

uHeartMonitor

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1 Topic Index

1.1 Topics

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2 Data Structure Index

2.1 Data Structures

Here are the data structures with brief descriptions:

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3 File Index

3.1 File List

Here is a list of all documented files with brief descriptions:

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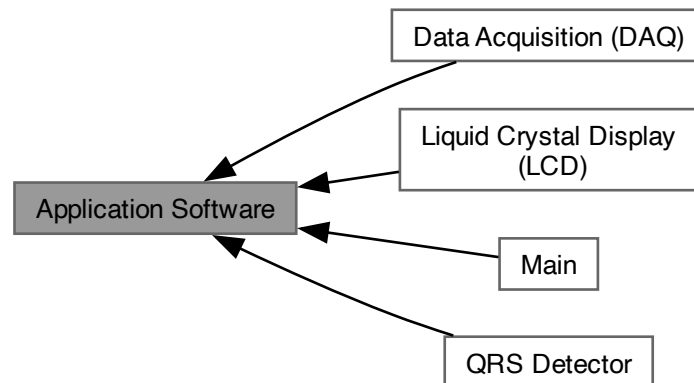
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4 Topic Documentation

4.1 Application Software

Application-specific software modules.

Collaboration diagram for Application Software:



Modules

- [Data Acquisition \(DAQ\)](#)
Module for managing data acquisition (DAQ) functions.
- [Liquid Crystal Display \(LCD\)](#)
Module for displaying graphs on an LCD via the [ILI9341](#) module.
- [QRS Detector](#)
Module for analyzing ECG data to determine heart rate.
- [Main](#)

4.1.1 Detailed Description

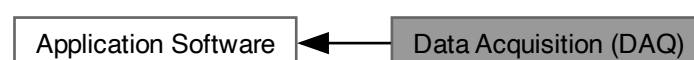
Application-specific software modules.

These modules contain functions built specifically for this project's purposes.

4.1.2 Data Acquisition (DAQ)

Module for managing data acquisition (DAQ) functions.

Collaboration diagram for Data Acquisition (DAQ):



Files

- file [DAQ.c](#)
Source code for DAQ module.
- file [DAQ.h](#)
Application software for handling data acquisition (DAQ) functions.
- file [DAQ_lookup.c](#)
Source code for DAQ module's lookup table.

Macros

- `#define SAMPLING_PERIOD_MS 5`
sampling period in ms ($T_s = \frac{1}{f_s}$)
- `#define DAQ_LOOKUP_MAX ((float32_t) 5.5f)`
maximum lookup table value
- `#define DAQ_LOOKUP_MIN ((float32_t) (-5.5f))`
minimum lookup table value

Variables

- static const float32_t **DAQ_LOOKUP_TABLE** [4096]
Lookup table for converting ADC data from unsigned 12-bit integer values to 32-bit floating point values.

Digital Filters

- enum {
 NUM_STAGES_NOTCH = 6 , **NUM_COEFFS_NOTCH** = NUM_STAGES_NOTCH * 5 , **STATE_BUFF_SIZE_NOTCH** = NUM_STAGES_NOTCH * 4 , **NUM_STAGES_BANDPASS** = 4 ,
 NUM_COEFFS_DAQ_BANDPASS = NUM_STAGES_BANDPASS * 5 , **STATE_BUFF_SIZE_BANDPASS** = NUM_STAGES_BANDPASS * 4 }
- typedef arm_biquad_casd_df1_inst_f32 **Filter_t**
- static const float32_t [COEFFS_NOTCH](#) [NUM_COEFFS_NOTCH]
- static const float32_t [COEFFS_BANDPASS](#) [NUM_COEFFS_DAQ_BANDPASS]
- static float32_t **stateBuffer_Notch** [STATE_BUFF_SIZE_NOTCH]
- static const Filter_t **notchFiltStruct** = { NUM_STAGES_NOTCH, stateBuffer_Notch, COEFFS_NOTCH }
- static const Filter_t *const **notchFilter** = ¬chFiltStruct
- static float32_t **stateBuffer_Bandpass** [STATE_BUFF_SIZE_BANDPASS]
- static const Filter_t [bandpassFiltStruct](#)
- static const Filter_t *const **bandpassFilter** = &bandpassFiltStruct

Initialization

- void [DAQ_Init](#) (void)
Initialize the data acquisition (DAQ) module.

Reading Input Data

- uint16_t `DAQ_readSample` (void)
Read a sample from the ADC.
- void `DAQ_acknowledgeInterrupt` (void)
Acknowledge the ADC interrupt.
- float32_t `DAQ_convertToMilliVolts` (uint16_t sample)
Convert a 12-bit ADC sample to a floating-point voltage value via LUT.

Digital Filtering Functions

- float32_t `DAQ_NotchFilter` (volatile float32_t xn)
Apply a 60 [Hz] notch filter to an input sample.
- float32_t `DAQ_BandpassFilter` (volatile float32_t xn)
Apply a 0.5-40 [Hz] bandpass filter to an input sample.

4.1.2.1 Detailed Description

Module for managing data acquisition (DAQ) functions.

4.1.2.2 Function Documentation

DAQ_Init()

```
void DAQ_Init (  
    void )
```

Initialize the data acquisition (DAQ) module.

Postcondition

The analog-to-digital converter (ADC) is initialized and configured for timer-triggered sample capture.

The timer is initialized in PERIODIC mode and triggers the ADC every $5ms$ (i.e. sampling frequency $f_s = 200Hz$).

The DAQ module has access to its lookup table (LUT).

DAQ_readSample()

```
uint16_t DAQ_readSample (  
    void )
```

Read a sample from the ADC.

Precondition

Initialize the DAQ module.

This should be used in an interrupt handler and/or at a consistent rate (i.e. the sampling frequency).

Parameters

out	<i>sample</i>	12-bit sample in range [0x000, 0xFFF]
-----	---------------	---------------------------------------

Postcondition

The sample can now be converted to millivolts.

See also

[DAQ_convertToMilliVolts\(\)](#)

DAQ_acknowledgeInterrupt()

```
void DAQ_acknowledgeInterrupt (
    void )
```

Acknowledge the ADC interrupt.

Precondition

This should be used within an interrupt handler.

DAQ_NotchFilter()

```
float32_t DAQ_NotchFilter (
    volatile float32_t xn )
```

Apply a 60 [Hz] notch filter to an input sample.

Precondition

Read a sample from the ADC and convert it to millivolts.

Parameters

in	<i>xn</i>	Raw input sample
out	<i>yn</i>	Filtered output sample

Postcondition

$y[n]$ is ready for analysis and/or further processing.

See also

[DAQ_BandpassFilter\(\)](#)

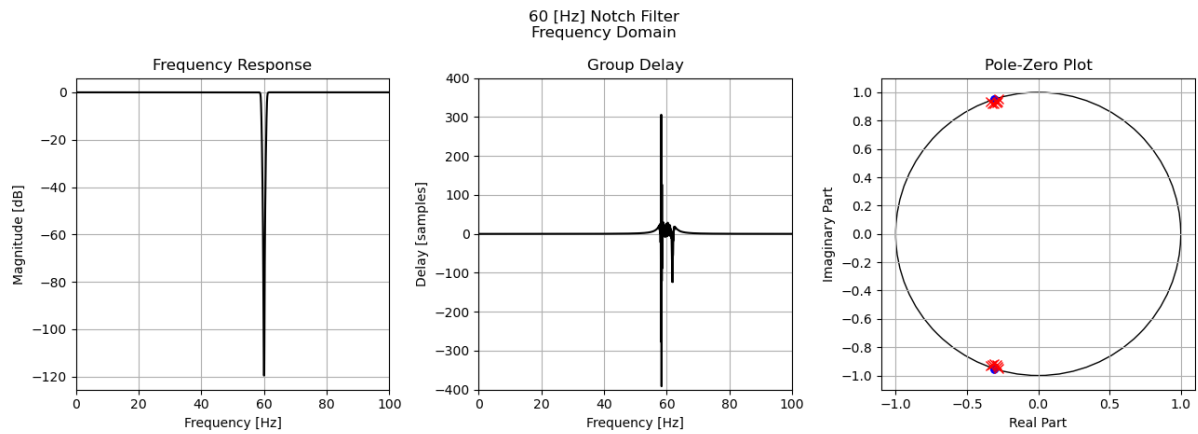


Figure 1 Frequency domain parameters for the notch filter.

DAQ_BandpassFilter()

```
float32_t DAQ_BandpassFilter (
    volatile float32_t xn )
```

Apply a 0.5-40 [Hz] bandpass filter to an input sample.

Precondition

Read a sample from the ADC and convert it to millivolts.

Parameters

in	xn	Input sample
out	yn	Filtered output sample

Postcondition

$y[n]$ is ready for analysis and/or further processing.

See also

[DAQ_NotchFilter\(\)](#)

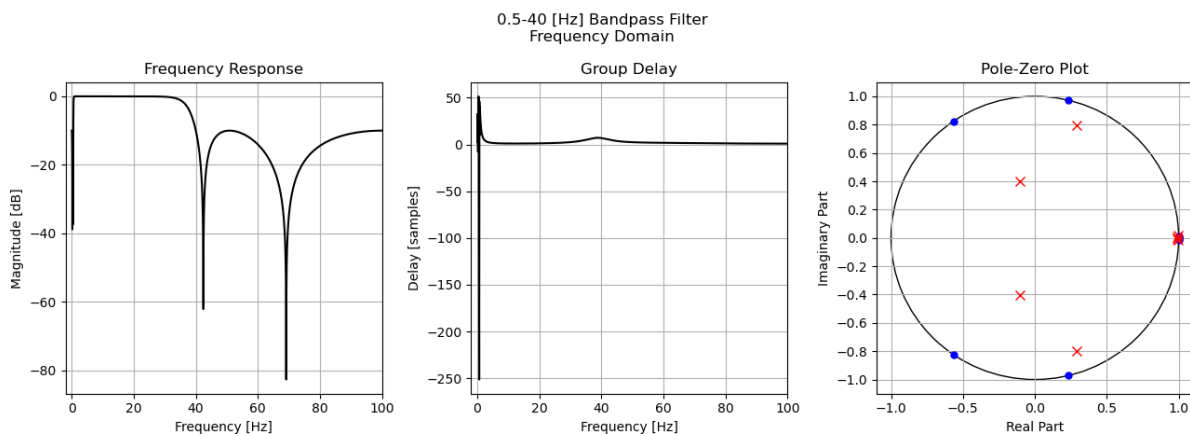


Figure 2 Frequency domain parameters for the bandpass filter.

DAQ_convertToMilliVolts()

```
float32_t DAQ_convertToMilliVolts (
    uint16_t sample )
```

Convert a 12-bit ADC sample to a floating-point voltage value via LUT.

Precondition

Read a sample from the ADC.

Parameters

in	<i>sample</i>	12-bit sample in range $[0x000, 0xFFF]$
out	<i>xn</i>	Voltage value in range $[-5.5, 5.5][mV]$

Postcondition

The sample $x[n]$ is ready for filtering.

See also

[DAQ_readSample\(\)](#)

Note

Defined in [DAQ_lookup.c](#) rather than [DAQ.c](#).

4.1.2.3 Variable Documentation

COEFFS_NOTCH

```
const float32_t COEFFS_NOTCH[NUM_COEFFS_NOTCH] [static]
```

Initial value:

```
= {
    0.8856732845306396f, 0.5476464033126831f, 0.8856732845306396f,
    -0.5850160717964172f, -0.9409302473068237f,

    1.0f, 0.6183391213417053f, 1.0f,
    -0.615153431892395f, -0.9412328004837036f,

    1.0f, 0.6183391213417053f, 1.0f,
    -0.5631667971611023f, -0.9562366008758545f,

    1.0f, 0.6183391213417053f, 1.0f,
    -0.6460562348365784f, -0.9568508863449097f,

    1.0f, 0.6183391213417053f, 1.0f,
    -0.5554963946342468f, -0.9837208390235901f,

    1.0f, 0.6183391213417053f, 1.0f,
    -0.6700929999351501f, -0.9840363264083862f,
}
```

COEFFS_BANDPASS

```
const float32_t COEFFS_BANDPASS[NUM_COEFFS_DAO_BANDPASS] [static]
```

Initial value:

```
= {
    0.3240305185317993f, 0.3665695786476135f, 0.3240305185317993f,
    -0.20968256890773773f, -0.1729172021150589f,

    1.0f, -0.4715292155742645f, 1.0f,
    0.5868059992790222f, -0.7193671464920044f,

    1.0f, -1.9999638795852661f, 1.0f,
    1.9863483905792236f, -0.986438512802124f,

    1.0f, -1.9997893571853638f, 1.0f,
    1.994096040725708f, -0.9943605065345764f,
}
```

bandpassFiltStruct

```
const Filter_t bandpassFiltStruct [static]
```

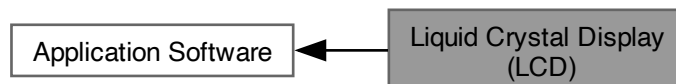
Initial value:

```
= { NUM_STAGES_BANDPASS, stateBuffer_Bandpass,
                                         COEFFS_BANDPASS }
```

4.1.3 Liquid Crystal Display (LCD)

Module for displaying graphs on an LCD via the [ILI9341](#) module.

Collaboration diagram for Liquid Crystal Display (LCD):



Files

- file [Font.c](#)
Contains bitmaps for a selection of ASCII characters.
- file [LCD.c](#)
Source code for LCD module.
- file [LCD.h](#)
Header file for LCD module.

Macros

- `#define CONVERT_INT_TO_ASCII(X) ((unsigned char) (X + 0x30))`

Functions

- static void [LCD_plotSample](#) (uint16_t x, uint16_t y, uint8_t color)
Plot a sample at coordinates (x, y).

Variables

- `const uint8_t *const FONT_ARRAY [128]`
- struct {
 - `uint16_t x1`
starting x-value in range [0, x2]
 - `uint16_t x2`
ending x-value in range [0, NUM_ROWS)
 - `uint16_t y1`
starting y-value in range [0, y2]
 - `uint16_t y2`
ending x-value in range [0, NUM_COLS)
 - `uint16_t lineNum`
line number for text; in range [0, NUM_LINES)
 - `uint16_t colNum`
column number for text; in range [0, NUM_COLS)
 - `uint8_t color`
 - `bool isInit`
if true, LCD has been initialized
- `lcd = { 0 }`
- `const uint8_t *const FONT_ARRAY [128]`

Initialization & Configuration

- enum **LCD_PLOT_INFO** { **LCD_X_MAX** = ILI9341_NUM_ROWS - 1 , **LCD_Y_MAX** = ILI9341_NUM_COLS - 1 }
- enum **LCD_COLORS** {
LCD_BLACK = 0x00 ^ 0x07 , **LCD_RED** = 0x04 ^ 0x07 , **LCD_GREEN** = 0x02 ^ 0x07 , **LCD_BLUE** = 0x01 ^ 0x07 ,
LCD_YELLOW = 0x06 ^ 0x07 , **LCD_CYAN** = 0x03 ^ 0x07 , **LCD_PURPLE** = 0x05 ^ 0x07 , **LCD_WHITE** = 0x07 ^ 0x07 }
- void **LCD_Init** (void)
Initialize the LCD.
- void **LCD_setOutputMode** (bool isOn)
Toggle display output ON or OFF (OFF by default).
- void **LCD_setX** (uint16_t x1, uint16_t x2)
Set new x-coordinates to be written to. $0 \leq x1 \leq x2 \leq X_{MAX}$.
- void **LCD_setY** (uint16_t y1, uint16_t y2)
Set new y-coordinates to be written to. $0 \leq y1 \leq y2 \leq Y_{MAX}$.
- void **LCD_setColor** (uint8_t color)
Set the color value.

Writing

- enum **LCD_WRITING_INFO** { **HEIGHT_CHAR** = 8 , **LEN_CHAR** = 5 , **NUM_LINES** = 30 , **NUM_COLS** = 64 }
- void **LCD_setCursor** (uint16_t lineNum, uint16_t colNum)
Set the cursor to line x, column y.
- void **LCD_writeChar** (unsigned char inputChar)
- void **LCD_writeStr** (void *asciiString)
- void **LCD_writeInt** (int32_t num)
- void **LCD_writeFloat** (float num)

ASCII Characters (Punctuation)

- static const uint8_t **FONT_SPACE** [8]
- static const uint8_t **FONT_PERIOD** [8]
- static const uint8_t **FONT_COLON** [8]

ASCII Characters (Numbers)

- static const uint8_t **FONT_0** [8]
- static const uint8_t **FONT_1** [8]
- static const uint8_t **FONT_2** [8]
- static const uint8_t **FONT_3** [8]
- static const uint8_t **FONT_4** [8]
- static const uint8_t **FONT_5** [8]
- static const uint8_t **FONT_6** [8]
- static const uint8_t **FONT_7** [8]
- static const uint8_t **FONT_8** [8]
- static const uint8_t **FONT_9** [8]

ASCII Characters (Uppercase Letters)

- static const uint8_t [FONT_UPPER_A](#) [8]
- static const uint8_t [FONT_UPPER_B](#) [8]
- static const uint8_t [FONT_UPPER_C](#) [8]
- static const uint8_t [FONT_UPPER_D](#) [8]
- static const uint8_t [FONT_UPPER_E](#) [8]
- static const uint8_t [FONT_UPPER_F](#) [8]
- static const uint8_t [FONT_UPPER_G](#) [8]
- static const uint8_t [FONT_UPPER_H](#) [8]
- static const uint8_t [FONT_UPPER_I](#) [8]
- static const uint8_t [FONT_UPPER_J](#) [8]
- static const uint8_t [FONT_UPPER_K](#) [8]
- static const uint8_t [FONT_UPPER_L](#) [8]
- static const uint8_t [FONT_UPPER_M](#) [8]
- static const uint8_t [FONT_UPPER_N](#) [8]
- static const uint8_t [FONT_UPPER_O](#) [8]
- static const uint8_t [FONT_UPPER_P](#) [8]
- static const uint8_t [FONT_UPPER_Q](#) [8]
- static const uint8_t [FONT_UPPER_R](#) [8]
- static const uint8_t [FONT_UPPER_S](#) [8]
- static const uint8_t [FONT_UPPER_T](#) [8]
- static const uint8_t [FONT_UPPER_U](#) [8]
- static const uint8_t [FONT_UPPER_V](#) [8]
- static const uint8_t [FONT_UPPER_W](#) [8]
- static const uint8_t [FONT_UPPER_X](#) [8]
- static const uint8_t [FONT_UPPER_Y](#) [8]
- static const uint8_t [FONT_UPPER_Z](#) [8]

ASCII Characters (Lowercase Letters)

- static const uint8_t [FONT_LOWER_A](#) [8]
- static const uint8_t [FONT_LOWER_B](#) [8]
- static const uint8_t [FONT_LOWER_C](#) [8]
- static const uint8_t [FONT_LOWER_D](#) [8]
- static const uint8_t [FONT_LOWER_E](#) [8]
- static const uint8_t [FONT_LOWER_F](#) [8]
- static const uint8_t [FONT_LOWER_G](#) [8]
- static const uint8_t [FONT_LOWER_H](#) [8]
- static const uint8_t [FONT_LOWER_I](#) [8]
- static const uint8_t [FONT_LOWER_J](#) [8]
- static const uint8_t [FONT_LOWER_K](#) [8]
- static const uint8_t [FONT_LOWER_L](#) [8]
- static const uint8_t [FONT_LOWER_M](#) [8]
- static const uint8_t [FONT_LOWER_N](#) [8]
- static const uint8_t [FONT_LOWER_O](#) [8]
- static const uint8_t [FONT_LOWER_P](#) [8]
- static const uint8_t [FONT_LOWER_Q](#) [8]
- static const uint8_t [FONT_LOWER_R](#) [8]
- static const uint8_t [FONT_LOWER_S](#) [8]
- static const uint8_t [FONT_LOWER_T](#) [8]
- static const uint8_t [FONT_LOWER_U](#) [8]
- static const uint8_t [FONT_LOWER_V](#) [8]
- static const uint8_t [FONT_LOWER_W](#) [8]
- static const uint8_t [FONT_LOWER_X](#) [8]
- static const uint8_t [FONT_LOWER_Y](#) [8]
- static const uint8_t [FONT_LOWER_Z](#) [8]

Helper Functions

- static void `LCD_drawLine` (uint16_t center, uint16_t lineWidth, bool is_horizontal)

Helper function for drawing straight lines.

- static void `LCD_updateCursor` (void)

Update the cursor for after writing text on the display.

Drawing

- void `LCD_Draw` (void)

Draw on the LCD.

- void `LCD_Fill` (void)

Fill the display with a single color.

- void `LCD_drawHoriLine` (uint16_t yCenter, uint16_t lineWidth)

Draw a horizontal line across the entire display.

- void `LCD_drawVertLine` (uint16_t xCenter, uint16_t lineWidth)

Draw a vertical line across the entire display.

- void `LCD_drawRectangle` (uint16_t x1, uint16_t dx, uint16_t y1, uint16_t dy)

Draw a rectangle of size $dx \times dy$ onto the display. The bottom-left corner will be located at $(x1, y1)$.

4.1.3.1 Detailed Description

Module for displaying graphs on an LCD via the [ILI9341](#) module.

4.1.3.2 Function Documentation

`LCD_drawLine()`

```
static void LCD_drawLine (
    uint16_t center,
    uint16_t lineWidth,
    bool is_horizontal ) [static]
```

Helper function for drawing straight lines.

Parameters

<i>center</i>	Row or column that the line is centered on. <code>center</code> is increased or decreased if the line to be written would have gone out of bounds.
<i>lineWidth</i>	Width of the line. Should be a positive, odd number.
<i>is_row</i>	<code>true</code> for horizontal line, <code>false</code> for vertical line

`LCD_Init()`

```
void LCD_Init (
    void )
```

Initialize the LCD.

Postcondition

The display will be ready to accept commands, but output will be off.

LCD_setOutputMode()

```
void LCD_setOutputMode (
    bool isOn )
```

Toggle display output ON or OFF (OFF by default).

Parameters

in	<i>isOn</i>	true to turn display output ON, false to turn OFF
----	-------------	---

Postcondition

When OFF, the display is cleared. When ON, the IC writes pixel data from its memory to the display.

LCD_setX()

```
void LCD_setX (
    uint16_t x1,
    uint16_t x2 )
```

Set new x-coordinates to be written to. $0 \leq x1 \leq x2 \leq X_{MAX}$.

Parameters

in	<i>x1</i>	left-most x-coordinate
in	<i>x2</i>	right-most x-coordinate

See also

[LCD_setY\(\)](#)

LCD_setY()

```
void LCD_setY (
    uint16_t y1,
    uint16_t y2 )
```

Set new y-coordinates to be written to. $0 \leq y1 \leq y2 \leq Y_{MAX}$.

Parameters

in	<i>y1</i>	lowest y-coordinate
in	<i>y2</i>	highest y-coordinate

See also

[LCD_setX\(\)](#)

LCD_setColor()

```
void LCD_setColor (
    uint8_t color )
```

Set the color value.

Parameters

in	<i>color</i>	Color to use.
----	--------------	---------------

Postcondition

Outgoing pixel data will use the selected color.

LCD_Draw()

```
void LCD_Draw (
    void )
```

Draw on the LCD.

Precondition

Set the drawable area and the color to use for that area.

Postcondition

The selected areas of the display will be drawn onto with the selected color.

See also

[LCD_setX\(\)](#), [LCD_setY\(\)](#), [LCD_setColor\(\)](#)

References [ILI9341_writeMemCmd\(\)](#), and [ILI9341_writePixel\(\)](#).

LCD_Fill()

```
void LCD_Fill (
    void )
```

Fill the display with a single color.

Precondition

Select the desired color to fill the display with.

See also

[LCD_setColor\(\)](#)

LCD_drawHoriLine()

```
void LCD_drawHoriLine (
    uint16_t yCenter,
    uint16_t lineWidth )
```

Draw a horizontal line across the entire display.

Precondition

Select the desired color to use for the line.

Parameters

in	<i>yCenter</i>	y-coordinate to center the line on
in	<i>lineWidth</i>	width of the line; should be a positive, odd number

See also

[LCD_drawVertLine](#), [LCD_drawRectangle\(\)](#)

LCD_drawVertLine()

```
void LCD_drawVertLine (
    uint16_t xCenter,
    uint16_t lineWidth )
```

Draw a vertical line across the entire display.

Precondition

Select the desired color to use for the line.

Parameters

in	<i>xCenter</i>	x-coordinate to center the line on
in	<i>lineWidth</i>	width of the line; should be a positive, odd number

See also

[LCD_drawHoriLine](#), [LCD_drawRectangle\(\)](#)

LCD_drawRectangle()

```
void LCD_drawRectangle (
    uint16_t x1,
    uint16_t dx,
    uint16_t y1,
    uint16_t dy )
```

Draw a rectangle of size dx x dy onto the display. The bottom-left corner will be located at (x1, y1).

Precondition

Select the desired color to use for the rectangle.

Parameters

in	<i>x1</i>	lowest (left-most) x-coordinate
in	<i>dx</i>	length (horizontal distance) of the rectangle
in	<i>y1</i>	lowest (bottom-most) y-coordinate
in	<i>dy</i>	height (vertical distance) of the rectangle

See also

[LCD_Draw\(\)](#), [LCD_Fill\(\)](#), [LCD_drawHoriLine\(\)](#), [LCD_drawVertLine\(\)](#)

LCD_plotSample()

```
static void LCD_plotSample (
    uint16_t x,
    uint16_t y,
    uint8_t color ) [static]
```

Plot a sample at coordinates (*x*, *y*).

Parameters

in	<i>x</i>	x-coordinate (i.e. sample number) in range [0, X_MAX]
in	<i>y</i>	y-coordinate (i.e. amplitude) in range [0, Y_MAX]
in	<i>color</i>	Color to use

See also

[LCD_setX\(\)](#), [LCD_setY\(\)](#), [LCD_setColor\(\)](#), [LCD_Draw\(\)](#)

LCD_setCursor()

```
void LCD_setCursor (
    uint16_t lineNum,
    uint16_t colNum )
```

Set the cursor to line *x*, column *y*.

Parameters

in	<i>lineNum</i>	Line number to place characters. Should be in range [0, 30).
in	<i>colNum</i>	Column number to place characters. Should be in range [0, 64).

4.1.3.3 Variable Documentation

FONT_SPACE

```
const uint8_t FONT_SPACE[8]  [static]
```

Initial value:

```
= {  
    0x00,  
    0x00,  
    0x00,  
    0x00,  
    0x00,  
    0x00,  
    0x00,  
    0x00  
}
```

FONT_PERIOD

```
const uint8_t FONT_PERIOD[8]  [static]
```

Initial value:

```
= {  
    0x00,  
    0x00,  
    0x00,  
    0x00,  
    0x00,  
    0x00,  
    0x04,  
    0x04  
}
```

FONT_COLON

```
const uint8_t FONT_COLON[8]  [static]
```

Initial value:

```
= {  
    0x00,  
    0x04,  
    0x00,  
    0x00,  
    0x00,  
    0x04,  
    0x00,  
    0x00  
}
```

FONT_0

```
const uint8_t FONT_0[8]  [static]
```

Initial value:

```
= {  
    0x0E,  
    0x11,  
    0x13,  
    0x15,  
    0x19,  
    0x11,  
    0x11,  
    0x0E  
}
```

FONT_1

```
const uint8_t FONT_1[8]  [static]
```

Initial value:

```
= {  
    0x06,  
    0x0E,  
    0x16,  
    0x06,  
    0x06,  
    0x06,  
    0x06,  
    0x1F  
}
```

FONT_2

```
const uint8_t FONT_2[8]  [static]
```

Initial value:

```
= {  
    0x0E,  
    0x11,  
    0x01,  
    0x06,  
    0x08,  
    0x10,  
    0x11,  
    0x1F  
}
```

FONT_3

```
const uint8_t FONT_3[8]  [static]
```

Initial value:

```
= {  
    0x0E,  
    0x11,  
    0x01,  
    0x06,  
    0x01,  
    0x11,  
    0x11,  
    0x0E  
}
```

FONT_4

```
const uint8_t FONT_4[8]  [static]
```

Initial value:

```
= {  
    0x02,  
    0x06,  
    0x0A,  
    0x12,  
    0x1F,  
    0x02,  
    0x02,  
    0x02  
}
```

FONT_5

```
const uint8_t FONT_5[8]  [static]
```

Initial value:

```
= {  
    0x1F,  
    0x10,  
    0x10,  
    0x1E,  
    0x01,  
    0x11,  
    0x11,  
    0x0E  
}
```

FONT_6

```
const uint8_t FONT_6[8]  [static]
```

Initial value:

```
= {  
    0x0E,  
    0x11,  
    0x10,  
    0x1E,  
    0x11,  
    0x11,  
    0x11,  
    0x11,  
    0x0E  
}
```

FONT_7

```
const uint8_t FONT_7[8]  [static]
```

Initial value:

```
= {  
    0x1F,  
    0x11,  
    0x01,  
    0x02,  
    0x04,  
    0x04,  
    0x04,  
    0x04  
}
```

FONT_8

```
const uint8_t FONT_8[8]  [static]
```

Initial value:

```
= {  
    0x0E,  
    0x11,  
    0x11,  
    0x0E,  
    0x11,  
    0x11,  
    0x11,  
    0x0E  
}
```


FONT_9

```
const uint8_t FONT_9[8]  [static]
```

Initial value:

```
= {  
    0x0E,  
    0x11,  
    0x11,  
    0x0F,  
    0x01,  
    0x01,  
    0x11,  
    0x0E  
}
```

FONT_UPPER_A

```
const uint8_t FONT_UPPER_A[8]  [static]
```

Initial value:

```
= {  
    0x0E,  
    0x11,  
    0x11,  
    0x1F,  
    0x11,  
    0x11,  
    0x11,  
    0x11,  
    0x11  
}
```

FONT_UPPER_B

```
const uint8_t FONT_UPPER_B[8]  [static]
```

Initial value:

```
= {  
    0x1E,  
    0x11,  
    0x11,  
    0x1E,  
    0x11,  
    0x11,  
    0x11,  
    0x11,  
    0x1E  
}
```

FONT_UPPER_C

```
const uint8_t FONT_UPPER_C[8]  [static]
```

Initial value:

```
= {  
    0x0E,  
    0x11,  
    0x10,  
    0x10,  
    0x10,  
    0x11,  
    0x0E,  
    0x0E  
}
```

FONT_UPPER_D

```
const uint8_t FONT_UPPER_D[8]  [static]
```

Initial value:

```
= {  
    0x1E,  
    0x11,  
    0x11,  
    0x11,  
    0x11,  
    0x11,  
    0x11,  
    0x11,  
    0x1E  
}
```

FONT_UPPER_E

```
const uint8_t FONT_UPPER_E[8]  [static]
```

Initial value:

```
= {  
    0x1F,  
    0x10,  
    0x10,  
    0x1E,  
    0x10,  
    0x10,  
    0x10,  
    0x10,  
    0x1F  
}
```

FONT_UPPER_F

```
const uint8_t FONT_UPPER_F[8]  [static]
```

Initial value:

```
= {  
    0x1F,  
    0x10,  
    0x10,  
    0x1E,  
    0x10,  
    0x10,  
    0x10,  
    0x10,  
    0x10  
}
```

FONT_UPPER_G

```
const uint8_t FONT_UPPER_G[8]  [static]
```

Initial value:

```
= {  
    0x0E,  
    0x11,  
    0x10,  
    0x10,  
    0x17,  
    0x11,  
    0x11,  
    0x0E  
}
```

FONT_UPPER_H

```
const uint8_t FONT_UPPER_H[8]  [static]
```

Initial value:

```
= {  
    0x11,  
    0x11,  
    0x11,  
    0x1F,  
    0x1F,  
    0x11,  
    0x11,  
    0x11  
}
```

FONT_UPPER_I

```
const uint8_t FONT_UPPER_I[8]  [static]
```

Initial value:

```
= {  
    0x1F,  
    0x0A,  
    0x0A,  
    0x0A,  
    0x0A,  
    0x0A,  
    0x0A,  
    0x1F  
}
```

FONT_UPPER_J

```
const uint8_t FONT_UPPER_J[8]  [static]
```

Initial value:

```
= {  
    0x0E,  
    0x05,  
    0x05,  
    0x05,  
    0x05,  
    0x15,  
    0x15,  
    0x0E  
}
```

FONT_UPPER_K

```
const uint8_t FONT_UPPER_K[8]  [static]
```

Initial value:

```
= {  
    0x12,  
    0x14,  
    0x18,  
    0x1C,  
    0x1C,  
    0x14,  
    0x12,  
    0x11  
}
```

FONT_UPPER_L

```
const uint8_t FONT_UPPER_L[8]  [static]
```

Initial value:

```
= {  
    0x10,  
    0x10,  
    0x10,  
    0x10,  
    0x10,  
    0x10,  
    0x10,  
    0x1F,  
    0x1F  
}
```

FONT_UPPER_M

```
const uint8_t FONT_UPPER_M[8]  [static]
```

Initial value:

```
= {  
    0x11,  
    0x1B,  
    0x1B,  
    0x15,  
    0x15,  
    0x11,  
    0x11,  
    0x11  
}
```

FONT_UPPER_N

```
const uint8_t FONT_UPPER_N[8]  [static]
```

Initial value:

```
= {  
    0x11,  
    0x19,  
    0x19,  
    0x1D,  
    0x15,  
    0x13,  
    0x11,  
    0x11  
}
```

FONT_UPPER_O

```
const uint8_t FONT_UPPER_O[8]  [static]
```

Initial value:

```
= {  
    0x0E,  
    0x11,  
    0x11,  
    0x11,  
    0x11,  
    0x11,  
    0x11,  
    0x0E  
}
```

FONT_UPPER_P

```
const uint8_t FONT_UPPER_P[8] [static]
```

Initial value:

```
= {  
    0x1E,  
    0x11,  
    0x11,  
    0x1E,  
    0x10,  
    0x10,  
    0x10,  
    0x10  
}
```

FONT_UPPER_Q

```
const uint8_t FONT_UPPER_Q[8] [static]
```

Initial value:

```
= {  
    0x0E,  
    0x11,  
    0x11,  
    0x11,  
    0x15,  
    0x19,  
    0x16,  
    0x0D  
}
```

FONT_UPPER_R

```
const uint8_t FONT_UPPER_R[8] [static]
```

Initial value:

```
= {  
    0x1E,  
    0x11,  
    0x11,  
    0x1F,  
    0x18,  
    0x14,  
    0x12,  
    0x11  
}
```

FONT_UPPER_S

```
const uint8_t FONT_UPPER_S[8] [static]
```

Initial value:

```
= {  
    0x0E,  
    0x11,  
    0x11,  
    0x0E,  
    0x01,  
    0x01,  
    0x11,  
    0x0E  
}
```

FONT_UPPER_T

```
const uint8_t FONT_UPPER_T[8]  [static]
```

Initial value:

```
= {  
    0x1F,  
    0x04,  
    0x04,  
    0x04,  
    0x04,  
    0x04,  
    0x04,  
    0x04  
}
```

FONT_UPPER_U

```
const uint8_t FONT_UPPER_U[8]  [static]
```

Initial value:

```
= {  
    0x11,  
    0x11,  
    0x11,  
    0x11,  
    0x11,  
    0x11,  
    0x11,  
    0x11,  
    0x0E  
}
```

FONT_UPPER_V

```
const uint8_t FONT_UPPER_V[8]  [static]
```

Initial value:

```
= {  
    0x11,  
    0x11,  
    0x11,  
    0x11,  
    0x11,  
    0x11,  
    0x0A,  
    0x0A,  
    0x04  
}
```

FONT_UPPER_W

```
const uint8_t FONT_UPPER_W[8]  [static]
```

Initial value:

```
= {  
    0x11,  
    0x11,  
    0x11,  
    0x15,  
    0x15,  
    0x1B,  
    0x11,  
    0x11  
}
```

FONT_UPPER_X

```
const uint8_t FONT_UPPER_X[8]  [static]
```

Initial value:

```
= {  
    0x11,  
    0x11,  
    0x0A,  
    0x0A,  
    0x04,  
    0x0A,  
    0x0A,  
    0x11  
}
```

FONT_UPPER_Y

```
const uint8_t FONT_UPPER_Y[8]  [static]
```

Initial value:

```
= {  
    0x11,  
    0x11,  
    0x11,  
    0x0A,  
    0x04,  
    0x04,  
    0x04,  
    0x04,  
    0x04  
}
```

FONT_UPPER_Z

```
const uint8_t FONT_UPPER_Z[8]  [static]
```

Initial value:

```
= {  
    0x1F,  
    0x01,  
    0x01,  
    0x02,  
    0x04,  
    0x08,  
    0x10,  
    0x1F  
}
```

FONT_LOWER_A

```
const uint8_t FONT_LOWER_A[8]  [static]
```

Initial value:

```
= {  
    0x00,  
    0x00,  
    0x0E,  
    0x01,  
    0x0F,  
    0x11,  
    0x0F,  
    0x00  
}
```

FONT_LOWER_B

```
const uint8_t FONT_LOWER_B[8]  [static]
```

Initial value:

```
= {  
    0x10,  
    0x10,  
    0x1E,  
    0x11,  
    0x11,  
    0x11,  
    0x1E,  
    0x00  
}
```

FONT_LOWER_C

```
const uint8_t FONT_LOWER_C[8]  [static]
```

Initial value:

```
= {  
    0x00,  
    0x00,  
    0x0E,  
    0x10,  
    0x10,  
    0x11,  
    0x0E,  
    0x00  
}
```

FONT_LOWER_D

```
const uint8_t FONT_LOWER_D[8]  [static]
```

Initial value:

```
= {  
    0x01,  
    0x01,  
    0x0F,  
    0x11,  
    0x11,  
    0x11,  
    0x0F,  
    0x00  
}
```

FONT_LOWER_E

```
const uint8_t FONT_LOWER_E[8]  [static]
```

Initial value:

```
= {  
    0x00,  
    0x00,  
    0x0E,  
    0x11,  
    0x1F,  
    0x10,  
    0x0E,  
    0x00  
}
```


FONT_LOWER_F

```
const uint8_t FONT_LOWER_F[8] [static]
```

Initial value:

```
= {  
    0x06,  
    0x09,  
    0x08,  
    0x1C,  
    0x08,  
    0x08,  
    0x08,  
    0x08,  
    0x00  
}
```

FONT_LOWER_G

```
const uint8_t FONT_LOWER_G[8] [static]
```

Initial value:

```
= {  
    0x00,  
    0x00,  
    0x0F,  
    0x11,  
    0x11,  
    0x0F,  
    0x01,  
    0x0E  
}
```

FONT_LOWER_H

```
const uint8_t FONT_LOWER_H[8] [static]
```

Initial value:

```
= {  
    0x10,  
    0x10,  
    0x1E,  
    0x11,  
    0x11,  
    0x11,  
    0x11,  
    0x11,  
    0x00  
}
```

FONT_LOWER_I

```
const uint8_t FONT_LOWER_I[8] [static]
```

Initial value:

```
= {  
    0x04,  
    0x00,  
    0x0C,  
    0x04,  
    0x04,  
    0x04,  
    0x0E,  
    0x00  
}
```

FONT_LOWER_J

```
const uint8_t FONT_LOWER_J[8]  [static]
```

Initial value:

```
= {  
    0x02,  
    0x00,  
    0x06,  
    0x02,  
    0x02,  
    0x12,  
    0x12,  
    0x0C  
}
```

FONT_LOWER_K

```
const uint8_t FONT_LOWER_K[8]  [static]
```

Initial value:

```
= {  
    0x10,  
    0x10,  
    0x12,  
    0x14,  
    0x18,  
    0x14,  
    0x12,  
    0x00  
}
```

FONT_LOWER_L

```
const uint8_t FONT_LOWER_L[8]  [static]
```

Initial value:

```
= {  
    0x0C,  
    0x04,  
    0x04,  
    0x04,  
    0x04,  
    0x04,  
    0x0E,  
    0x00  
}
```

FONT_LOWER_M

```
const uint8_t FONT_LOWER_M[8]  [static]
```

Initial value:

```
= {  
    0x00,  
    0x00,  
    0x1A,  
    0x15,  
    0x15,  
    0x11,  
    0x11,  
    0x00  
}
```

FONT_LOWER_N

```
const uint8_t FONT_LOWER_N[8] [static]
```

Initial value:

```
= {  
    0x00,  
    0x00,  
    0x1E,  
    0x11,  
    0x11,  
    0x11,  
    0x11,  
    0x11,  
    0x00  
}
```

FONT_LOWER_O

```
const uint8_t FONT_LOWER_O[8] [static]
```

Initial value:

```
= {  
    0x00,  
    0x00,  
    0x0E,  
    0x11,  
    0x11,  
    0x11,  
    0x0E,  
    0x00  
}
```

FONT_LOWER_P

```
const uint8_t FONT_LOWER_P[8] [static]
```

Initial value:

```
= {  
    0x00,  
    0x00,  
    0x1E,  
    0x11,  
    0x11,  
    0x1E,  
    0x10,  
    0x10  
}
```

FONT_LOWER_Q

```
const uint8_t FONT_LOWER_Q[8] [static]
```

Initial value:

```
= {  
    0x00,  
    0x00,  
    0x0F,  
    0x11,  
    0x11,  
    0x0F,  
    0x01,  
    0x01  
}
```

FONT_LOWER_R

```
const uint8_t FONT_LOWER_R[8]  [static]
```

Initial value:

```
= {  
    0x00,  
    0x00,  
    0x1A,  
    0x15,  
    0x10,  
    0x10,  
    0x10,  
    0x00  
}
```

FONT_LOWER_S

```
const uint8_t FONT_LOWER_S[8]  [static]
```

Initial value:

```
= {  
    0x00,  
    0x00,  
    0x0E,  
    0x10,  
    0x0E,  
    0x01,  
    0x0E,  
    0x00  
}
```

FONT_LOWER_T

```
const uint8_t FONT_LOWER_T[8]  [static]
```

Initial value:

```
= {  
    0x04,  
    0x04,  
    0x0E,  
    0x04,  
    0x04,  
    0x04,  
    0x02,  
    0x00  
}
```

FONT_LOWER_U

```
const uint8_t FONT_LOWER_U[8]  [static]
```

Initial value:

```
= {  
    0x00,  
    0x00,  
    0x11,  
    0x11,  
    0x11,  
    0x11,  
    0x0F,  
    0x00  
}
```

FONT_LOWER_V

```
const uint8_t FONT_LOWER_V[8]  [static]
```

Initial value:

```
= {  
    0x00,  
    0x00,  
    0x11,  
    0x11,  
    0x11,  
    0x11,  
    0x0A,  
    0x04,  
    0x00  
}
```

FONT_LOWER_W

```
const uint8_t FONT_LOWER_W[8]  [static]
```

Initial value:

```
= {  
    0x00,  
    0x00,  
    0x11,  
    0x11,  
    0x15,  
    0x15,  
    0x0A,  
    0x00  
}
```

FONT_LOWER_X

```
const uint8_t FONT_LOWER_X[8]  [static]
```

Initial value:

```
= {  
    0x00,  
    0x00,  
    0x11,  
    0x0A,  
    0x04,  
    0x0A,  
    0x11,  
    0x00  
}
```

FONT_LOWER_Y

```
const uint8_t FONT_LOWER_Y[8]  [static]
```

Initial value:

```
= {  
    0x00,  
    0x00,  
    0x11,  
    0x11,  
    0x0F,  
    0x01,  
    0x0E,  
    0x00  
}
```

FONT_LOWER_Z

```
const uint8_t FONT_LOWER_Z[8]  [static]
```

Initial value:

```
= {
    0x00,
    0x00,
    0x1F,
    0x02,
    0x04,
    0x08,
    0x1F,
    0x00
}
```

4.1.4 QRS Detector

Module for analyzing ECG data to determine heart rate.

Collaboration diagram for QRS Detector:



Files

- file [QRS.c](#)
Source code for QRS detection module.
- file [QRS.h](#)
Header file for QRS detection module.

Macros

- **#define QRS_NUM_FID_MARKS** 40
- **#define FLOAT_COMPARE_TOLERANCE** (float32_t)(1E-5f)
- **#define IS_GREATER**(X, Y) (bool) ((X - Y) > FLOAT_COMPARE_TOLERANCE)
- **#define IS_PEAK**(X_MINUS_1, X, X_PLUS_1) (bool) (IS_GREATER(X, X_MINUS_1) && IS_GREATER(X, X_PLUS_1))
- **#define QRS_SAMP_FREQ** ((uint32_t) 200)
- **#define QRS_SAMP_PERIOD_SEC** ((float32_t) 0.005f)
- **#define QRS_NUM_SAMP** ((uint16_t) (1 << 11))

Variables

- struct {
 - bool **isCalibrated**
 - float32_t **signalLevel**
estimated signal level
 - float32_t **noiseLevel**
estimated noise level
 - float32_t **threshold**
amplitude threshold
 - uint16_t **fidMarkArray** [QRS_NUM_FID_MARKS]
 - float32_t **utilityBuffer1** [QRS_NUM_FID_MARKS]
array to hold fidMark indices
 - float32_t **utilityBuffer2** [QRS_NUM_FID_MARKS]
- } **Detector** = { false, 0.0f, 0.0f, 0.0f, { 0 }, { 0 }, { 0 } }

Digital Filters

- enum {
 - NUM_STAGES_BANDPASS** = 4 , **NUM_COEFF_HIGHPASS** = NUM_STAGES_BANDPASS * 5 , **STATE_↵**
 - _BUFF_SIZE_BANDPASS** = NUM_STAGES_BANDPASS * 4 , **NUM_COEFF_DERFILT** = 5 ,
 - BLOCK_SIZE_DERFILT** = (1 << 8) , **STATE_BUFF_SIZE_DERFILT** = NUM_COEFF_DERFILT + BLOCK_↵
 - _SIZE_DERFILT - 1** , **NUM_COEFF_MOVAVG** = 10 , **BLOCK_SIZE_MOVAVG** = BLOCK_SIZE_DERFILT ,
 - STATE_BUFF_SIZE_MOVAVG** = NUM_COEFF_MOVAVG + BLOCK_SIZE_MOVAVG - 1 }
- typedef arm_biquad_casd_df1_inst_f32 **IIR_Filt_t**
- typedef arm_fir_instance_f32 **FIR_Filt_t**
- static const float32_t **COEFF_BANDPASS** [NUM_COEFF_HIGHPASS]
- static const float32_t **COEFF_DERFILT** [NUM_COEFF_DERFILT]
- static const float32_t **COEFF_MOVAVG** [NUM_COEFF_MOVAVG]
- static float32_t **stateBuffer_bandPass** [STATE_BUFF_SIZE_BANDPASS] = { 0 }
- static const IIR_Filt_t **bandpassFiltStruct** = { NUM_STAGES_BANDPASS, stateBuffer_bandPass, COEFF_↵
- _BANDPASS** }
- static const IIR_Filt_t *const **bandpassFilter** = &bandpassFiltStruct
- static float32_t **stateBuffer_DerFilt** [STATE_BUFF_SIZE_DERFILT] = { 0 }
- static const FIR_Filt_t **derivativeFiltStruct** = { NUM_COEFF_DERFILT, stateBuffer_DerFilt, COEFF_↵
- DERFILT** }
- static const FIR_Filt_t *const **derivativeFilter** = &derivativeFiltStruct
- static float32_t **stateBuffer_MovingAvg** [STATE_BUFF_SIZE_MOVAVG] = { 0 }
- static const FIR_Filt_t **movingAvgFiltStruct** = { NUM_COEFF_MOVAVG, stateBuffer_MovingAvg, COEFF_↵
- _MOVAVG** }
- static const FIR_Filt_t *const **movingAverageFilter** = &movingAvgFiltStruct

Implementation

- static uint8_t **QRS_findFiducialMarks** (const float32_t yn[], uint16_t fidMarkArray[])
Mark local peaks in the input signal y as potential candidates for QRS complexes (AKA "fiducial marks").
- static void **QRS_initLevels** (const float32_t yn[], float32_t *sigLvlPtr, float32_t *noiseLvlPtr)
Initialize the signal and noise levels for the QRS detector using the initial block of input signal data.
- static float32_t **QRS_updateLevel** (const float32_t peakAmplitude, float32_t level)
Update the signal level (if a fiducial mark is a confirmed peak) or the noise level (if a fiducial mark is rejected).
- static float32_t **QRS_updateThreshold** (const float32_t signalLevel, const float32_t noiseLevel)
Update the amplitude threshold used to identify peaks based on the signal and noise levels.

Interface Functions

- void `QRS_Init` (void)
Initialize the QRS detector.
- void `QRS_Preprocess` (const float32_t xn[], float32_t yn[])
Preprocess the ECG data to remove noise and/or exaggerate the signal characteristic(s) of interest.
- float32_t `QRS_applyDecisionRules` (const float32_t yn[])
Calculate the average heart rate (HR) using predetermined decision rules.
- float32_t `QRS_runDetection` (const float32_t xn[], float32_t yn[])
Run the full algorithm (preprocessing and decision rules) on the inputted ECG data.

4.1.4.1 Detailed Description

Module for analyzing ECG data to determine heart rate.

4.1.4.2 Function Documentation

QRS_findFiducialMarks()

```
static uint8_t QRS_findFiducialMarks (
    const float32_t yn[],
    uint16_t fidMarkArray[] ) [static]
```

Mark local peaks in the input signal y as potential candidates for QRS complexes (AKA "fiducial marks").

Parameters

in	<i>yn</i>	Array containing the preprocessed ECG signal $y[n]$
in	<i>fidMarkArray</i>	Array to place the fiducial mark's sample indices into.
out	<i>numMarks</i>	Number of identified fiducial marks

Postcondition

fidMarkArray will hold the values of the fiducial marks.

The fiducial marks must be spaced apart by at least 200 [ms] (40 samples @ $f_s = 200$ [Hz]). If a peak is found within this range, the one with the largest amplitude is taken to be the correct peak and the other is ignored.

QRS_initLevels()

```
static void QRS_initLevels (
    const float32_t yn[],
    float32_t * sigLvlPtr,
    float32_t * noiseLvlPtr ) [static]
```

Initialize the signal and noise levels for the QRS detector using the initial block of input signal data.

Parameters

in	<i>yn</i>	Array containing the preprocessed ECG signal $y[n]$
in	<i>sigLvIPtr</i>	Pointer to variable holding the signal level value.
in	<i>noiseLvIPtr</i>	Pointer to variable holding the noise level value.

Postcondition

The signal and noise levels are initialized.

QRS_updateLevel()

```
static float32_t QRS_updateLevel (
    const float32_t peakAmplitude,
    float32_t level ) [static]
```

Update the signal level (if a fiducial mark is a confirmed peak) or the noise level (if a fiducial mark is rejected).

Parameters

in	<i>peakAmplitude</i>	Amplitude of the fiducial mark in signal $y[n]$
in	<i>level</i>	The current value of the signal level or noise level
out	<i>newLevel</i>	The updated value of the signal level or noise level

$$signalLevel_1 = f(peakAmplitude, signalLevel_0) = \frac{1}{8}peakAmplitude + \frac{7}{8}signalLevel_0$$

$$noiseLevel_1 = f(peakAmplitude, noiseLevel_0) = \frac{1}{8}peakAmplitude + \frac{7}{8}noiseLevel_0$$

QRS_updateThreshold()

```
static float32_t QRS_updateThreshold (
    const float32_t signalLevel,
    const float32_t noiseLevel ) [static]
```

Update the amplitude threshold used to identify peaks based on the signal and noise levels.

Parameters

in	<i>signalLevel</i>	Current signal level.
in	<i>noiseLevel</i>	Current noise level.
out	<i>threshold</i>	New threshold to use for next comparison.

See also

[QRS_updateLevel\(\)](#), [QRS_applyDecisionRules](#)

$$threshold = f(signalLevel, noiseLevel) = noiseLevel + 0.25(signalLevel - noiseLevel)$$

QRS_Init()

```
void QRS_Init (
    void )
```

Initialize the QRS detector.

Note

This function isn't necessary anymore, but I'm keeping it here just in case.

This function originally initialized the filter `structs` but now does nothing since those have been made `const` and their initialization functions have been removed entirely.

QRS_Preprocess()

```
void QRS_Preprocess (
    const float32_t xn[],
    float32_t yn[] )
```

Preprocess the ECG data to remove noise and/or exaggerate the signal characteristic(s) of interest.

Precondition

Fill input buffer `xn` with raw or lightly preprocessed ECG data.

Parameters

in	<i>xn</i>	Array of raw ECG signal values.
in	<i>yn</i>	Array used to store preprocessed ECG signal values.

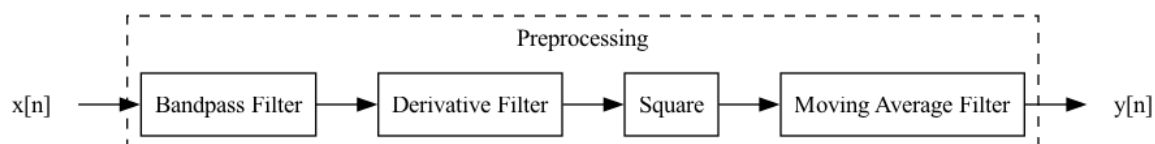
Postcondition

The preprocessed signal data $y[n]$ is stored in `yn` and is ready to be analyzed to calculate the heart rate in [bpm].

See also

[QRS_applyDecisionRules\(\)](#)

This function uses the same overall preprocessing pipeline as the original Pan-Tompkins algorithm, but the high-pass and low-pass filters have been replaced with ones generated using Scipy.



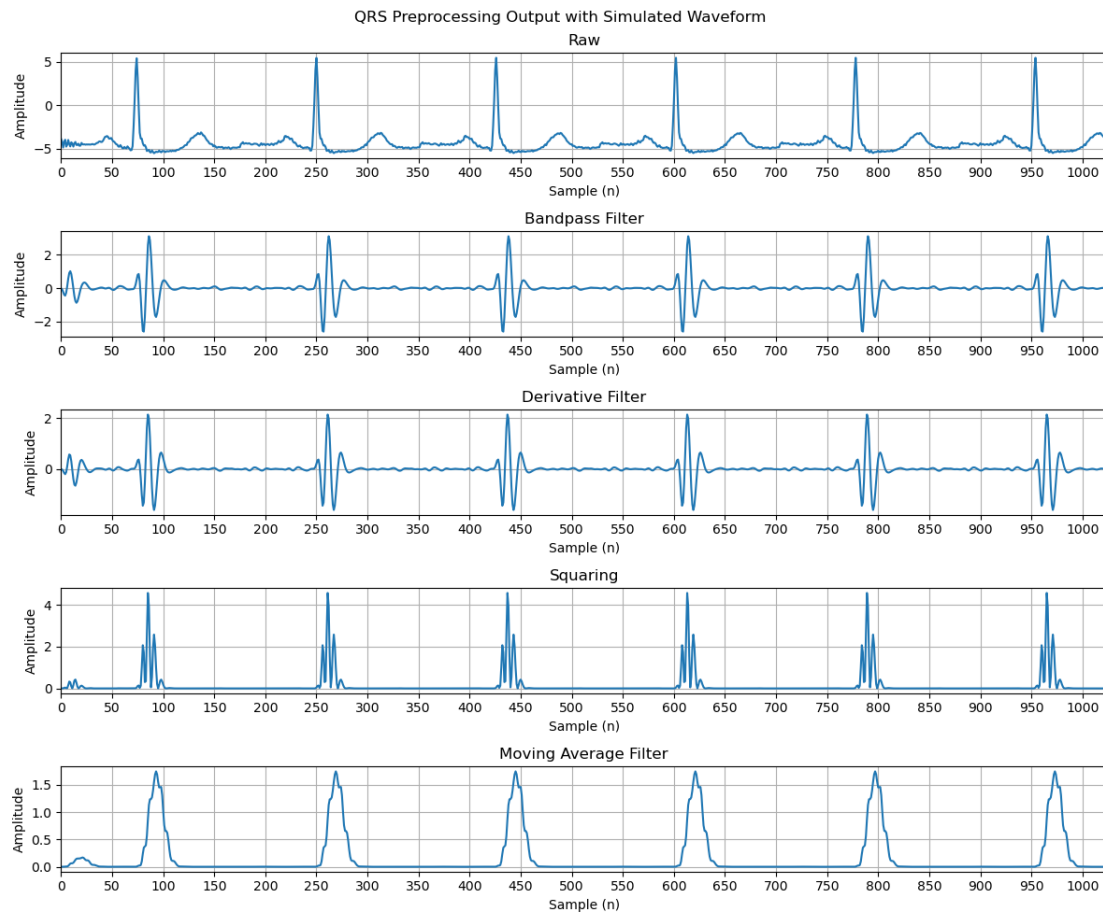


Figure 3 Output of each preprocessing step.

Note

The FIR filters are applied in blocks to decrease the amount of memory needed for their state buffers.

QRS_applyDecisionRules()

```
float32_t QRS_applyDecisionRules (
    const float32_t yn[] )
```

Calculate the average heart rate (HR) using predetermined decision rules.

Precondition

Preprocess the raw ECG data.

Parameters

in	<i>yn</i>	Array of preprocessed ECG signal values.
out	<i>heartRate</i>	Average heart rate in [bpm].

Postcondition

Certain information (signal/noise levels, thresholds, etc.) is retained between calls and used to improve further detection.

Warning

The current implementation only processes one block at a time and discards the data immediately after, so peaks that are cut off between one block and another might not be being counted.

See also

[QRS_Preprocess\(\)](#)

QRS_runDetection()

```
float32_t QRS_runDetection (
    const float32_t xn[],
    float32_t yn[] )
```

Run the full algorithm (preprocessing and decision rules) on the inputted ECG data.

This function simply combines the preprocessing and decision rules functions into a single function.

Parameters

in	<i>xn</i>	Array of raw ECG signal values.
in	<i>yn</i>	Array used to hold preprocessed ECG signal values.
out	<i>heartRate</i>	Average heart rate in [bpm].

Postcondition

yn will contain the preprocessed data.

Certain information (signal/noise levels, thresholds, etc.) is retained between calls.

See also

[QRS_Preprocess\(\)](#), [QRS_applyDecisionRules\(\)](#)

4.1.4.3 Variable Documentation**COEFF_BANDPASS**

```
const float32_t COEFF_BANDPASS[NUM_COEFF_HIGHPASS] [static]
```

Initial value:

```
= {
    0.002937758108600974f, 0.005875516217201948f, 0.002937758108600974f,
    1.0485996007919312f, -0.2961403429508209f,
```

```

1.0f, 2.0f, 1.0f,
1.3876197338104248f, -0.492422878742218f,

1.0f, -2.0f, 1.0f,
1.3209134340286255f, -0.6327387690544128f,

1.0f, -2.0f, 1.0f,
1.6299355030059814f, -0.7530401945114136f,
}

```

COEFF_DERFILT

```
const float32_t COEFF_DERFILT[NUM_COEFF_DERFILT] [static]
```

Initial value:

```

= {
    -0.125f, -0.25f, 0.0f, 0.25f, 0.125f
}

```

COEFF_MOVAVG

```
const float32_t COEFF_MOVAVG[NUM_COEFF_MOVAVG] [static]
```

Initial value:

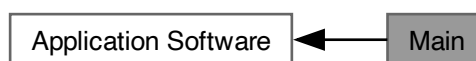
```

= {
    0.10000000149011612f, 0.10000000149011612f, 0.10000000149011612f,
    0.10000000149011612f, 0.10000000149011612f, 0.10000000149011612f,
    0.10000000149011612f, 0.10000000149011612f, 0.10000000149011612f, 0.10000000149011612f
}

```

4.1.5 Main

Collaboration diagram for Main:



Files

- file [main.c](#)
Main program file.

Enumerations

- enum `ISR_VECTOR_NUMS` { `DAQ_VECTOR_NUM` = INT_ADC0SS3 , `PROC_VECTOR_NUM` = INT_CAN0 , `LCD_VECTOR_NUM` = INT_TIMER1A }
- enum `FIFO_INFO` {
`DAQ_FIFO_CAP` = 3 , `DAQ_ARRAY_LEN` = DAQ_FIFO_CAP + 1 , `QRS_FIFO_CAP` = QRS_NUM_SAMP ,
`QRS_ARRAY_LEN` = QRS_FIFO_CAP + 1 ,
`LCD_FIFO_1_CAP` = DAQ_FIFO_CAP , `LCD_ARRAY_1_LEN` = LCD_FIFO_1_CAP + 1 , `LCD_FIFO_2_CAP`
= 1 , `LCD_ARRAY_2_LEN` = LCD_FIFO_2_CAP + 1 }
- enum `LCD_INFO` {
`LCD_TOP_LINE` = (LCD_Y_MAX - 24) , `LCD_WAVE_NUM_Y` = LCD_TOP_LINE , `LCD_WAVE_X_OFFSET`
= 0 , `LCD_WAVE_Y_MIN` = (0 + LCD_WAVE_X_OFFSET) ,
`LCD_WAVE_Y_MAX` = (LCD_WAVE_NUM_Y + LCD_WAVE_X_OFFSET) , `LCD_TEXT_LINE_NUM` = 28 ,
`LCD_TEXT_COL_NUM` = 24 }

Functions

- static void `DAQ_Handler` (void)
ISR for the data acquisition system.
- static void `Processing_Handler` (void)
ISR for intermediate processing of the input data.
- static void `LCD_Handler` (void)
ISR for plotting the waveform and outputting the heart rate to the LCD.
- int `main` (void)
Main function for the project.

Variables

- static volatile `Fifo_t` `DAQ_Fifo` = 0
- static volatile `uint32_t` `DAQ_fifoBuffer` [`DAQ_ARRAY_LEN`] = { 0 }
- static volatile `Fifo_t` `QRS_Fifo` = 0
- static volatile `uint32_t` `QRS_fifoBuffer` [`QRS_ARRAY_LEN`] = { 0 }
- static volatile `Fifo_t` `LCD_Fifo1` = 0
- static volatile `uint32_t` `LCD_fifoBuffer1` [`LCD_ARRAY_1_LEN`] = { 0 }
- static volatile `Fifo_t` `LCD_Fifo2` = 0
- static volatile `uint32_t` `LCD_fifoBuffer2` [`LCD_ARRAY_2_LEN`] = { 0 }
- static volatile `bool` `qrsBufferIsFull` = false
flag for QRS detection to start
- static volatile `bool` `heartRateIsReady` = false
flag for LCD to output heart rate
- static `float32_t` `QRS_processingBuffer` [`QRS_ARRAY_LEN`] = { 0 }
- static `uint16_t` `LCD_prevSampleBuffer` [`LCD_X_MAX`] = { 0 }

4.1.5.1 Detailed Description

4.1.5.2 Enumeration Type Documentation

ISR_VECTOR_NUMS

enum `ISR_VECTOR_NUMS`

Enumerator

DAQ_VECTOR_NUM	vector number for the DAQ_Handler()
PROC_VECTOR_NUM	vector number for the Processing_Handler()
LCD_VECTOR_NUM	vector number for the LCD_Handler()

FIFO_INFOenum [FIFO_INFO](#)

Enumerator

DAQ_FIFO_CAP	capacity of DAQ's FIFO buffer
DAQ_ARRAY_LEN	actual size of underlying array
QRS_FIFO_CAP	capacity of QRS detector's FIFO buffer
QRS_ARRAY_LEN	actual size of underlying array
LCD_FIFO_1_CAP	capacity of LCD's waveform FIFO buffer
LCD_ARRAY_1_LEN	actual size of underlying array
LCD_FIFO_2_CAP	capacity of LCD's heart rate FIFO buffer
LCD_ARRAY_2_LEN	actual size of underlying array

LCD_INFOenum [LCD_INFO](#)

Enumerator

LCD_TOP_LINE	separates waveform from text
LCD_WAVE_NUM_Y	num. of y-vals available for plotting waveform
LCD_WAVE_X_OFFSET	waveform's offset from X axis
LCD_WAVE_Y_MIN	waveform's min y-value
LCD_WAVE_Y_MAX	waveform's max y-value
LCD_TEXT_LINE_NUM	line num. of text
LCD_TEXT_COL_NUM	starting col. num. for heart rate

4.1.5.3 Function Documentation**DAQ_Handler()**

```
static void DAQ_Handler (
    void ) [static]
```

ISR for the data acquisition system.

This ISR has a priority level of 1, is triggered when the ADC has finished capturing a sample, and also triggers the intermediate processing handler. It reads the 12-bit ADC output, converts it from an integer to a raw voltage sample, and sends it to the processing ISR via the DAQ_Fifo.

Precondition

Initialize the DAQ module.

Postcondition

The converted sample is placed in the DAQ FIFO, and the processing ISR is triggered.

See also

[DAQ_Init\(\)](#), [Processing_Handler\(\)](#)

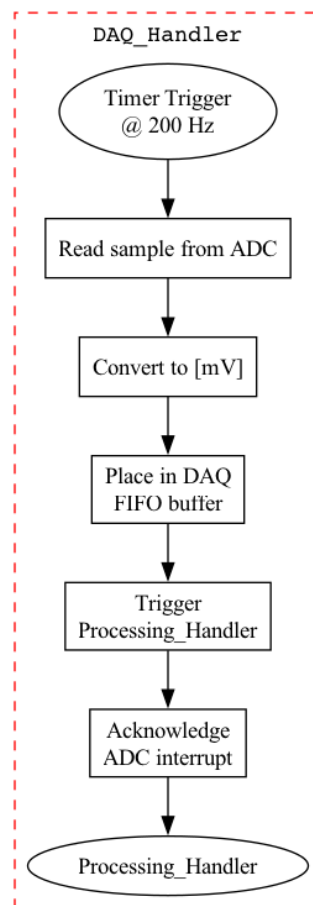


Figure 4 Flowchart for the DAQ handler.

Processing_Handler()

```
static void Processing_Handler (
    void ) [static]
```

ISR for intermediate processing of the input data.

This ISR has a priority level of 1, is triggered by the DAQ ISR, and triggers the LCD handler. It removes baseline drift and power line interference (PLI) from a sample, and then moves it to the QRS_Fifo and the LCD_Fifo. It also notifies the superloop in [main\(\)](#) when the QRS buffer is full.

Postcondition

The converted sample is placed in the LCD FIFO, and the LCD ISR is triggered.

The converted sample is placed in the QRS FIFO, and the flag is set.

See also

[DAQ_Handler\(\)](#), [main\(\)](#), [LCD_Handler\(\)](#)

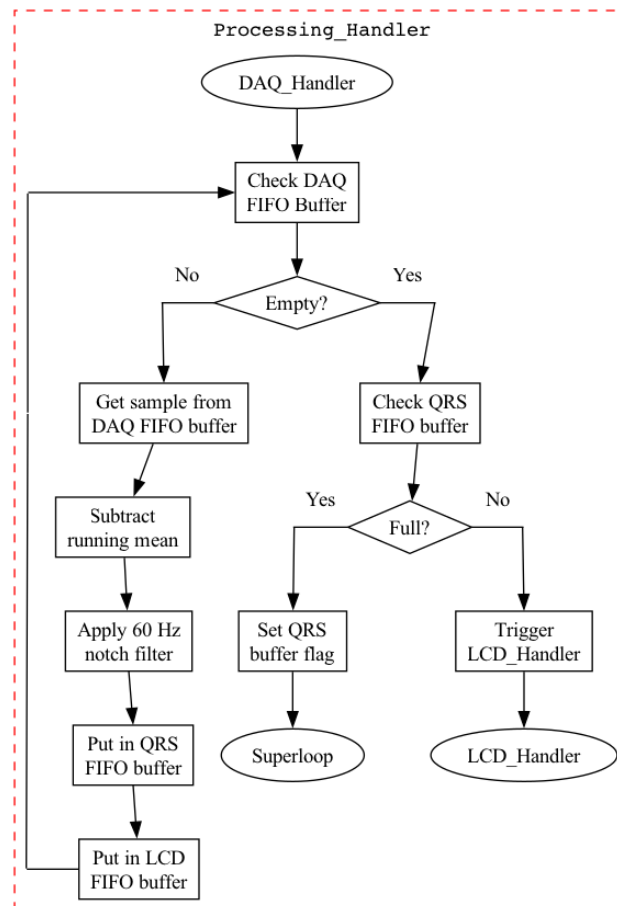


Figure 5 Flowchart for the processing handler.

LCD_Handler()

```
static void LCD_Handler (
    void ) [static]
```

ISR for plotting the waveform and outputting the heart rate to the LCD.

This ISR has a priority level of 1 and is triggered by the Processing ISR. It applies a 0.5-40 [Hz] bandpass filter to the sample and plots it. It also outputs the heart rate.

Precondition

Initialize the LCD module.

Postcondition

The bandpass-filtered sample is plotted to the LCD.

The heart rate is updated after each block is analyzed.

See also

[LCD_Init\(\)](#), [Processing_Handler\(\)](#), [main\(\)](#)

main()

```
int main (
    void )
```

Main function for the project.

Moves the interrupt vector table to RAM; configures and enables the ISRs; initializes all modules and static variables; and performs QRS detection once the buffer has been filled.

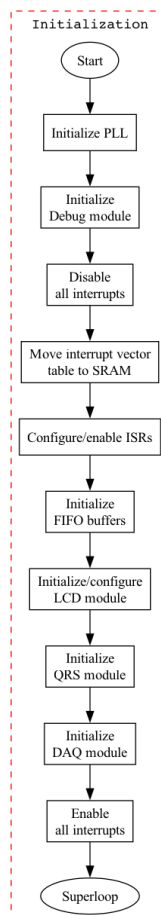


Figure 6 Flowchart for the initialization phase.

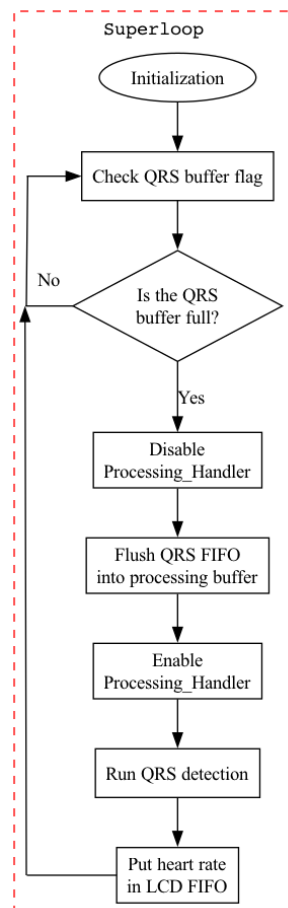
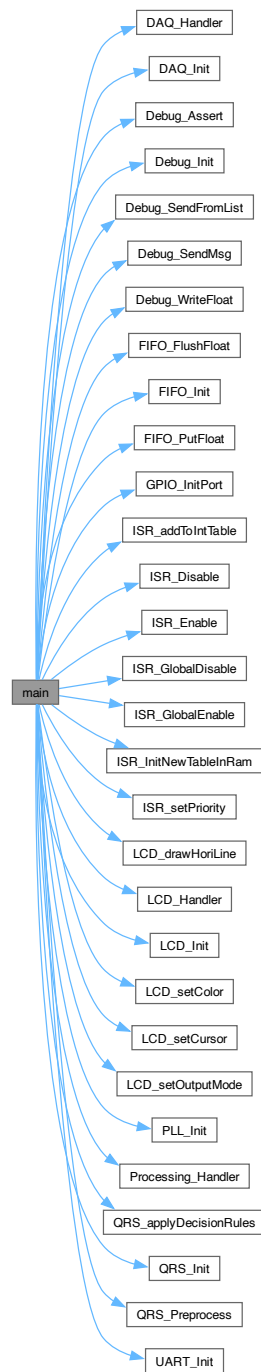


Figure 7 Flowchart for the superloop.

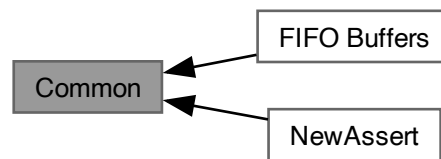
Here is the call graph for this function:



4.2 Common

Modules that are used by multiple layers and/or don't fit into any one layer.

Collaboration diagram for Common:



Modules

- [FIFO Buffers](#)
- [NewAssert](#)

Files

- file [NewAssert.c](#)
Source code for custom assert implementation.
- file [NewAssert.h](#)
Header file for custom assert implementation.

Functions

- void [Assert](#) (bool condition)
Custom assert implementation that is more lightweight than the one from newlib.

4.2.1 Detailed Description

Modules that are used by multiple layers and/or don't fit into any one layer.

4.2.2 Function Documentation

Assert()

```
void Assert (
    bool condition )
```

Custom `assert` implementation that is more lightweight than the one from `newlib`.

Parameters

in	<i>condition</i>	Conditional to test.
----	------------------	----------------------

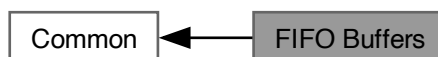
Postcondition

If `condition == true`, the function simply returns.

If `condition == false`, a breakpoint is initiated.

4.2.3 FIFO Buffers

Collaboration diagram for FIFO Buffers:

**Files**

- file [Fifo.c](#)
Source code for FIFO buffer module.
- file [Fifo.h](#)
Header file for FIFO buffer implementation.

Data Structures

- struct [Fifo_t](#)

Macros

- `#define FIFO_POOL_SIZE 5`

Functions

- `Fifo_t FIFO_Init` (volatile uint32_t buffer[], const uint32_t N)
Initialize a FIFO buffer of length N.
- `void FIFO_Reset` (volatile Fifo_t fifo)
Reset the FIFO buffer.

Variables

- static `FifoStruct_t fifoPool` [FIFO_POOL_SIZE] = { 0 }
pre-allocated pool
- static `uint8_t numFreeFifos` = FIFO_POOL_SIZE

Basic Operations

- void `FIFO_Put` (volatile `Fifo_t` fifo, const `uint32_t` val)
Add a value to the end of the buffer.
- `uint32_t` `FIFO_Get` (volatile `Fifo_t` fifo)
Remove the first value of the buffer.
- void `FIFO_Flush` (volatile `Fifo_t` fifo, `uint32_t` outputBuffer[])
Empty the FIFO buffer's contents into an array.
- void `FIFO_PutFloat` (volatile `Fifo_t` fifo, const `float` val)
Add a floating-point value to the end of the buffer.
- `float` `FIFO_GetFloat` (volatile `Fifo_t` fifo)
Remove the first value of the buffer, and cast it to `float`.
- void `FIFO_FlushFloat` (volatile `Fifo_t` fifo, `float` outputBuffer[])
Empty the FIFO buffer into an array of floating-point values.

Peeking

- `uint32_t` `FIFO_PeekOne` (volatile `Fifo_t` fifo)
See the first element in the FIFO without removing it.
- void `FIFO_PeekAll` (volatile `Fifo_t` fifo, `uint32_t` outputBuffer[])
See the FIFO buffer's contents without removing them.

Status Checks

- bool `FIFO_isFull` (volatile `Fifo_t` fifo)
Check if the FIFO buffer is full.
- bool `FIFO_isEmpty` (volatile `Fifo_t` fifo)
Check if the FIFO buffer is empty.
- `uint32_t` `FIFO_getCurrSize` (volatile `Fifo_t` fifo)
Get the current size of the FIFO buffer.

4.2.3.1 Detailed Description

Module for using the "first-in first-out (FIFO) buffer" data structure.

4.2.3.2 Function Documentation

FIFO_Init()

```
Fifo_t FIFO_Init (
    volatile uint32_t buffer[],
    const uint32_t N )
```

Initialize a FIFO buffer of length N.

Parameters

in	<i>buffer</i>	Array of size N to be used as FIFO buffer
in	<i>N</i>	Length of <i>buffer</i> . Usable length is $N - 1$.
out	<i>fifo</i>	pointer to the FIFO buffer

Postcondition

The number of available FIFO buffers is reduced by 1.

TODO: Add details

FIFO_Reset()

```
void FIFO_Reset (
    volatile Fifo_t fifo )
```

Reset the FIFO buffer.

Parameters

in	<i>fifo</i>	Pointer to FIFO buffer.
----	-------------	-------------------------

Postcondition

The FIFO is now considered empty. The underlying buffer's contents are not affected.

FIFO_Put()

```
void FIFO_Put (
    volatile Fifo_t fifo,
    const uint32_t val )
```

Add a value to the end of the buffer.

Parameters

in	<i>fifo</i>	Pointer to FIFO object
in	<i>val</i>	Value to add to the buffer.

Postcondition

If the FIFO is not full, *val* is placed in the buffer. If the FIFO is full, nothing happens.

See also

[FIFO_PutFloat\(\)](#)

FIFO_Get()

```
uint32_t FIFO_Get (
    volatile Fifo_t fifo )
```

Remove the first value of the buffer.

Parameters

in	<i>fifo</i>	Pointer to FIFO object
out	<i>val</i>	First sample in the FIFO.

Postcondition

If the FIFO is not empty, the next value is returned. If the FIFO is empty, 0 is returned.

See also

[FIFO_GetFloat\(\)](#)

FIFO_Flush()

```
void FIFO_Flush (
    volatile Fifo_t fifo,
    uint32_t outputBuffer[] )
```

Empty the FIFO buffer's contents into an array.

Parameters

in	<i>fifo</i>	Pointer to source FIFO buffer.
in	<i>outputBuffer</i>	Array to output values to. Should be the same length as the FIFO buffer.

Postcondition

The FIFO buffer's contents are transferred to the output buffer.

See also

[FIFO_FlushFloat\(\)](#)

FIFO_PutFloat()

```
void FIFO_PutFloat (
    volatile Fifo_t fifo,
    const float val )
```

Add a floating-point value to the end of the buffer.

Parameters

in	<i>fifo</i>	Pointer to FIFO object
in	<i>val</i>	Value to add to the buffer.

Postcondition

If the FIFO is not full, `val` is placed in the buffer. If the FIFO is full, nothing happens.

Note

This was added to avoid needing to type-pun floating-point values.

```
// type-punning example
float num = 4.252603;
FIFO_Put(fifo, *((uint32_t *) &num));
FIFO_PutFloat(fifo, num); // same thing, but cleaner
```

See also

[FIFO_Put\(\)](#)

Remarks

To properly use floating-point values, type-punning is necessary.

FIFO_GetFloat()

```
float FIFO_GetFloat (
    volatile Fifo_t fifo )
```

Remove the first value of the buffer, and cast it to `float`.

Parameters

in	<i>fifo</i>	Pointer to FIFO object
out	<i>val</i>	First sample in the FIFO.

Postcondition

If the FIFO is not empty, the next value is returned. If the FIFO is empty, 0 is returned.

Note

This was added to avoid needing to type-pun floating-point values.

```
// type-punning example
float num;
*((uint32_t *) &num) = FIFO_Get(fifo);
num = FIFO_GetFloat(fifo);
```

See also

[FIFO_Get\(\)](#)

Remarks

To properly use floating-point values, type-punning is necessary.

FIFO_FlushFloat()

```
void FIFO_FlushFloat (
    volatile Fifo_t fifo,
    float outputBuffer[] )
```

Empty the FIFO buffer into an array of floating-point values.

Parameters

in	<i>fifo</i>	Pointer to source FIFO buffer.
in	<i>outputBuffer</i>	Array to output values to. Should be the same length as the FIFO buffer.

Postcondition

The FIFO buffer's contents are transferred to the output buffer.

Note

This was added to avoid needing to type-pun floating-point values.

```
// type-punning example
FIFO_Flush(fifo, (uint32_t *) outputBuffer);
FIFO_FlushFloat(fifo, outputBuffer); // same thing, but cleaner
```

See also

[FIFO_Flush\(\)](#)

FIFO_PeekOne()

```
uint32_t FIFO_PeekOne (
    volatile Fifo_t fifo )
```

See the first element in the FIFO without removing it.

Parameters

in	<i>fifo</i>	Pointer to FIFO object
out	<i>val</i>	First sample in the FIFO.

FIFO_PeekAll()

```
void FIFO_PeekAll (
    volatile Fifo_t fifo,
    uint32_t outputBuffer[] )
```

See the FIFO buffer's contents without removing them.

Parameters

in	<i>fifo</i>	Pointer to source FIFO buffer.
in	<i>outputBuffer</i>	Array to output values to. Should be the same length as the FIFO buffer.

Postcondition

The FIFO buffer's contents are copied to the output buffer.

FIFO_isFull()

```
bool FIFO_isFull (
    volatile Fifo_t fifo )
```

Check if the FIFO buffer is full.

Parameters

in	<i>fifo</i>	Pointer to the FIFO buffer.
out	<i>true</i>	The FIFO buffer is full.
out	<i>false</i>	The FIFO buffer is not full.

FIFO_isEmpty()

```
bool FIFO_isEmpty (
    volatile Fifo_t fifo )
```

Check if the FIFO buffer is empty.

Parameters

in	<i>fifo</i>	Pointer to the FIFO buffer.
out	<i>true</i>	The FIFO buffer is empty.
out	<i>false</i>	The FIFO buffer is not empty.

FIFO_getCurrSize()

```
uint32_t FIFO_getCurrSize (
    volatile Fifo_t fifo )
```

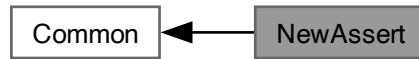
Get the current size of the FIFO buffer.

Parameters

in	<i>fifo</i>	Pointer to the FIFO buffer.
out	<i>size</i>	Current number of values in the FIFO buffer.

4.2.4 NewAssert

Collaboration diagram for NewAssert:

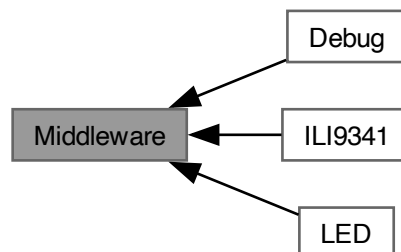


Module for using a custom `assert` implementation.

4.3 Middleware

High-level device driver modules.

Collaboration diagram for Middleware:



Modules

- [Debug](#)
- [ILI9341](#)
- [LED](#)

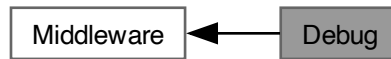
4.3.1 Detailed Description

High-level device driver modules.

These modules contain functions for interfacing with external devices/peripherals using low-level drivers.

4.3.2 Debug

Collaboration diagram for Debug:



Files

- file [Debug.h](#)

Functions to output debugging information to a serial port via UART.

Serial Output

- enum **Msg_t** { **DEBUG_DAQ_INIT** , **DEBUG_QRS_INIT** , **DEBUG_LCD_INIT** , **DEBUG_QRS_START** }
- void [Debug_SendMsg](#) (void *message)
Send a message to the serial port.
- void [Debug_SendFromList](#) (Msg_t msg)
Send a message from the message list.
- void [Debug_WriteFloat](#) (double value)
Write a floating-point value to the serial port.

Initialization

- void [Debug_Init](#) (Uart_t uart)
Initialize the Debug module.

Assertions

- void [Debug_Assert](#) (bool condition)
Stops program if `condition` is `true`. Useful for bug detection during debugging.

4.3.2.1 Detailed Description

Module for debugging functions, including serial output and assertions.

4.3.2.2 Function Documentation

Debug_Init()

```
void Debug_Init (
    Uart_t uart )
```

Initialize the Debug module.

Parameters

<i>in</i>	<i>uart</i>	UART to use for serial output.
-----------	-------------	--------------------------------

Postcondition

An initialization message is sent to the serial port.

Debug_SendMsg()

```
void Debug_SendMsg (
    void * message )
```

Send a message to the serial port.

Precondition

Initialize the Debug module.

Parameters

<i>message</i>	(Pointer to) array of ASCII characters.
----------------	---

Postcondition

A floating point value is written to the serial port.

See also

[Debug_SendMsg\(\)](#)

Debug_SendFromList()

```
void Debug_SendFromList (
    Msg_t msg )
```

Send a message from the message list.

Precondition

Initialize the Debug module.

Parameters

<i>in</i>	<i>msg</i>	An entry from the enumeration.
-----------	------------	--------------------------------

Postcondition

The corresponding message is sent to the serial port.

See also

[Debug_SendMsg\(\)](#)

Debug_WriteFloat()

```
void Debug_WriteFloat (
    double value )
```

Write a floating-point value to the serial port.

Precondition

Initialize the Debug module.

Parameters

in	<i>value</i>	Floating-point value.
----	--------------	-----------------------

Postcondition

A floating point value is written to the serial port.

See also

[Debug_SendMsg\(\)](#)

Debug_Assert()

```
void Debug_Assert (
    bool condition )
```

Stops program if `condition` is `true`. Useful for bug detection during debugging.

Precondition

Initialize the Debug module.

Parameters

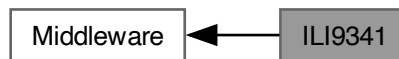
in	<i>condition</i>	Conditional statement to evaluate.
----	------------------	------------------------------------

Postcondition

If `condition == true`, the program continues normally. If `condition == false`, a message is sent and a breakpoint is activated.

4.3.3 ILI9341

Collaboration diagram for ILI9341:

**Files**

- file [ILI9341.c](#)
Source code for ILI9341 module.
- file [ILI9341.h](#)
Driver module for interfacing with an ILI9341 LCD driver.

Enumerations

- enum { [ILI9341_NUM_COLS](#) = 240 , [ILI9341_NUM_ROWS](#) = 320 }
- enum [Cmd_t](#) {
[NOP](#) = 0x00 , [SWRESET](#) = 0x01 , [SPLIN](#) = 0x10 , [SPLOUT](#) = 0x11 ,
[PTLON](#) = 0x12 , [NORON](#) = 0x13 , [DINVOFF](#) = 0x20 , [DINVON](#) = 0x21 ,
[CASET](#) = 0x2A , [PASET](#) = 0x2B , [RAMWR](#) = 0x2C , [DISPOFF](#) = 0x28 ,
[DISPON](#) = 0x29 , [PLTAR](#) = 0x30 , [VSCRDEF](#) = 0x33 , [MADCTL](#) = 0x36 ,
[VSCRADD](#) = 0x37 , [IDMOFF](#) = 0x38 , [IDMON](#) = 0x39 , [PIXSET](#) = 0x3A ,
[FRMCTR1](#) = 0xB1 , [FRMCTR2](#) = 0xB2 , [FRMCTR3](#) = 0xB3 , [PRCTR](#) = 0xB5 ,
[IFCTL](#) = 0xF6 }
- enum [sleepMode_t](#) { [SLEEP_ON](#) = [SPLIN](#) , [SLEEP_OFF](#) = [SPLOUT](#) }
- enum [displayArea_t](#) { [NORMAL_AREA](#) = [NORON](#) , [PARTIAL_AREA](#) = [PTLON](#) }
- enum [colorExpr_t](#) { [FULL_COLORS](#) = [IDMOFF](#) , [PARTIAL_COLORS](#) = [IDMON](#) }
- enum [invertMode_t](#) { [INVERT_ON](#) = [DINVON](#) , [INVERT_OFF](#) = [DINVOFF](#) }
- enum [outputMode_t](#) { [OUTPUT_ON](#) = [DISPON](#) , [OUTPUT_OFF](#) = [DISPOFF](#) }
- enum [colorDepth_t](#) { [COLORDEPTH_16BIT](#) = 0x55 , [COLORDEPTH_18BIT](#) = 0x66 }

Functions

- static void [ILI9341_setMode](#) (uint8_t param)
- static void [ILI9341_setAddress](#) (uint16_t start_address, uint16_t end_address, bool is_row)
- static void [ILI9341_sendParams](#) ([Cmd_t](#) cmd)
Send a command and/or the data within the FIFO buffer. A command is only sent when `cmd != NOP` (where `NOP = 0`). Data is only sent if the FIFO buffer is not empty.
- void [ILI9341_Init](#) (Timer_t timer)

- Initialize the LCD driver and the SPI module.*

 - void **ILI9341_setInterface** (void)

Sets the interface for the ILI9341.
- void **ILI9341_resetHard** (Timer_t timer)

Perform a hardware reset of the LCD driver.
- void **ILI9341_resetSoft** (Timer_t timer)

Perform a software reset of the LCD driver.
- void **ILI9341_setSleepMode** (sleepMode_t sleepMode, Timer_t timer)

Enter or exit sleep mode (ON by default).
- void **ILI9341_setDisplayArea** (displayArea_t displayArea)

Set the display area.
- void **ILI9341_setColorExpression** (colorExpr_t colorExpr)

Set the color expression (FULL_COLORS by default).
- void **ILI9341_setPartialArea** (uint16_t rowStart, uint16_t rowEnd)

Set the display area for partial mode. Call before activating partial mode.
- void **ILI9341_setDisplInversion** (invertMode_t invertMode)

Toggle display inversion (OFF by default).
- void **ILI9341_setDispOutput** (outputMode_t outputMode)

Change whether the IC is outputting to the display for not.
- void **ILI9341_setMemAccessCtrl** (bool areRowsFlipped, bool areColsFlipped, bool areRowsAndCols↔ Switched, bool isVertRefreshFlipped, bool isColorOrderFlipped, bool isHorRefreshFlipped)

Set how data is converted from memory to display.
- void **ILI9341_setColorDepth** (colorDepth_t colorDepth)

Set the color depth for the display.
- void **ILI9341 setFrameRate** (uint8_t divisionRatio, uint8_t clocksPerLine)

TODO: Write brief.
- void **ILI9341_setRowAddress** (uint16_t startRow, uint16_t endRow)

Sets the start/end rows to be written to.
- void **ILI9341_setColAddress** (uint16_t startCol, uint16_t endCol)

Sets the start/end columns to be written to.
- void **ILI9341_writeMemCmd** (void)

Signal to the driver that pixel data is incoming and should be written to memory.
- void **ILI9341_writePixel** (uint8_t red, uint8_t green, uint8_t blue)

Write a single pixel to frame memory.

Variables

- static uint32_t **ILI9341_Buffer** [8]
- static Fifo_t **ILI9341_Fifo**
- struct {
 - sleepMode_t **sleepMode**
 - displayArea_t **displayArea**
 - colorExpr_t **colorExpression**
 - invertMode_t **invertMode**
 - outputMode_t **outputMode**
 - colorDepth_t **colorDepth**
 - bool **isInit**
- } **ili9341** = { SLEEP_ON, NORMAL_AREA, FULL_COLORS, INVERT_OFF, OUTPUT_ON, COLORDEPTH_16BIT, false }

4.3.3.1 Detailed Description

Functions for interfacing an ILI9341-based 240RGBx320 LCD via [Serial Peripheral Interface \(SPI\)](#).

4.3.3.2 Enumeration Type Documentation

anonymous enum

anonymous enum

Enumerator

ILI9341_NUM_COLS	4.3.3.3 of columns available on the display
ILI9341_NUM_ROWS	4.3.3.4 of rows available on the display

Cmd_t

enum [Cmd_t](#)

Enumerator

NOP	No Operation.
SWRESET	Software Reset.
SPLIN	Enter Sleep Mode.
SPLOUT	Sleep Out (i.e. Exit Sleep Mode)
PTLON	Partial Display Mode ON.
NORON	Normal Display Mode ON.
DINVOFF	Display Inversion OFF.
DINVON	Display Inversion ON.
CASET	Column Address Set.
PASET	Page Address Set.
RAMWR	Memory Write.
DISPOFF	Display OFF.
DISPON	Display ON.
PLTAR	Partial Area.
VSCRDEF	Vertical Scrolling Definition.
MADCTL	Memory Access Control.
VSCRSADD	Vertical Scrolling Start Address.
IDMOFF	Idle Mode OFF.
IDMON	Idle Mode ON.
PIXSET	Pixel Format Set.
FRMCTR1	Frame Rate Control Set (Normal Mode)

Enumerator

FRMCTR2	Frame Rate Control Set (Idle Mode)
FRMCTR3	Frame Rate Control Set (Partial Mode)
PRCTR	Blanking Porch Control.
IFCTL	Interface Control.

4.3.3.5 Function Documentation**ILI9341_setMode()**

```
static void ILI9341_setMode (
    uint8_t param ) [static]
```

This function simply groups each of the configuration functions into one to reduce code duplication.

ILI9341_setAddress()

```
static void ILI9341_setAddress (
    uint16_t start_address,
    uint16_t end_address,
    bool is_row ) [static]
```

This function implements the "Column Address Set" (CASET) and "Page Address Set" (PASET) commands from p. 110-113 of the ILI9341 datasheet.

The input parameters represent the first and last addresses to be written to when [ILI9341_writePixel\(\)](#) is called.

To work correctly, `startAddress` must be no greater than `endAddress`, and `endAddress` cannot be greater than the max number of rows/columns.

ILI9341_sendParams()

```
static void ILI9341_sendParams (
    Cmd_t cmd ) [static]
```

Send a command and/or the data within the FIFO buffer. A command is only sent when `cmd != NOP` (where `NOP = 0`). Data is only sent if the FIFO buffer is not empty.

Parameters

in	<i>cmd</i>	Command to send.
----	------------	------------------

ILI9341_Init()

```
void ILI9341_Init (
    Timer_t timer )
```

Initialize the LCD driver and the SPI module.

Parameters

in	<i>timer</i>	Hardware timer to use during initialization.
----	--------------	--

ILI9341_setInterface()

```
void ILI9341_setInterface (
    void )
```

Sets the interface for the ILI9341.

The parameters for this command are hard-coded, so it only needs to be called once upon initialization.

This function implements the "Interface Control" (IFCTL) command from p. 192-194 of the ILI9341 datasheet, which controls how the LCD driver handles 16-bit data and what interfaces (internal or external) are used.

Name	Bit #	Param #	Effect when set = 1
MY_EOR	7	0	flips value of corresponding MADCTL bit
MX_EOR	6		flips value of corresponding MADCTL bit
MV_EOR	5		flips value of corresponding MADCTL bit
BGR_EOR	3		flips value of corresponding MADCTL bit
WEMODE	0		overflowing pixel data is not ignored
EPF[1:0]	5:4	1	controls 16 to 18-bit pixel data conversion
MDT[1:0]	1:0		controls display data transfer method
ENDIAN	5	2	host sends LSB first
DM[1:0]	3:2		selects display operation mode
RM	1		selects GRAM interface mode
RIM	0		specifies RGB interface-specific details

The first param's bits are cleared so that the corresponding MADCTL bits (ILI9341_setMemoryAccessCtrl()) are unaffected and overflowing pixel data is ignored. The EPF bits are cleared so that the LSB of the R and B values is copied from the MSB when using 16-bit color depth. The TM4C123 sends the MSB first, so the ENDIAN bit is cleared. The other bits are cleared and/or irrelevant since the RGB and VSYNC interfaces aren't used.

ILI9341_resetHard()

```
void ILI9341_resetHard (
    Timer_t timer )
```

Perform a hardware reset of the LCD driver.

Parameters

in	<i>timer</i>	Hardware timer to use during reset.
----	--------------	-------------------------------------

The LCD driver's RESET pin requires a negative logic (i.e. active `LOW`) signal for ≥ 10 [us] and an additional 5 [ms] before further commands can be sent.

ILI9341_resetSoft()

```
void ILI9341_resetSoft (
    Timer_t timer )
```

Perform a software reset of the LCD driver.

Parameters

in	<i>timer</i>	Hardware timer to use during reset.
----	--------------	-------------------------------------

the driver needs 5 [ms] before another command

ILI9341_setSleepMode()

```
void ILI9341_setSleepMode (
    sleepMode_t sleepMode,
    Timer_t timer )
```

Enter or exit sleep mode (ON by default).

Parameters

in	<i>sleepMode</i>	SLEEP_ON or SLEEP_OFF
in	<i>timer</i>	Hardware timer to use for a slight delay after the mode change.

Postcondition

The IC will be in or out of sleep mode depending on the value of `sleepMode`.

The MCU must wait ≥ 5 [ms] before sending further commands regardless of the selected mode.

It's also necessary to wait 120 [ms] before sending `SPLOUT` after sending `SPLIN` or a reset, so this function waits 120 [ms] regardless of the preceding event.

ILI9341_setDisplayArea()

```
void ILI9341_setDisplayArea (
    displayArea_t displayArea )
```

Set the display area.

Precondition

If using partial mode, set the partial area first.

Parameters

in	<i>displayArea</i>	NORMAL_AREA or PARTIAL_AREA
----	--------------------	-----------------------------

See also

[ILI9341_setPartialArea\(\)](#)

ILI9341_setColorExpression()

```
void ILI9341_setColorExpression (
    colorExpr_t colorExpr )
```

Set the color expression (FULL_COLORS by default).

Parameters

in	<i>colorExpr</i>	FULL_COLORS or PARTIAL_COLORS
----	------------------	-------------------------------

Postcondition

With partial color expression, the display only uses 8 colors. Otherwise, the color depth determines the number of colors available.

ILI9341_setPartialArea()

```
void ILI9341_setPartialArea (
    uint16_t rowStart,
    uint16_t rowEnd )
```

Set the display area for partial mode. Call before activating partial mode.

Parameters

in	<i>rowStart</i>	
in	<i>rowEnd</i>	

See also

[ILI9341_setDisplayArea\(\)](#)

ILI9341_setDispInversion()

```
void ILI9341_setDispInversion (
    invertMode_t invertMode )
```

Toggle display inversion (OFF by default).

Parameters

in	<i>invertMode</i>	INVERT_ON or INVERT_OFF
----	-------------------	-------------------------

Postcondition

When inversion is ON, the display colors are inverted. (e.g. BLACK -> WHITE, GREEN -> PURPLE)

ILI9341_setDispOutput()

```
void ILI9341_setDispOutput (
    outputMode_t outputMode )
```

Change whether the IC is outputting to the display for not.

Parameters

in	<i>outputMode</i>	OUTPUT_ON or OUTPUT_OFF
----	-------------------	-------------------------

Postcondition

If ON, the IC outputs data from its memory to the display. If OFF, the display is cleared and the IC stops outputting data.

TODO: Write description

ILI9341_setMemAccessCtrl()

```
void ILI9341_setMemAccessCtrl (
    bool areRowsFlipped,
    bool areColsFlipped,
    bool areRowsAndColsSwitched,
    bool isVertRefreshFlipped,
    bool isColorOrderFlipped,
    bool isHorRefreshFlipped )
```

Set how data is converted from memory to display.

Parameters

in	<i>areRowsFlipped</i>	
in	<i>areColsFlipped</i>	
in	<i>areRowsAndColsSwitched</i>	
in	<i>isVertRefreshFlipped</i>	
in	<i>isColorOrderFlipped</i>	
in	<i>isHorRefreshFlipped</i>	

This function implements the "Memory Access Control" (MADCTL) command from p. 127-128 of the ILI9341

datasheet, which controls how the LCD driver displays data upon writing to memory.

Name	Bit #	Effect when set = 1
MY	7	flip row (AKA "page") addresses
MX	6	flip column addresses
MV	5	exchange rows and column addresses
ML	4	reverse horizontal refresh order
BGR	3	reverse color input order (RGB -> BGR)
MH	2	reverse vertical refresh order

All bits are clear after powering on or HWRESET.

ILI9341_setColorDepth()

```
void ILI9341_setColorDepth (
    colorDepth_t colorDepth )
```

Set the color depth for the display.

Parameters

in	<i>colorDepth</i>	COLORDEPTH_16BIT or COLORDEPTH_18BIT
----	-------------------	--------------------------------------

Postcondition

16BIT mode allows for ~65K (2^{16}) colors and requires 2 transfers. 18BIT mode allows for ~262K (2^{18}) colors but requires 3 transfers.

ILI9341_setFrameRate()

```
void ILI9341_setFrameRate (
    uint8_t divisionRatio,
    uint8_t clocksPerLine )
```

TODO: Write brief.

TODO: Write description

ILI9341_setRowAddress()

```
void ILI9341_setRowAddress (
    uint16_t startRow,
    uint16_t endRow )
```

Sets the start/end rows to be written to.

Parameters

in		
----	--	--

$0 \leq \text{startRow} \leq \text{endRow}$

Parameters

in		
----	--	--

$\text{startRow} \leq \text{endRow} \leq 240$

See also

[ILI9341_setRowAddress](#), [ILI9341_writePixel\(\)](#)

This function is simply an interface to [ILI9341_setAddress\(\)](#). To work correctly, `start_row` must be no greater than `end_row`, and `end_row` cannot be greater than the max row number (default 320).

ILI9341_setColAddress()

```
void ILI9341_setColAddress (
    uint16_t startCol,
    uint16_t endCol )
```

Sets the start/end columns to be written to.

Parameters

in		
----	--	--

$0 \leq \text{startCol} \leq \text{endCol}$

Parameters

in		
----	--	--

$\text{startCol} \leq \text{endCol} \leq 240$

See also

[ILI9341_setColAddress](#), [ILI9341_writePixel\(\)](#)

This function is simply an interface to [ILI9341_setAddress\(\)](#). To work correctly, `start_col` must be no greater than `end_col`, and `end_col` cannot be greater than the max column number (default 240).

ILI9341_writeMemCmd()

```
void ILI9341_writeMemCmd (
    void )
```

Signal to the driver that pixel data is incoming and should be written to memory.

Precondition

Set the row and/or column addresses.

Postcondition

The LCD driver is ready to accept pixel data.

See also

[ILI9341_setRowAddress](#), [ILI9341_setColAddress\(\)](#), [ILI9341_writePixel\(\)](#)

ILI9341_writePixel()

```
void ILI9341_writePixel (
    uint8_t red,
    uint8_t green,
    uint8_t blue )
```

Write a single pixel to frame memory.

Precondition

Send the "Write Memory" command.

Set the desired color depth for the display.

Parameters

in	<i>red</i>	5 or 6-bit R value
in	<i>green</i>	5 or 6-bit G value
in	<i>blue</i>	5 or 6-bit B value

See also

[ILI9341_setColorDepth](#), [ILI9341_writeMemCmd\(\)](#), [ILI9341_writePixel\(\)](#)

This function sends one pixel to the display. Because the serial interface (SPI) is used, each pixel requires 2 transfers in 16-bit mode and 3 transfers in 18-bit mode.

The following table (adapted from p. 63 of the datasheet) visualizes how the RGB data is sent to the display when using 16-bit color depth.

Transfer	1								2							
Bit #	7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0
Value	R4	R3	R2	R1	R0	G5	G4	G3	G2	G1	G0	B4	B3	B2	B1	B0

The following table (adapted from p. 64 of the datasheet) visualizes how the RGB data is sent to the display when using 18-bit color depth.

Transfer	1								2		
Bit #	7	6	5	4	3	2	1	0	7	6	...
Value	R5	R4	R3	R2	R1	R0	0/1	0/1	G5	G4	...

4.3.4 LED

Collaboration diagram for LED:



Files

- file [Led.c](#)
Source code for LED module.
- file [Led.h](#)
Interface for LED module.

Data Structures

- struct [Led_t](#)

Macros

- `#define LED_POOL_SIZE 1`

Variables

- static [LedStruct_t](#) **Led_ObjPool** [LED_POOL_SIZE] = { 0 }
- static uint8_t **num_free_leds** = LED_POOL_SIZE

Initialization & Configuration

- [Led_t](#) **Led_Init** (GpioPort_t gpioPort, GpioPin_t pin)
Initialize a light-emitting diode (LED) as an [Led_t](#).
- GpioPort_t **Led_GetPort** (Led_t led)
Get the GPIO port associated with the LED.
- GpioPin_t **Led_GetPin** (Led_t led)
Get the GPIO pin associated with the LED.

Status Checking

- bool `Led_isInit` (Led_t led)
Check if an LED is initialized.
- bool `Led_isOn` (Led_t led)
Check the LED's status.

Operations

- void `Led_TurnOn` (Led_t led)
Turn an LED ON.
- void `Led_TurnOff` (Led_t led)
Turn an LED OFF.
- void `Led_Toggle` (Led_t led)
Toggle an LED.

4.3.4.1 Detailed Description

Functions for driving light-emitting diodes (LEDs) via [General-Purpose Input/Output \(GPIO\)](#).

4.3.4.2 Function Documentation

Led_Init()

```
Led_t Led_Init (
    GpioPort_t gpioPort,
    GpioPin_t pin )
```

Initialize a light-emitting diode (LED) as an `Led_t`.

Parameters

in	<i>gpioPort</i>	Pointer to a <code>struct</code> representing a GPIO port.
in	<i>pin</i>	GPIO pin to use.
out	<i>led</i>	Pointer to LED data structure.

Led_GetPort()

```
GpioPort_t Led_GetPort (
    Led_t led )
```

Get the GPIO port associated with the LED.

Precondition

Initialize the LED.

Parameters

in	<i>led</i>	Pointer to LED data structure.
out	<i>gpioPort</i>	Pointer to a GPIO port data structure.

See also

[Led_Init\(\)](#), [Led_GetPin\(\)](#)

Led_GetPin()

```
GpioPin_t Led_GetPin (  
    Led_t led )
```

Get the GPIO pin associated with the LED.

Precondition

Initialize the LED.

Parameters

in	<i>led</i>	Pointer to LED data structure.
out	<i>pin</i>	GPIO pin associated with the LED.

See also

[Led_Init\(\)](#), [Led_GetPort\(\)](#)

Led_isInit()

```
bool Led_isInit (  
    Led_t led )
```

Check if an LED is initialized.

Parameters

in	<i>led</i>	Pointer to LED data structure.
out	<i>true</i>	The LED is initialized.
out	<i>false</i>	The LED is not initialized.

See also

[Led_Init\(\)](#)

Led_isOn()

```
bool Led_isOn (
    Led_t led )
```

Check the LED's status.

Precondition

Initialize the LED.

Parameters

in	<i>led</i>	Pointer to LED data structure.
out	<i>true</i>	the LED is ON.
out	<i>false</i>	the LED is OFF.

See also

[Led_TurnOn\(\)](#), [Led_TurnOff\(\)](#), [Led_Toggle\(\)](#)

Led_TurnOn()

```
void Led_TurnOn (
    Led_t led )
```

Turn an LED ON.

Precondition

Initialize the LED.

Parameters

in	<i>led</i>	Pointer to LED data structure.
----	------------	--------------------------------

Postcondition

The LED is turned ON.

See also

[Led_TurnOff\(\)](#), [Led_Toggle\(\)](#)

Led_TurnOff()

```
void Led_TurnOff (
    Led_t led )
```

Turn an LED OFF.

Precondition

Initialize the LED.

Parameters

in	<i>led</i>	Pointer to LED data structure.
----	------------	--------------------------------

Postcondition

The LED is turned OFF.

See also

[Led_TurnOn\(\)](#), [Led_Toggle\(\)](#)

Led_Toggle()

```
void Led_Toggle (
    Led_t led )
```

Toggle an LED.

Precondition

Initialize the LED.

Parameters

in	<i>led</i>	Pointer to LED data structure.
----	------------	--------------------------------

Postcondition

The LED's state is flipped (i.e. ON -> OFF or OFF -> ON).

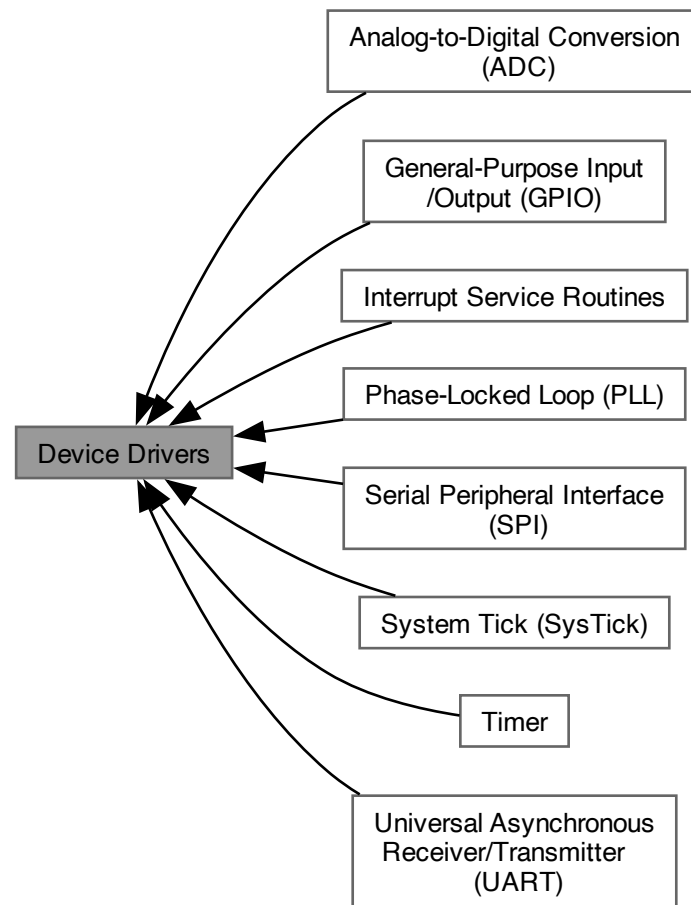
See also

[Led_TurnOn\(\)](#), [Led_TurnOff\(\)](#)

4.4 Device Drivers

Low level device driver modules.

Collaboration diagram for Device Drivers:



Modules

- [Analog-to-Digital Conversion \(ADC\)](#)
- [General-Purpose Input/Output \(GPIO\)](#)
- [Phase-Locked Loop \(PLL\)](#)
- [Serial Peripheral Interface \(SPI\)](#)
- [System Tick \(SysTick\)](#)
- [Timer](#)
- [Universal Asynchronous Receiver/Transmitter \(UART\)](#)
- [Interrupt Service Routines](#)

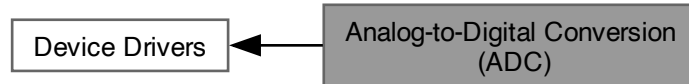
4.4.1 Detailed Description

Low level device driver modules.

These modules contain functions for interfacing with the TM4C123 microcontroller's built-in peripherals.

4.4.2 Analog-to-Digital Conversion (ADC)

Collaboration diagram for Analog-to-Digital Conversion (ADC):



Files

- file [ADC.c](#)
Source code for analog-to-digital conversion (ADC) module.
- file [ADC.h](#)
Header file for analog-to-digital conversion (ADC) module.

Functions

- void [ADC_Init](#) (void)
Initialize ADC0 as a single-input analog-to-digital converter.

4.4.2.1 Detailed Description

Functions for differential-input analog-to-digital conversion.

4.4.2.2 Function Documentation

ADC_Init()

```
void ADC_Init (  
    void )
```

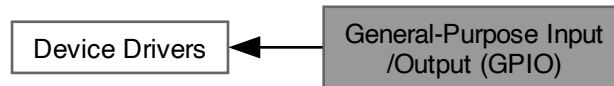
Initialize ADC0 as a single-input analog-to-digital converter.

Postcondition

Analog input 8 (Ain8) – AKA GPIO pin PE5 – captures samples when triggered by one of the hardware timers, and initiates an interrupt once sample capture is complete.

4.4.3 General-Purpose Input/Output (GPIO)

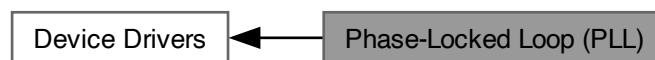
Collaboration diagram for General-Purpose Input/Output (GPIO):



Functions for using general-purpose input/output (GPIO) ports.

4.4.4 Phase-Locked Loop (PLL)

Collaboration diagram for Phase-Locked Loop (PLL):



Files

- file [PLL.c](#)
Implementation details for phase-lock-loop (PLL) functions.
- file [PLL.h](#)
Driver module for activating the phase-locked-loop (PLL).

Functions

- void [PLL_Init](#) (void)
Initialize the phase-locked-loop to change the bus frequency.

4.4.4.1 Detailed Description

Function for initializing the phase-locked loop.

4.4.4.2 Function Documentation

PLL_Init()

```
void PLL_Init (
    void )
```

Initialize the phase-locked-loop to change the bus frequency.

Postcondition

The bus frequency is now running at 80 [MHz].

4.4.5 Serial Peripheral Interface (SPI)

Collaboration diagram for Serial Peripheral Interface (SPI):



Files

- file [SPI.c](#)
Source code for serial peripheral interface (SPI) module.
- file [SPI.h](#)
Header file for serial peripheral interface (SPI) module.

Macros

- `#define SPI_IS_BUSY (SSI0_SR_R & 0x10)`
- `#define SPI_TX_ISNOTFULL (SSI0_SR_R & 0x02)`
- `#define SPI_CLEAR_RESET() (GPIO_PORTA_DATA_R &= ~(0x80))`
- `#define SPI_SET_RESET() (GPIO_PORTA_DATA_R |= 0x80)`

Enumerations

- enum {
SPI_CLK_PIN = GPIO_PIN2 , **SPI_CS_PIN** = GPIO_PIN3 , **SPI_RX_PIN** = GPIO_PIN4 , **SPI_TX_PIN** = GPIO_PIN5 ,
SPI_DC_PIN = GPIO_PIN6 , **SPI_RESET_PIN** = GPIO_PIN7 , **SPI_SSI0_PINS** = (SPI_CLK_PIN | SPI_CS_PIN | SPI_RX_PIN | SPI_TX_PIN) , **SPI_GPIO_PINS** = (SPI_DC_PIN | SPI_RESET_PIN) ,
SPI_ALL_PINS = (SPI_SSI0_PINS | SPI_GPIO_PINS) }

Functions

- void `SPI_Init` (void)
Initialize SSI0 to act as an SPI Controller (AKA Master) in mode 0.
- uint8_t `SPI_Read` (void)
Read data from the serial port.
- void `SPI_WriteCmd` (uint8_t cmd)
Write a command to the serial port.
- void `SPI_WriteData` (uint8_t data)
Write data to the serial port.

Variables

- static register_t `gpioPortReg` = 0

4.4.5.1 Detailed Description

Functions for SPI-based communication via SSI0 peripheral.

4.4.5.2 Function Documentation

`SPI_Init()`

```
void SPI_Init (
    void )
```

Initialize SSI0 to act as an SPI Controller (AKA Master) in mode 0.

The bit rate `BR` is set using the (positive, even-numbered) clock prescale divisor `CPSDVSR` and the `SCR` field in the SSI Control 0 (`CR0`) register:

$$BR = f_{bus} / (CPSDVSR * (1 + SCR))$$

The ILI9341 driver has a min. read cycle of 150 [ns] and a min. write cycle of 100 [ns], so the bit rate `BR` is set to be equal to the bus frequency ($f_{bus} = 80[MHz]$) divided by 8, allowing a bit rate of 10 [MHz], or a period of 100 [ns].

`SPI_Read()`

```
uint8_t SPI_Read (
    void )
```

Read data from the serial port.

Precondition

Initialize the SPI module.

Parameters

out	<i>data</i>	8-bit data received from the hardware's receive FIFO.
-----	-------------	---

SPI_WriteCmd()

```
void SPI_WriteCmd (
    uint8_t cmd )
```

Write a command to the serial port.

Precondition

Initialize the SPI module.

Parameters

in	<i>cmd</i>	8-bit command to write.
----	------------	-------------------------

Postcondition

The D/C pin is cleared.

The data is added to the hardware's transmit FIFO.

SPI_WriteData()

```
void SPI_WriteData (
    uint8_t data )
```

Write data to the serial port.

Precondition

Initialize the SPI module.

Parameters

in	<i>data</i>	8-bit data to write.
----	-------------	----------------------

Postcondition

The D/C pin is set.

The data is added to the hardware's transmit FIFO.

4.4.6 System Tick (SysTick)

Collaboration diagram for System Tick (SysTick):

**Files**

- file [SysTick.c](#)
Implementation details for SysTick functions.
- file [SysTick.h](#)
Driver module for using SysTick-based timing and/or interrupts.

Functions

- void **SysTick_Timer_Init** (void)
Initialize SysTick for timing purposes.
- void **SysTick_Wait1ms** (uint32_t delay_ms)
Delay for specified amount of time in [ms]. Assumes f_bus = 80[MHz].
- void [SysTick_Interrupt_Init](#) (uint32_t time_ms)
Initialize SysTick for interrupts.

4.4.6.1 Detailed Description

Functions for timing and periodic interrupts via SysTick.

4.4.6.2 Function Documentation**SysTick_Interrupt_Init()**

```
void SysTick_Interrupt_Init (  
    uint32_t time_ms )
```

Initialize SysTick for interrupts.

Parameters

<code>time_ms</code>	Time in [ms] between interrupts. Cannot be more than 200[ms].
----------------------	---

4.4.7 Timer

Collaboration diagram for Timer:



Files

- file [Timer.c](#)
Source code for Timer module.
- file [Timer.h](#)
Device driver for general-purpose timer modules.

Data Structures

- struct [Timer_t](#)

Enumerations

- enum {
 TIMER0_BASE = 0x40030000 , **TIMER1_BASE** = 0x40031000 , **TIMER2_BASE** = 0x40032000 , **TIMER3**
 _BASE = 0x40033000 ,
 TIMER4_BASE = 0x40034000 , **TIMER5_BASE** = 0x40035000 }
- enum **REGISTER_OFFSETS** {
 CONFIG = 0x00 , **MODE** = 0x04 , **CTRL** = 0x0C , **INT_MASK** = 0x18 ,
 INT_CLEAR = 0x24 , **INTERVAL** = 0x28 , **VALUE** = 0x054 }
- enum **timerName_t** {
 TIMER0 , **TIMER1** , **TIMER2** , **TIMER3** ,
 TIMER4 , **TIMER5** }
- enum [timerMode_t](#) { [ONESHOT](#) , [PERIODIC](#) }
- enum [timerDirection_t](#) { [UP](#) , [DOWN](#) }

Functions

- `Timer_t Timer_Init` (timerName_t timerName)
Initialize a hardware timer.
- `void Timer_Deinit` (Timer_t timer)
De-initialize a hardware timer.
- `timerName_t Timer_getName` (Timer_t timer)
Get the name of a timer object.
- `bool Timer_isInit` (Timer_t timer)
Check if a timer object is initialized.
- `void Timer_setMode` (Timer_t timer, timerMode_t timerMode, timerDirection_t timerDirection)
Set the mode for the timer.
- `void Timer_enableAdcTrigger` (Timer_t timer)
Set the timer to trigger ADC sample capture once it reaches timeout (i.e. down to 0 or up to its reload value).
- `void Timer_disableAdcTrigger` (Timer_t timer)
Disable ADC sample capture on timeout.
- `void Timer_enableInterruptOnTimeout` (Timer_t timer)
Set the timer to trigger an interrupt on timeout.
- `void Timer_disableInterruptOnTimeout` (Timer_t timer)
Stop the timer from triggering interrupts on timeout.
- `void Timer_clearInterruptFlag` (Timer_t timer)
Clear the timer's interrupt flag to acknowledge the interrupt.
- `void Timer_setInterval_ms` (Timer_t timer, uint32_t time_ms)
Set the interval to use.
- `uint32_t Timer_getCurrentValue` (Timer_t timer)
- `void Timer_Start` (Timer_t timer)
Start the timer.
- `void Timer_Stop` (Timer_t timer)
Stop the timer.
- `bool Timer_isCounting` (Timer_t timer)
Check if the timer is currently counting.
- `void Timer_Wait1ms` (Timer_t timer, uint32_t time_ms)
Initiate a time delay.

Variables

- `static TimerStruct_t TIMER_POOL` [6]

4.4.7.1 Detailed Description

Functions for timing and periodic interrupts via general-purpose timer modules (GPTM).

4.4.7.2 Enumeration Type Documentation

timerMode_t

```
enum timerMode_t
```

Enumerator

ONESHOT	the timer runs once, then stops
PERIODIC	the timer runs continuously once started

timerDirection_t

```
enum timerDirection_t
```

Enumerator

UP	the timer starts and 0 and counts to the reload value
DOWN	the timer starts at its reload value and counts down

4.4.7.3 Function Documentation**Timer_Init()**

```
Timer_t Timer_Init (
    timerName_t timerName )
```

Initialize a hardware timer.

Parameters

in	<i>timerName</i>	Name of the hardware timer to use.
out	<i>timer</i>	Pointer to timer object.

Postcondition

The timer is ready to be configured and used.

See also

[Timer_isInit\(\)](#), [Timer_Deinit\(\)](#)

Timer_Deinit()

```
void Timer_Deinit (
    Timer_t timer )
```

De-initialize a hardware timer.

Parameters

in	<i>timerName</i>	Name of the hardware timer to use.
----	------------------	------------------------------------

Postcondition

The hardware timer is no longer initialized or receiving power.

See also

[Timer_Init\(\)](#), [Timer_isInit\(\)](#)

Timer_getName()

```
timerName_t Timer_getName (
    Timer_t timer )
```

Get the name of a timer object.

Parameters

in	<i>timer</i>	Pointer to timer object.
out	<i>timer</i> ↔ <i>Name_t</i>	Name of the hardware timer being used.

Timer_isInit()

```
bool Timer_isInit (
    Timer_t timer )
```

Check if a timer object is initialized.

Parameters

in	<i>timer</i>	Pointer to timer object.
out	<i>true</i>	The timer is initialized.
out	<i>false</i>	The timer is not initialized.

See also

[Timer_Init\(\)](#), [Timer_Deinit\(\)](#)

Timer_setMode()

```
void Timer_setMode (
    Timer_t timer,
    timerMode_t timerMode,
    timerDirection_t timerDirection )
```

Set the mode for the timer.

Parameters

in	<i>timer</i>	Pointer to timer object.
in	<i>timerMode</i>	Mode for hardware timer to use.
in	<i>timerDirection</i>	Direction to count towards.

Timer_enableAdcTrigger()

```
void Timer_enableAdcTrigger (
    Timer_t timer )
```

Set the timer to trigger ADC sample capture once it reaches timeout (i.e. down to 0 or up to its reload value).

Precondition

Initialize and configure an ADC module to be timer-triggered.

Parameters

in	<i>timer</i>	Pointer to timer object.
----	--------------	--------------------------

Postcondition

A timeout event triggers ADC sample capture.

See also

[Timer_disableAdcTrigger\(\)](#)

Timer_disableAdcTrigger()

```
void Timer_disableAdcTrigger (
    Timer_t timer )
```

Disable ADC sample capture on timeout.

Precondition

Initialize and configure an ADC module to be timer-triggered.

Parameters

in	<i>timer</i>	Pointer to timer object.
----	--------------	--------------------------

Postcondition

A timeout event no longer triggers ADC sample capture.

See also

[Timer_enableAdcTrigger\(\)](#)

Timer_enableInterruptOnTimeout()

```
void Timer_enableInterruptOnTimeout (
    Timer_t timer )
```

Set the timer to trigger an interrupt on timeout.

Precondition

Configure the interrupt service routine using the ISR module.

Parameters

in	<i>timer</i>	Pointer to timer object.
----	--------------	--------------------------

Postcondition

Upon timeout, an interrupt is triggered.

See also

[Timer_disableInterruptOnTimeout\(\)](#)

Timer_disableInterruptOnTimeout()

```
void Timer_disableInterruptOnTimeout (
    Timer_t timer )
```

Stop the timer from triggering interrupts on timeout.

Parameters

in	<i>timer</i>	Pointer to timer object.
----	--------------	--------------------------

Postcondition

Timeout no longer triggers ADC sample capture.

See also

[Timer_enableInterruptOnTimeout\(\)](#)

Timer_clearInterruptFlag()

```
void Timer_clearInterruptFlag (
    Timer_t timer )
```

Clear the timer's interrupt flag to acknowledge the interrupt.

Precondition

Call this during a timer's interrupt service routine (ISR).

Parameters

in	<i>timer</i>	Pointer to timer object.
----	--------------	--------------------------

Timer_setInterval_ms()

```
void Timer_setInterval_ms (
    Timer_t timer,
    uint32_t time_ms )
```

Set the interval to use.

Precondition

Initialize and configure the timer.

Parameters

in	<i>timer</i>	Pointer to timer object.
in	<i>time_ms</i>	Time in [ms].

Postcondition

Upon starting, the Timer counts down from or up to this value.

See also

[Timer_Init\(\)](#), [Timer_setMode\(\)](#)

Timer_Start()

```
void Timer_Start (
    Timer_t timer )
```

Start the timer.

Precondition

Initialize and configure the timer.

Parameters

in	<i>timer</i>	Pointer to timer object.
----	--------------	--------------------------

Postcondition

The timer is counting.

See also

[Timer_Stop\(\)](#), [Timer_isCounting\(\)](#)

Timer_Stop()

```
void Timer_Stop (
    Timer_t timer )
```

Stop the timer.

Precondition

Start the timer.

Parameters

in	<i>timer</i>	Pointer to timer object.
----	--------------	--------------------------

Postcondition

The timer is no longer counting.

See also

[Timer_Start\(\)](#), [Timer_isCounting\(\)](#)

Timer_isCounting()

```
bool Timer_isCounting (
    Timer_t timer )
```

Check if the timer is currently counting.

Parameters

in	<i>timer</i>	Pointer to timer object.
out	<i>true</i>	The timer is counting.
out	<i>false</i>	The timer is not counting.

See also

[Timer_Start\(\)](#), [Timer_Stop\(\)](#)

Timer_Wait1ms()

```
void Timer_Wait1ms (
    Timer_t timer,
    uint32_t time_ms )
```

Initiate a time delay.

Precondition

Initialize and configure the timer.

Parameters

in	<i>timer</i>	Pointer to timer object.
in	<i>time_ms</i>	Time in [ms] to wait for.

Postcondition

The program is delayed for the desired time.

4.4.7.4 Variable Documentation**TIMER_POOL**

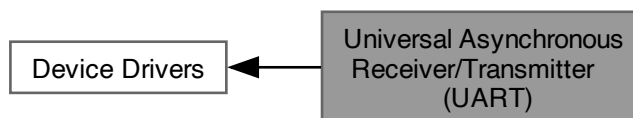
```
TimerStruct_t TIMER_POOL[6] [static]
```

Initial value:

```
= {
    { TIMER0, TIMER0_BASE, (register_t) (TIMER0_BASE + CTRL), (register_t) (TIMER0_BASE + INTERVAL),
      (register_t) (TIMER0_BASE + INT_CLEAR), false },
    { TIMER1, TIMER1_BASE, (register_t) (TIMER1_BASE + CTRL), (register_t) (TIMER1_BASE + INTERVAL),
      (register_t) (TIMER1_BASE + INT_CLEAR), false },
    { TIMER2, TIMER2_BASE, (register_t) (TIMER2_BASE + CTRL), (register_t) (TIMER2_BASE + INTERVAL),
      (register_t) (TIMER2_BASE + INT_CLEAR), false },
    { TIMER3, TIMER3_BASE, (register_t) (TIMER3_BASE + CTRL), (register_t) (TIMER3_BASE + INTERVAL),
      (register_t) (TIMER3_BASE + INT_CLEAR), false },
    { TIMER4, TIMER4_BASE, (register_t) (TIMER4_BASE + CTRL), (register_t) (TIMER4_BASE + INTERVAL),
      (register_t) (TIMER4_BASE + INT_CLEAR), false },
    { TIMER5, TIMER5_BASE, (register_t) (TIMER5_BASE + CTRL), (register_t) (TIMER5_BASE + INTERVAL),
      (register_t) (TIMER5_BASE + INT_CLEAR), false }
}
```


4.4.8 Universal Asynchronous Receiver/Transmitter (UART)

Collaboration diagram for Universal Asynchronous Receiver/Transmitter (UART):



Files

- file [UART.c](#)
Source code for UART module.
- file [UART.h](#)
Driver module for serial communication via UART0 and UART 1.

Data Structures

- struct [Uart_t](#)

Macros

- `#define ASCII_CONVERSION 0x30`

Enumerations

- enum **GPIO_BASE_ADDRESSES** {
GPIO_PORTA_BASE = (uint32_t) 0x40004000 , **GPIO_PORTB_BASE** = (uint32_t) 0x40005000 , **GPIO_PORTC_BASE** = (uint32_t) 0x40006000 , **GPIO_PORTD_BASE** = (uint32_t) 0x40007000 ,
GPIO_PORTE_BASE = (uint32_t) 0x40024000 , **GPIO_PORTF_BASE** = (uint32_t) 0x40025000 }
- enum **UART_BASE_ADDRESSES** {
UART0_BASE = (uint32_t) 0x4000C000 , **UART1_BASE** = (uint32_t) 0x4000D000 , **UART2_BASE** = (uint32_t) 0x4000E000 , **UART3_BASE** = (uint32_t) 0x4000F000 ,
UART4_BASE = (uint32_t) 0x40010000 , **UART5_BASE** = (uint32_t) 0x40011000 , **UART6_BASE** = (uint32_t) 0x40012000 , **UART7_BASE** = (uint32_t) 0x40013000 }
- enum **UART_REG_OFFSETS** {
UART_FR_R_OFFSET = (uint32_t) 0x18 , **IBRD_R_OFFSET** = (uint32_t) 0x24 , **FBRD_R_OFFSET** = (uint32_t) 0x28 , **LCRH_R_OFFSET** = (uint32_t) 0x2C ,
CTL_R_OFFSET = (uint32_t) 0x30 , **CC_R_OFFSET** = (uint32_t) 0xFC8 }
- enum **uartNum_t** {
UART0 , **UART1** , **UART2** , **UART3** ,
UART4 , **UART5** , **UART6** , **UART7** }

Functions

- `Uart_t UART_Init` (GpioPort_t port, uartNum_t uartNum)
Initialize the specified UART peripheral.
- `bool UART_IsInit` (Uart_t uart)
Check if the UART object is initialized.
- `unsigned char UART_ReadChar` (Uart_t uart)
Read a single ASCII character from the UART.
- `void UART_WriteChar` (Uart_t uart, unsigned char inputChar)
Write a single character to the UART.
- `void UART_WriteStr` (Uart_t uart, void *inputStr)
Write a C string to the UART.
- `void UART_WriteInt` (Uart_t uart, int32_t n)
Write a 32-bit unsigned integer the UART.
- `void UART_WriteFloat` (Uart_t uart, double n, uint8_t numDecimals)
Write a floating-point number the UART.

Variables

- static `UartStruct_t UART_ARR` [8]

4.4.8.1 Detailed Description

Functions for UART-based communication.

4.4.8.2 Function Documentation

UART_Init()

```
Uart_t UART_Init (
    GpioPort_t port,
    uartNum_t uartNum )
```

Initialize the specified UART peripheral.

Parameters

in	<i>port</i>	GPIO port to use.
in	<i>uartNum</i>	UART number. Should be either one of the enumerated constants or an int in range [0, 7].
out	<i>uart</i>	(Pointer to) initialized UART peripheral.

Given the bus frequency (f_{bus}) and desired baud rate (BR), the baud rate divisor (BRD) can be calculated:
 $BRD = f_{bus} / (16 * BR)$

The integer BRD ($IBRD$) is simply the integer part of the BRD: $IBRD = int(BRD)$

The fractional BRD ($FBRD$) is calculated using the fractional part ($mod(BRD, 1)$) of the BRD: $FBRD = int((mod(BRD, 1) * 64) + 0.5)$

UART_isInit()

```
bool UART_isInit (
    Uart_t uart )
```

Check if the UART object is initialized.

Parameters

in	<i>uart</i>	UART to check.
out	<i>true</i>	The UART object is initialized.
out	<i>false</i>	The UART object is not initialized.

UART_ReadChar()

```
unsigned char UART_ReadChar (
    Uart_t uart )
```

Read a single ASCII character from the UART.

Parameters

in	<i>uart</i>	UART to read from.
out	<i>unsigned</i>	char ASCII character from sender.

UART_WriteChar()

```
void UART_WriteChar (
    Uart_t uart,
    unsigned char inputChar )
```

Write a single character to the UART.

Parameters

in	<i>uart</i>	UART to write to.
in	<i>input_char</i>	ASCII character to send.

UART_WriteStr()

```
void UART_WriteStr (
    Uart_t uart,
    void * inputStr )
```

Write a C string to the UART.

Parameters

in	<i>uart</i>	UART to write to.
in	<i>input_str</i>	Array of ASCII characters.

UART_WriteInt()

```
void UART_WriteInt (
    Uart_t uart,
    int32_t n )
```

Write a 32-bit unsigned integer the UART.

Parameters

in	<i>uart</i>	UART to write to.
in	<i>n</i>	Unsigned 32-bit <code>int</code> to be converted and transmitted.

UART_WriteFloat()

```
void UART_WriteFloat (
    Uart_t uart,
    double n,
    uint8_t numDecimals )
```

Write a floating-point number the UART.

Parameters

in	<i>uart</i>	UART to write to.
in	<i>n</i>	Floating-point number to be converted and transmitted.
in	<i>num_decimals</i>	Number of digits after the decimal point to include.

4.4.8.3 Variable Documentation**UART_ARR**

```
UartStruct_t UART_ARR[8] [static]
```

Initial value:

```
= {
    { UART0_BASE, ((register_t) (UART0_BASE + UART_FR_R_OFFSET)), 0, GPIO_PIN0, GPIO_PIN1, false },
    { UART1_BASE, ((register_t) (UART1_BASE + UART_FR_R_OFFSET)), 0, GPIO_PIN0, GPIO_PIN1, false },
    { UART2_BASE, ((register_t) (UART2_BASE + UART_FR_R_OFFSET)), 0, GPIO_PIN6, GPIO_PIN7, false },
    { UART3_BASE, ((register_t) (UART3_BASE + UART_FR_R_OFFSET)), 0, GPIO_PIN6, GPIO_PIN7, false },
    { UART4_BASE, ((register_t) (UART4_BASE + UART_FR_R_OFFSET)), 0, GPIO_PIN4, GPIO_PIN5, false },
    { UART5_BASE, ((register_t) (UART5_BASE + UART_FR_R_OFFSET)), 0, GPIO_PIN4, GPIO_PIN5, false },
    { UART6_BASE, ((register_t) (UART6_BASE + UART_FR_R_OFFSET)), 0, GPIO_PIN4, GPIO_PIN5, false },
    { UART7_BASE, ((register_t) (UART7_BASE + UART_FR_R_OFFSET)), 0, GPIO_PIN0, GPIO_PIN1, false }
}
```

4.4.9 Interrupt Service Routines

Collaboration diagram for Interrupt Service Routines:



Files

- file [ISR.c](#)
Source code for interrupt service routine (ISR) configuration module.
- file [ISR.h](#)
Header file for interrupt service routine (ISR) configuration module.

Macros

- `#define VECTOR_TABLE_BASE_ADDR ((uint32_t) 0x00000000)`
- `#define VECTOR_TABLE_SIZE ((uint32_t) 155)`
- `#define VECTOR_TABLE_ALIGNMENT ((uint32_t) (1 << 10))`
- `#define NVIC_EN_BASE_ADDR ((uint32_t) 0xE000E100)`
- `#define NVIC_DIS_BASE_ADDR ((uint32_t) 0xE000E180)`
- `#define NVIC_PRI_BASE_ADDR ((uint32_t) 0xE000E400)`
- `#define NVIC_UNPEND_BASE_ADDR ((uint32_t) 0xE000E280)`

Typedefs

- `typedef void(* ISR_t) (void)`
Type definition for function pointers representing ISRs.

Functions

- static void **ISR_setStatus** (const uint8_t vectorNum, const bool isEnabled)
- void [ISR_GlobalDisable](#) (void)
Disable all interrupts globally.
- void [ISR_GlobalEnable](#) (void)
Enable all interrupts globally.
- static [ISR_t](#) newVectorTable[VECTOR_TABLE_SIZE] `__attribute__((aligned(VECTOR_TABLE_ALIGNMENT)))`
- void [ISR_InitNewTableInRam](#) (void)
Relocate the vector table to RAM.
- void [ISR_addToIntTable](#) ([ISR_t](#) isr, const uint8_t vectorNum)
Add an ISR to the interrupt table.
- void [ISR_setPriority](#) (const uint8_t vectorNum, const uint8_t priority)

Set the priority for an interrupt.

- void [ISR_Enable](#) (const uint8_t vectorNum)

Enable an interrupt in the NVIC.

- void [ISR_Disable](#) (const uint8_t vectorNum)

Disable an interrupt in the NVIC.

- void [ISR_triggerInterrupt](#) (const uint8_t vectorNum)

Generate a software-generated interrupt (SGI).

Variables

- static bool **interruptsAreEnabled** = true
- void(*const **interruptVectorTable** [])(void)
- static bool **isTableCopiedToRam** = false

4.4.9.1 Detailed Description

Functions for manipulating the interrupt vector table and setting up interrupt handlers via the NVIC.

4.4.9.2 Function Documentation

ISR_GlobalDisable()

```
void ISR_GlobalDisable (  
    void )
```

Disable all interrupts globally.

See also

[ISR_GlobalEnable\(\)](#)

ISR_GlobalEnable()

```
void ISR_GlobalEnable (  
    void )
```

Enable all interrupts globally.

See also

[ISR_GlobalDisable\(\)](#)

ISR_InitNewTableInRam()

```
void ISR_InitNewTableInRam (
    void )
```

Relocate the vector table to RAM.

Precondition

Disable interrupts globally before calling this.

Postcondition

The vector table is now located in RAM, allowing the ISRs listed in the startup file to be replaced.

See also

[ISR_GlobalDisable\(\)](#), [ISR_addToIntTable\(\)](#)

ISR_addToIntTable()

```
void ISR_addToIntTable (
    ISR_t isr,
    const uint8_t vectorNum )
```

Add an ISR to the interrupt table.

Precondition

Initialize a new vector table in RAM before calling this function.

Parameters

in	<i>isr</i>	Name of the ISR to add.
in	<i>vectorNum</i>	ISR's vector number (i.e. offset from the top of the table). Should be in range [16, 154].

Postcondition

The ISR is now added to the vector table and available to be called.

See also

[ISR_InitNewTableInRam\(\)](#)

ISR_setPriority()

```
void ISR_setPriority (
    const uint8_t vectorNum,
    const uint8_t priority )
```

Set the priority for an interrupt.

Precondition

Disable the interrupt before adjusting its priority.

Parameters

in	<i>vectorNum</i>	ISR's vector number (i.e. offset from the top of the table). Should be in range [16, 154].
in	<i>priority</i>	Priority to assign. Highest priority is 0, lowest is 7.

Postcondition

The interrupt's priority has now been changed in the NVIC.

See also

[ISR_Disable\(\)](#)

ISR_Enable()

```
void ISR_Enable (
    const uint8_t vectorNum )
```

Enable an interrupt in the NVIC.

Precondition

If needed, add the interrupt to the vector table.

If needed, set the interrupt's priority (default 0, or highest priority) before calling this.

Parameters

in	<i>vectorNum</i>	ISR's vector number (i.e. offset from the top of the table). Should be in range [16, 154].
----	------------------	--

Postcondition

The interrupt is now enabled in the NVIC.

See also

[ISR_addToIntTable\(\)](#), [ISR_setPriority\(\)](#), [ISR_Disable\(\)](#)

ISR_Disable()

```
void ISR_Disable (
    const uint8_t vectorNum )
```

Disable an interrupt in the NVIC.

Parameters

<code>in</code>	<code>vectorNum</code>	ISR's vector number (i.e. offset from the top of the table). Should be in range [16, 154].
-----------------	------------------------	--

Postcondition

The interrupt is now disabled in the NVIC.

See also

[ISR_Enable\(\)](#)

ISR_triggerInterrupt()

```
void ISR_triggerInterrupt (
    const uint8_t vectorNum )
```

Generate a software-generated interrupt (SGI).

Precondition

Enable the ISR (and set priority as needed).

Enable all interrupts.

Parameters

<code>in</code>	<code>vectorNum</code>	ISR's vector number (i.e. offset from the top of the table). Should be in range [16, 154].
-----------------	------------------------	--

Postcondition

The ISR should trigger once any higher priority ISRs return.

See also

[ISR_clearPending\(\)](#)

5 Data Structure Documentation

5.1 Fifo_t Struct Reference

Data Fields

- volatile uint32_t * **buffer**
(pointer to) array to use as FIFO buffer
- volatile uint32_t **N**
length of buffer

- volatile uint32_t **frontIdx**
idx of front of FIFO
- volatile uint32_t **backIdx**
idx of back of FIFO

The documentation for this struct was generated from the following file:

- [Fifo.c](#)

5.2 GpioPort_t Struct Reference

Data Fields

- const uint32_t **BASE_ADDRESS**
- const uint32_t **DATA_REGISTER**
- bool **isInit**

The documentation for this struct was generated from the following file:

- [GPIO.c](#)

5.3 Led_t Struct Reference

Data Fields

- GpioPort_t **GPIO_PORT_PTR**
pointer to GPIO port data structure
- GpioPin_t **GPIO_PIN**
GPIO pin number.
- volatile uint32_t * **gpioDataRegister**
- bool **isOn**
state indicator
- bool **isInit**

The documentation for this struct was generated from the following file:

- [Led.c](#)

5.4 Timer_t Struct Reference

Data Fields

- const timerName_t **NAME**
- const uint32_t **BASE_ADDR**
- register_t **controlRegister**
- register_t **intervalLoadRegister**
- register_t **interruptClearRegister**
- bool **isInit**

The documentation for this struct was generated from the following file:

- [Timer.c](#)

5.5 Uart_t Struct Reference

Data Fields

- const uint32_t **BASE_ADDRESS**
- register_t **FLAG_R_ADDRESS**
- GpioPort_t **GPIO_PORT**
pointer to GPIO port data structure
- GpioPin_t **RX_PIN_NUM**
GPIO pin number.
- GpioPin_t **TX_PIN_NUM**
GPIO pin number.
- bool **isInit**

The documentation for this struct was generated from the following file:

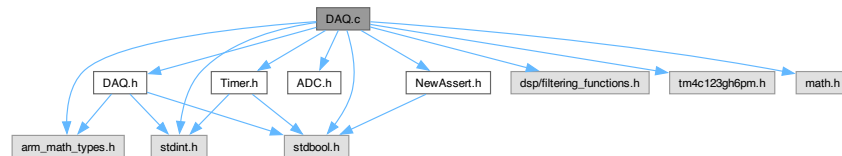
- [UART.c](#)

6 File Documentation

6.1 DAQ.c File Reference

Source code for DAQ module.

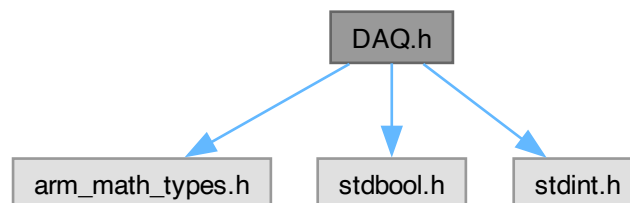
Include dependency graph for DAQ.c:



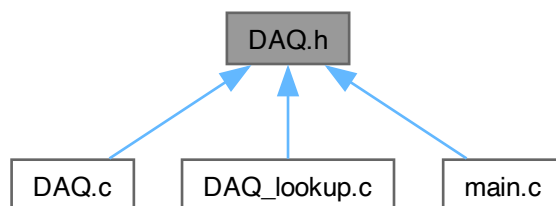
6.2 DAQ.h File Reference

Application software for handling data acquisition (DAQ) functions.

Include dependency graph for DAQ.h:



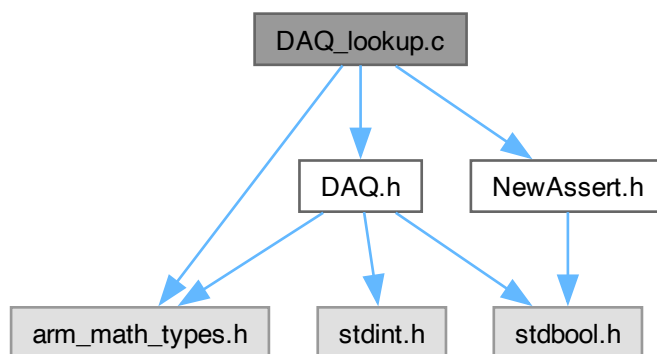
This graph shows which files directly or indirectly include this file:



6.3 DAQ_lookup.c File Reference

Source code for DAQ module's lookup table.

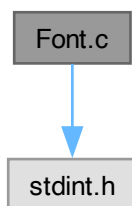
Include dependency graph for DAQ_lookup.c:



6.4 Font.c File Reference

Contains bitmaps for a selection of ASCII characters.

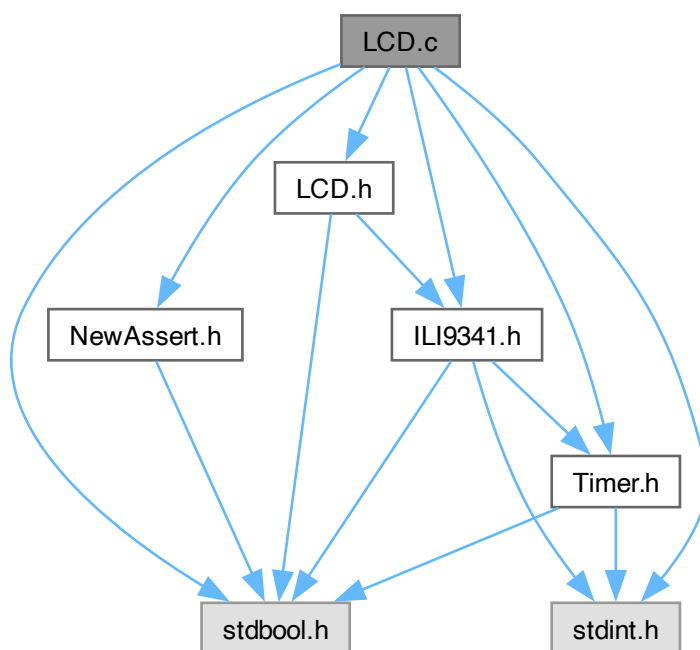
Include dependency graph for Font.c:



6.5 LCD.c File Reference

Source code for LCD module.

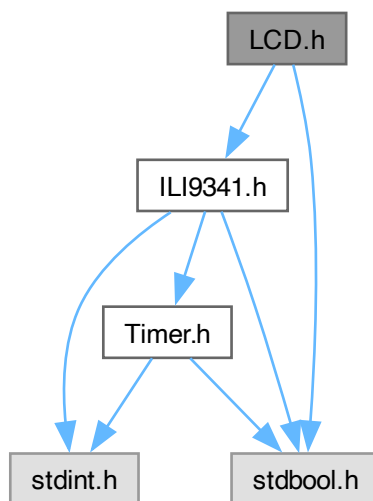
Include dependency graph for LCD.c:



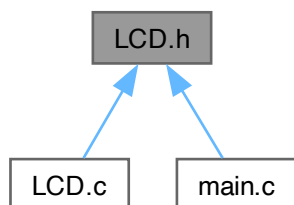
6.6 LCD.h File Reference

Header file for LCD module.

Include dependency graph for LCD.h:



This graph shows which files directly or indirectly include this file:



6.7 QRS.c File Reference

Source code for QRS detection module.

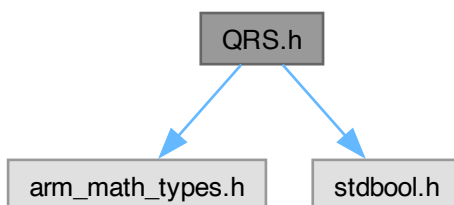
Include dependency graph for QRS.c:



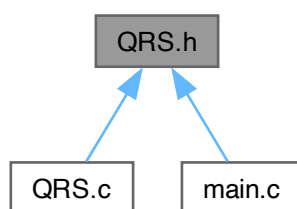
6.8 QRS.h File Reference

Header file for QRS detection module.

Include dependency graph for QRS.h:



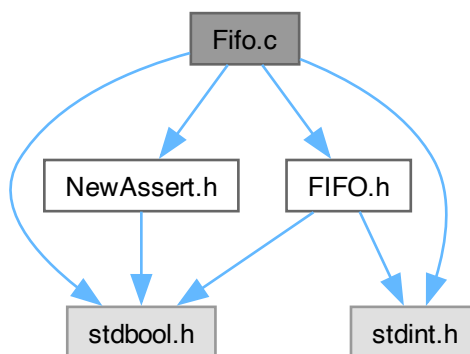
This graph shows which files directly or indirectly include this file:



6.9 Fifo.c File Reference

Source code for FIFO buffer module.

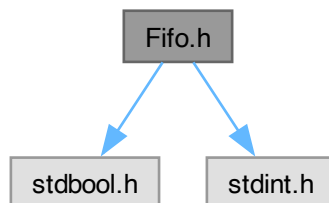
Include dependency graph for Fifo.c:



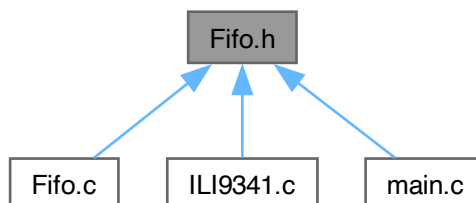
6.10 Fifo.h File Reference

Header file for FIFO buffer implementation.

Include dependency graph for Fifo.h:



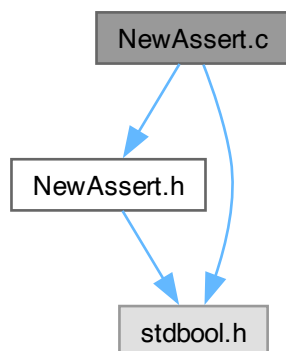
This graph shows which files directly or indirectly include this file:



6.11 NewAssert.c File Reference

Source code for custom `assert` implementation.

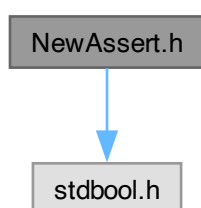
Include dependency graph for NewAssert.c:



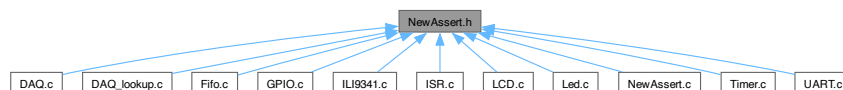
6.12 NewAssert.h File Reference

Header file for custom `assert` implementation.

Include dependency graph for NewAssert.h:



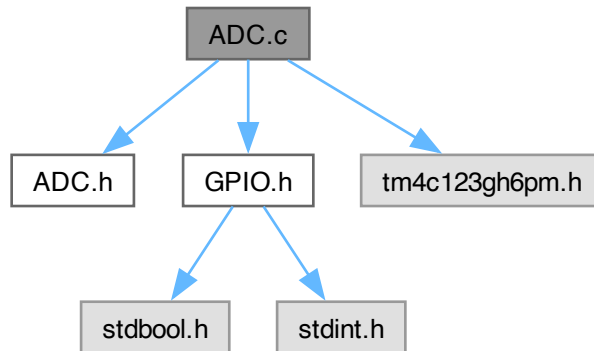
This graph shows which files directly or indirectly include this file:



6.13 ADC.c File Reference

Source code for analog-to-digital conversion (ADC) module.

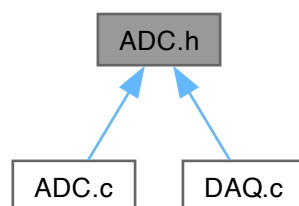
Include dependency graph for ADC.c:



6.14 ADC.h File Reference

Header file for analog-to-digital conversion (ADC) module.

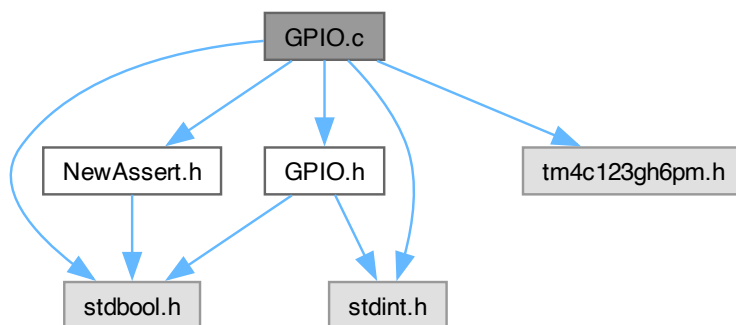
This graph shows which files directly or indirectly include this file:



6.15 GPIO.c File Reference

Source code for GPIO module.

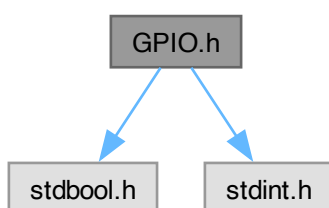
Include dependency graph for GPIO.c:



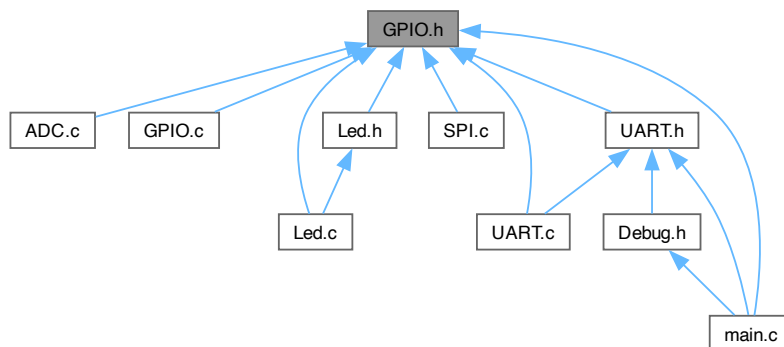
6.16 GPIO.h File Reference

Header file for general-purpose input/output (GPIO) device driver.

Include dependency graph for GPIO.h:



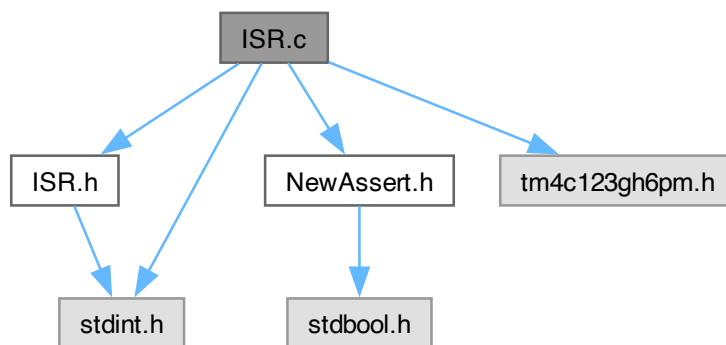
This graph shows which files directly or indirectly include this file:



6.17 ISR.c File Reference

Source code for interrupt service routine (ISR) configuration module.

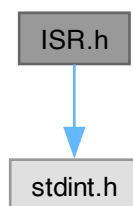
Include dependency graph for `ISR.c`:



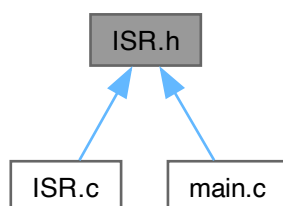
6.18 ISR.h File Reference

Header file for interrupt service routine (ISR) configuration module.

Include dependency graph for ISR.h:



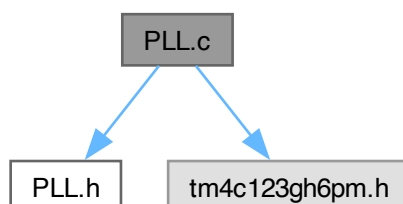
This graph shows which files directly or indirectly include this file:



6.19 PLL.c File Reference

Implementation details for phase-lock-loop (PLL) functions.

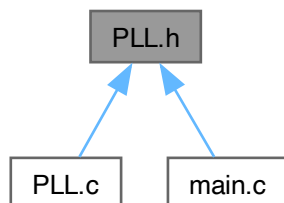
Include dependency graph for PLL.c:



6.20 PLL.h File Reference

Driver module for activating the phase-locked-loop (PLL).

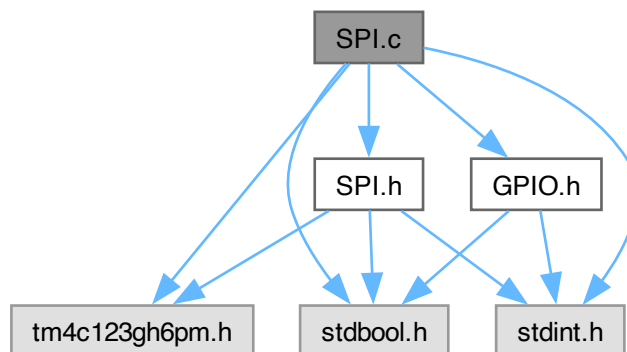
This graph shows which files directly or indirectly include this file:



6.21 SPI.c File Reference

Source code for serial peripheral interface (SPI) module.

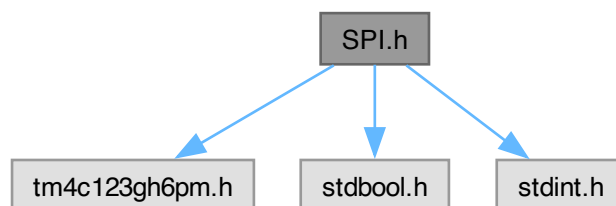
Include dependency graph for `SPI.c`:



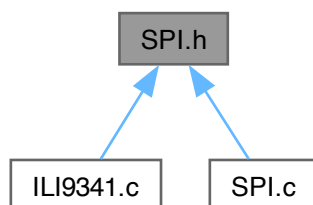
6.22 SPI.h File Reference

Header file for serial peripheral interface (SPI) module.

Include dependency graph for SPI.h:



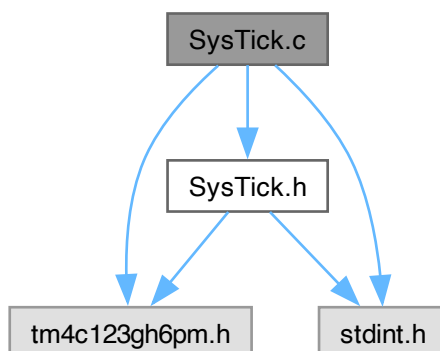
This graph shows which files directly or indirectly include this file:



6.23 SysTick.c File Reference

Implementation details for SysTick functions.

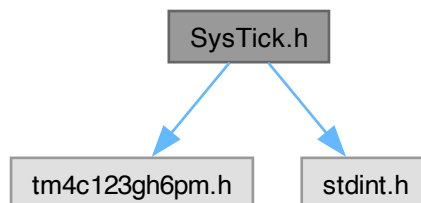
Include dependency graph for SysTick.c:



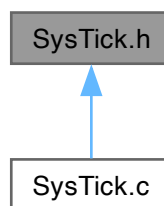
6.24 SysTick.h File Reference

Driver module for using SysTick-based timing and/or interrupts.

Include dependency graph for SysTick.h:



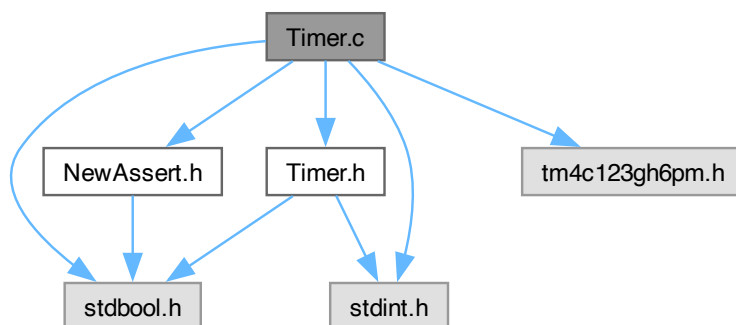
This graph shows which files directly or indirectly include this file:



6.25 Timer.c File Reference

Source code for Timer module.

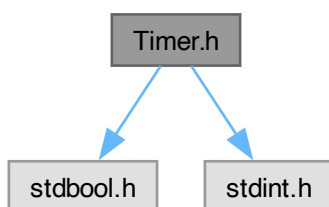
Include dependency graph for Timer.c:



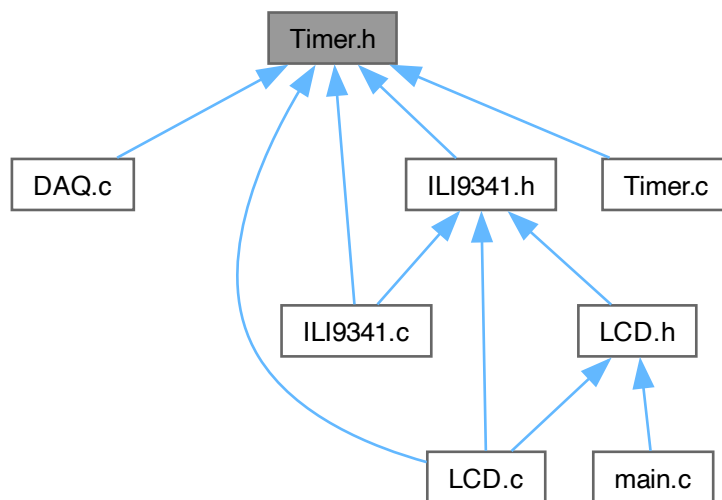
6.26 Timer.h File Reference

Device driver for general-purpose timer modules.

Include dependency graph for Timer.h:



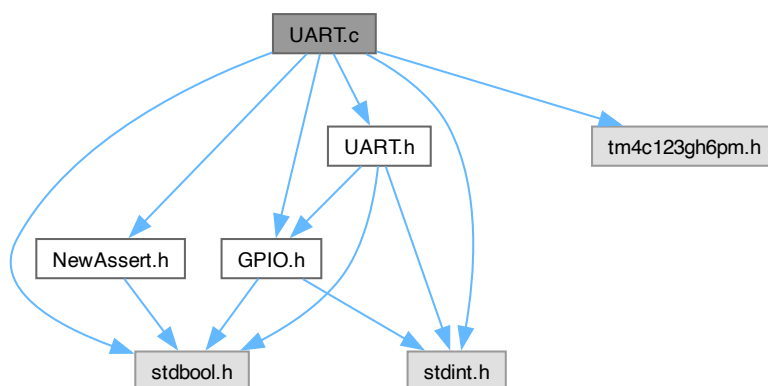
This graph shows which files directly or indirectly include this file:



6.27 UART.c File Reference

Source code for UART module.

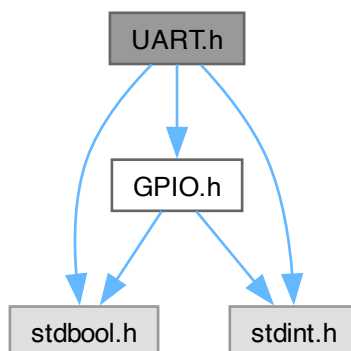
Include dependency graph for `UART.c`:



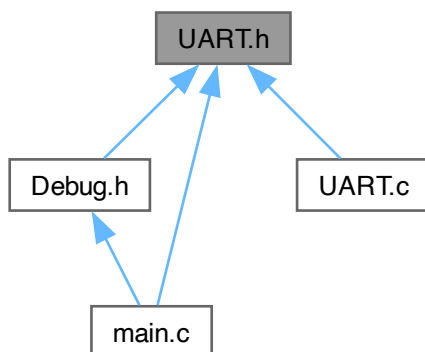
6.28 UART.h File Reference

Driver module for serial communication via UART0 and UART 1.

Include dependency graph for UART.h:



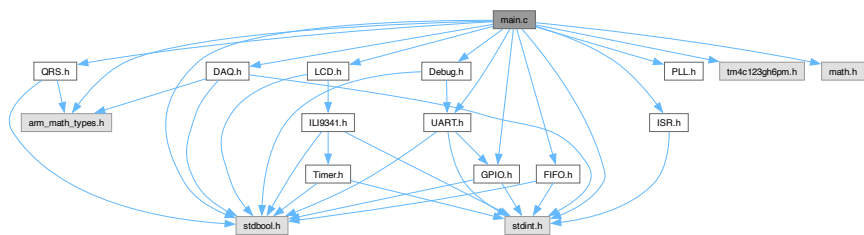
This graph shows which files directly or indirectly include this file:



6.29 main.c File Reference

Main program file.

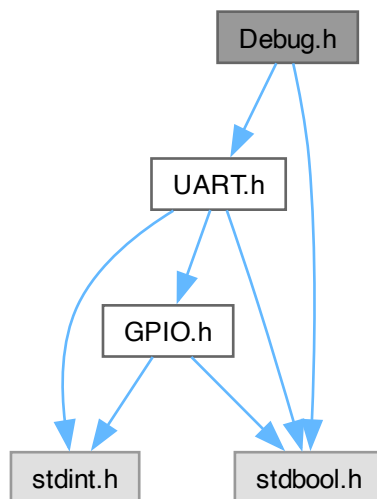
Include dependency graph for main.c:



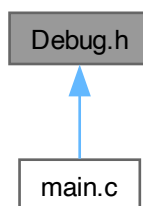
6.30 Debug.h File Reference

Functions to output debugging information to a serial port via UART.

Include dependency graph for Debug.h:



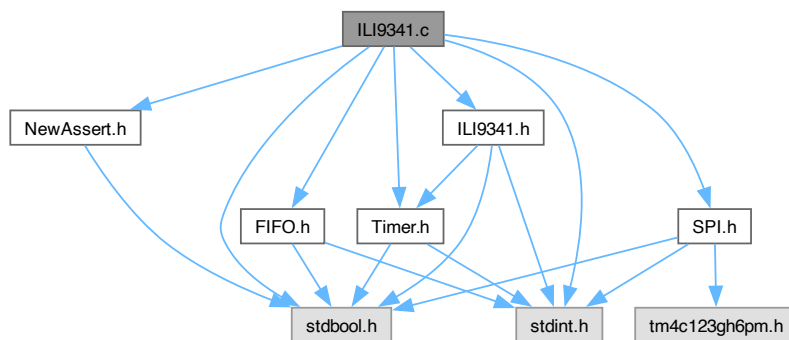
This graph shows which files directly or indirectly include this file:



6.31 ILI9341.c File Reference

Source code for ILI9341 module.

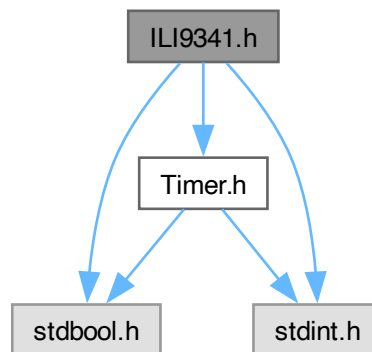
Include dependency graph for ILI9341.c:



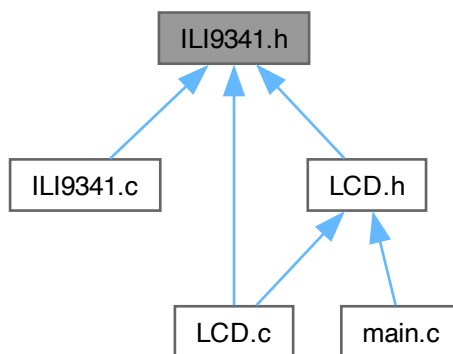
6.32 ILI9341.h File Reference

Driver module for interfacing with an ILI9341 LCD driver.

Include dependency graph for ILI9341.h:



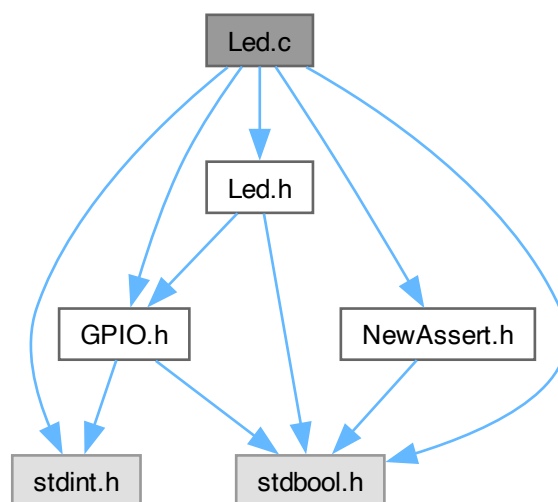
This graph shows which files directly or indirectly include this file:



6.33 Led.c File Reference

Source code for LED module.

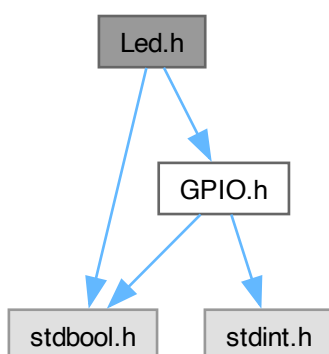
Include dependency graph for Led.c:



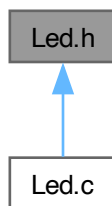
6.34 Led.h File Reference

Interface for LED module.

Include dependency graph for Led.h:



This graph shows which files directly or indirectly include this file:



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