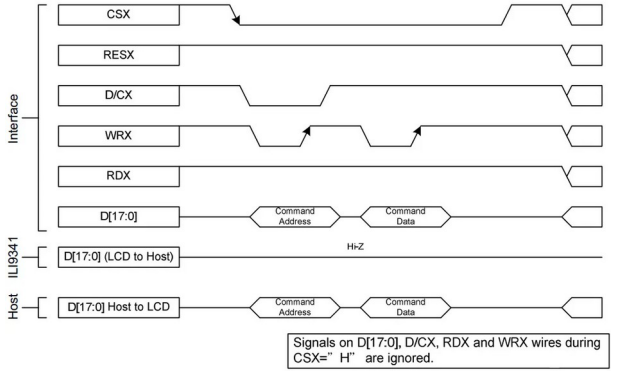


3. MCU interfaces

/drivers/mipi-dbi

MCU "Parallel" interfaces:

- Intel 8080 aka MIPI DBI type B
- Motorola 6800 aka MIPI DBI type A
- Has CSx (Chip Select), D/CX (Data/Command), WRX (Write), RDX (Read) and DATA[N]



Zephyr MCU peripherals support:
- NXP Flexio (I8080)
- STM32 FMC (I8080)
- Bitbang driver (I8080 and M6800)

Zephyr driver support:
- Sitronix ST7796S

Image source: https://cdn-shop.adafruit.com/datasheets/ILI9341.pdf

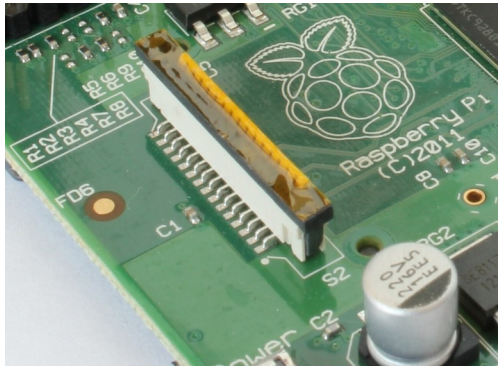
4. MIPI DSI®

/drivers/mipi-dsi

High-speed serial:

- 1 differential clock
- 4 differential data

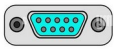
Connector-friendly



Supported MCU peripherals:
- NXP IMX
- STM32
- Renesas

Supported drivers:
- Sitronix ST7796S
- Himax HX8394

Display interfaces pro & cons

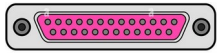
Serial interfaces 

I2C, SPI aka MIPI DBI type C

- Ideal for most applications
- Good Zephyr support
- Use widespread I2C & SPI peripherals
- Performances limits

MIPI DSI®

- Some MCU hardwares supported
- Driver support for most >= 480x800 RGB controllers
- Connector-friendly (differential)

Parallel interfaces 

LCD RGB interface aka MIPI DPI

- Some MCU hardwares supported
- Big displays (>240x360), high performances
- Only for TFT LCD with compatible controller or driver
- Harder to implement and debug

MCU interfaces: Intel 8080 aka MIPI DBI,
Motorola 6800 type A

- Some MCU hardwares supported
- Few drivers supported

Conclusion

My scenario:

- Simple user interface, display + 3 buttons
- Could be alphanumeric

My solution: PMOLED

- Cheap!
- Sold per unit
- Small enough to fit on my PCB
- 128x64 (More vertical space than the typical 16x2 x 5x7 TN LCD)
- Supported Sinowealth SH1106 controller (Solomon SSD1306 equivalent)
- SPI 4-wires interface

References

From manufacturers / distributors:

- Orient Display knowledge center: https://www.orientdisplay.com/knowledge-base/lcd-basics/what-is-fstn/

- NewHaven Display blog: https://newhavendisplay.com/fr/blog/a-beginners-guide-to-active-matrix-and-passive-matrix/

- Seengreat blog about Dot Matrix LED display: https://seengreat.com/blog/64/dot-matrix-led-display-panel

- Ilitek ILI9341 datasheet: https://cdn-shop.adafruit.com/datasheets/ILI9341.pdf

- Riverdi Youtube channel: https://www.youtube.com/watch?v=g92jnPKmUrI

From community:

- Wikipedia about LCD: https://en.wikipedia.org/wiki/Liquid-crystal_display

- Wikipedia about OLED: https://en.wikipedia.org/wiki/OLED

- Joey Castillo about old LCD upcycling: https://www.youtube.com/watch?v=fhKYbJMW5_U

- Self-promotion blog posts: https://redero.fr/?p=1012&lang=en and https://redero.fr/?p=1172&lang=en

Thanks!