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HEAPLab Project Report

Porting Mxgui to STM32F469I

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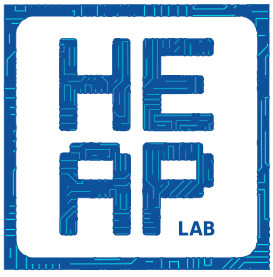
April 25, 2019



Abstract

The aim of this project is porting the graphical library Mxgui of Miosix to a new development board, which is STM32F469I. The major effort of this task has been writing a working driver for the display, consulting the necessary documentation provided by ST. In this document I will explain what are the main concepts to understand how the driver works and how to use it in a real application.

1 Introduction

The driver is tailored to the display already present on the board. It supports a color depth of 16 bpp and a resolution of 480*800 pixels both in portrait mode and landscape mode. Some simple modifications are needed inside /miosix/config/Makefile.inc to be able to use the library:

- First uncomment the line

  ```
  OPT_BOARD := stm32f469ni_stm32f469i-disco
  ```

  to tell the compiler which is the target board.

- In the section dedicated to board specific options, choose a linker script between

  ```
  LINKER_SCRIPT := $(LINKER_SCRIPT_PATH)stm32_2m+384k_rom.ld
  ```

  and

  ```
  LINKER_SCRIPT := $(LINKER_SCRIPT_PATH)stm32_2m+12m_xram.ld
  ```

  Do not use

  ```
  LINKER_SCRIPT := $(LINKER_SCRIPT_PATH)stm32_2m+16m_xram.ld
  ```

  otherwise the framebuffer for the display will overwrite the data used by the kernel.

- Uncomment the line

```
XRAM := -D__ENABLE_XRAM
```

since the framebuffer is stored in the external memory.

- As clock frequency, select

```
CLOCK_FREQ := -DHSE_VALUE=8000000 -DSYSCLK_FREQ_168MHz=168000000
```

All clock calculations inside the driver assume the board is running on those frequencies.

The driver uses two peripherals on the board, namely the LTDC and the DSI. Its code is written inside /mxgui/drivers/display_stm32f4discovery.cpp. It is structured in four parts:

- Clock configuration
- LTDC configuration
- DSI configuration
- Power-up sequence

In the following sections I will explain how those peripherals work at high level and how they are configured inside the library.

2 Design and Implementation

2.1 LTDC

The LTDC is a peripheral which autonomously fetches pixel data from the framebuffer and stores them in an internal FIFO. These pixels are then blended with the background color according to a blending factor, encoded in RGB888 and finally sent to the DSI.

Its configuration is quite straightforward and does not need special attention. What needs more caution is the configuration of its clock. The LTDC fetches a pixel from memory at each falling and raising edge of the LCD clock, which needs to be configured. This clock is generated starting from the HSE oscillator, which runs at 8 MHz on this board and passes through a series of frequency divisors and multipliers. Each of these can have a restricted

set of values and must guarantee an output frequency inside a certain range. The following picture represents the flow from the HSE oscillator to the LCD clock. For each step, the accepted range of output frequency and multiplier value is expressed in black color, while the red color represents the effective value which has been chosen inside the driver.

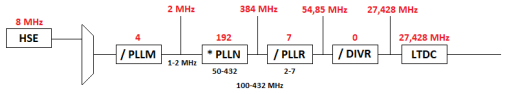


Figure 1: Simplified scheme of LTDC clock

To transport pixel data and synchronization events, many GPIOs are needed. The following table shows which GPIOs are used by the driver and their corresponding alternate function.

Task	GPIO	Alternate function
R0	PC10	14
R1	PJ2	14
R2	PA11	14
R3	PA12	14
R4	PJ5	14
G0	PA6	14
G1	PG10	9
G2	PJ13	9
G3	PH4	9
G4	PC7	14
G5	PD3	14
B0	PD6	14
B1	PG11	14
B2	PG12	9
B3	PA3	14
B4	PB8	14
Data enable	PF10	14
Clock	PG7	14
VSync	PA4	14
HSync	PC6	14

All of these GPIOs run at high speed. Note that an additional GPIO,

which is PH7, is used once to reset the display (as suggested by the documentation) but then it is never reused. Some GPIOs are part of the J port, which alongside the K port was not powered up at boot by Miosix. For this reason the kernel has been updated to power up also those ports at boot, modifying the code in /miosix/arch/cortexM4_stm32f4/stm32f469ni_stm32f469i-disco/interfaces-impl/bsp.cpp.

2.2 DSI

The DSI is a sophisticated peripheral to interface to various types of display, either with or without an internal controller and GRAM. This is possible since it can work in two different modes:

- *Video mode*: the DSI continuously sends a stream of pixels and synchronization signals to feed the display. This mode is suitable for displays without an internal controller and GRAM. However this consumes high bandwidth and requires an accurate configuration of synchronization events. It is also required a second framebuffer to avoid tearing.
- *Command mode*: the DSI sends a set of commands to update the display only when explicitly requested by the programmer. This drastically reduces memory bandwitdh, since the display is updated only when the framebuffer changes its content. Synchronization events are managed automatically, and there is no need to use a second framebuffer to avoid tearing. However this mode works only on displays with an integrated controller and GRAM.

Fortunately, the display on board of this controller is compatible with command mode, so this is the modality used by the driver.

The DSI peripheral is located between the LTDC and the display interface. It is composed by many parts which control the flow of pixels to the display.

- *DSI Wrapper*: it is the first component encountered by the pixels generated in the LTDC. Its task is to route those pixels in the correct part of the peripheral depending on the mode used (video or command).
- *DSI Host*: the core of the peripheral, it takes pixel data and generates a set of packets which will be redirected to the next layer, the D-PHY.

- *D-PHY*: it is the last layer of the peripheral, whose task is to serialize the received packets and send them to the display using a physical protocol called PPI.
- *PLL*: it is the component which generates the different clocks needed in the various components of the peripheral.
- *Regulator*: this component provides energy to all parts of the peripheral, both the PLL and the DSI Host.

As anticipated in this list, the DSI does not send bare pixels, but encapsulates them in a series of packets. The format of these packets is specified by the DSI protocol. Both in video and command mode, the packets are created automatically by the peripheral, but it is needed to know how they are structured, since they can be built and sent by software. This actually happens in the driver when the display is initialized in the power up sequence.

The DSI packets are divided into two categories: *short packets* and *long packets*. Short packets are always 4 bytes long and they are structured in this way:

- *DataID*: the first byte is called DataID, which is splitted in two subparts. The most significant two bits are called *Virtual Channel ID*, and they identify the target peripheral. In this driver, the Virtual Channel ID for the display is zero. The other six bits are the *Data Type*. The complete list of data types is specified in the DSI standard. Specific data types allow the peripheral to send, for example, a synchronization event without any payload (since the data type already specifies that this is, for instance, an HSYNC event). Other data types are generic and allow to send any data regardless of their meaning. Those are the ones used in the driver. The code *0x15* identifies the generic short packet (formally it is called *DSI_DCS_SHORT_PKT_WRITE_P1* in the standard).
- *Byte 0*: the first parameter sent.
- *Byte 1*: the second parameter sent.
- *ECC*: an error correction code for the header.

Long packets are used to send more data, and their structure is the following:

- *DataID*: same as before. The data type for a generic long packet is represented by the code *0x39* (formally called *DSI_DCS_LONG_PKT_WRITE* in the standard).
- *Word count*: this field is 2 bytes long and contains the length of the payload.
- *ECC*: an error correction code for the header.
- *Payload*: the actual data.
- *Checksum*: a 2 bytes long checksum for the payload.

As in the LTDC, the most critical part to make the DSI work is correctly configuring the clocks. The source of all clocks is, as usual, the HSE oscillator at 8 MHz. The possible ranges for each intermediate clock, multiplier and divisor are indicated in black color in this figure, while the actual assigned values are in red.

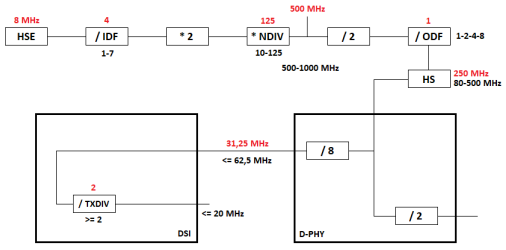


Figure 2: Simplified scheme of DSI clock

Once configured the DSI, the last part to initialize the display is the power-up sequence. This sequence works on all displays based on the OTM8009A and its code can be easily found on the internet. A small change on this code is required to make the display work both in portrait and landscape mode. The commands of the sequence are sent as DSI packets, and this is the reason why it is needed to know how to build them. However it is worth noting another fact: the DSI can send data in *high-speed mode* using the HS clock, or in *low-power mode*. Most displays, when being initialized, can receive data only in low-power mode. For this reason, the DSI is firstly configured to send commands only in low-power mode, then the power-up sequence is sent, and finally the DSI is configured again to send commands in high-speed mode.

As said initially, this driver works in command mode. An update of the display is requested explicitly by setting the bit *DSI_WCR_LTDCEN* inside the *DSI->WCR* register. This operation is executed inside the update() method of the library, which is called any time the DrawingContext is deallocated, preventing the creation of bad visual effects.

3 Experimental Results

The driver has been tested using the sample benchmark provided inside the library. It works with no problem and these are the performance measured by the benchmark, both in portrait and landscape mode.

Task	Time spent	Frames per Second
Monospace text	0.046750	21.39
Variable width text	0.038750	25.80
Antialiased text	0.042000	23.80
Horizontal lines	0.012000	83.33
Vertical lines	0.026000	38.46
Oblique lines	0.125500	7.96
Screen clear	0.005500	181.81
Draw image	0.035000	28.57
ScanLine	0.005000	200.00
ClippedDraw	0.066500	15.03
Clipped text	0.042000	23.80

Table 1: Benchmark in portrait mode

4 Conclusions

This is the necessary knowledge to understand how the driver works. For more detailed information, you can consult these documents:

- *Application note AN4861* for the LTDC
- *Application note AN4860* for the DSI
- *Reference manual RM0386* for the STM32F469xx and STM32F479xx boards

Task	Time spent	Frames per Second
Monospace text	0.029250	34.18
Variable width text	0.023000	43.47
Antialiased text	0.025000	40.00
Horizontal lines	0.011750	85.10
Vertical lines	0.027250	36.69
Oblique lines	0.125750	7.95
Screen clear	0.005500	181.81
Draw image	0.035250	28.36
ScanLine	0.003000	333.33
ClippedDraw	0.068000	14.70
Clipped text	0.025000	40.00

Table 2: Benchmark in landscape mode