uHeartMonitor

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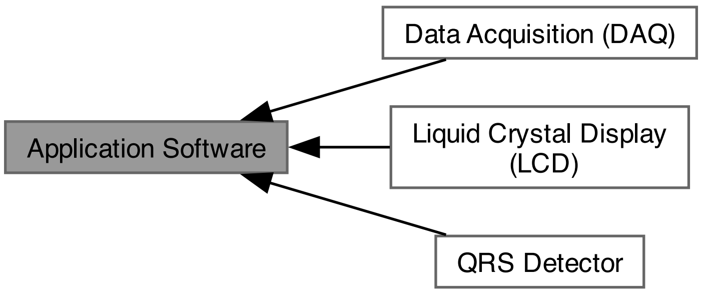
4 Topic Documentation

4.1 Application Software

Application-specific software modules.

Collaboration diagram for Application Software:



Modules

- Data Acquisition (DAQ)
- Liquid Crystal Display (LCD)
- QRS Detector

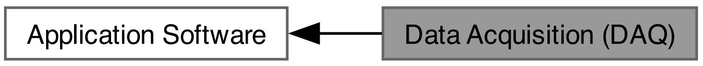
4.1.1 Detailed Description

Application-specific software modules.

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

4.1.2 Data Acquisition (DAQ)

Collaboration diagram for Data Acquisition (DAQ):



Files

- file DAQ.c

  Source code for DAQ module.
- file DAQ.h

  Application software for handling data acquision (DAQ) functions.
- file DAQ_lookup.c

  Source code for DAQ module's lookup table.

Macros

- #define **SAMPLING_PERIOD_MS** 5

  sampling period in ms ($T_s = 1/f_s$)
- #define **DAQ_LOOKUP_MAX** ((float32_t) 5.5f)
- #define **DAQ_LOOKUP_MIN** ((float32_t) (-5.5f))

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** = &notchFiltStruct
- 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 ADC and Timer are initialized, and 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	*sample*	12-bit sample in range `[0x000, 0xFFF]`

Postcondition

The sample can now be converted to millivolts.

See also

DAQ_convertToMilliVolts()

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`	*xn*	Raw input sample
`out`	*yn*	Filtered output sample

Postcondition

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

See also

DAQ_BandpassFilter()

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()

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`	*sample*	12-bit sample in range `[0x000, 0xFFF]`
`out`	*xn*	Voltage value in range $[-5.5, 5.5)[mV]$

Postcondition

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

See also

DAQ_readSample()

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_DAQ_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,
}
```

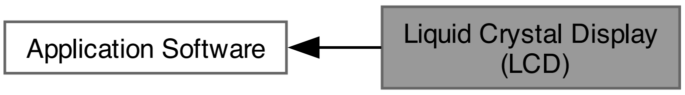
bandpassFiltStruct

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

Initial value:
```
= { NUM_STAGES_BANDPASS, stateBuffer_Bandpass,
                                             COEFFS_BANDPASS }
```

4.1.3 Liquid Crystal Display (LCD)

Collaboration diagram for Liquid Crystal Display (LCD):



Files

- 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_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.
- static void LCD_plotSample (uint16_t x, uint16_t y, LCD_Color_t color)

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

Variables

- 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**
  uint16_t **colNum**
  uint8_t **R_val**
  5 or 6-bit R value
  uint8_t **G_val**
  6-bit G value
  uint8_t **B_val**
  5 or 6-bit B value
  bool **isInit**
  if `true`, LCD has been initialized
  } **lcd** = { 0 }
- const uint8_t ∗const **FONT_ARRAY** [128]

Init./Config. Functions

- enum { **LCD_X_MAX** = ILI9341_NUM_ROWS - 1 , **LCD_Y_MAX** = ILI9341_NUM_COLS - 1 }
- enum **LCD_Color_t** {
  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. $0 <= x1 <= x2 <= X_{MAX}$.
- void LCD_setY (uint16_t y1, uint16_t y2)
  Set new y-coordinates to be written to. $0 <= y1 <= y2 <= Y_{MAX}$.
- void LCD_setColor (LCD_Color_t color)
  Set the color value.

Writing Functions

- enum { **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)

Drawing Functions

- 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, bool isFilled)

  Draw a rectangle of size `dx` x `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

center	Row or column that the line is centered on. `center` is increased or decreased if the line to be written would have gone out of bounds.
lineWidth	Width of the line. Should be a positive, odd number.
is_row	`true` for horizontal line, `false` 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	*isOn*	`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. $0 <= x1 <= x2 <= X_{MAX}$.

Parameters

in	*x1*	left-most x-coordinate
in	*x2*	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. $0 <= y1 <= y2 <= Y_{MAX}$.

Parameters

in	*y1*	lowest y-coordinate
in	*y2*	highest y-coordinate

See also

LCD_setX()

LCD_setColor()

```
void LCD_setColor (
            LCD_Color_t color )
```

Set the color value.

Parameters

in	*color*	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()

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`	*yCenter*	y-coordinate to center the line on
`in`	*lineWidth*	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`	*xCenter*	x-coordinate to center the line on
`in`	*lineWidth*	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,
            bool isFilled )
```

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	*x1*	lowest (left-most) x-coordinate
in	*dx*	length (horizontal distance) of the rectangle
in	*y1*	lowest (bottom-most) y-coordinate
in	*dy*	height (vertical distance) of the rectangle
in	*isFilled*	`true` to fill the rectangle, `false` to leave it unfilled

See also

LCD_Draw(), LCD_Fill(), LCD_drawHoriLine(), LCD_drawVertLine()

LCD_plotSample()

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

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

Parameters

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

See also

LCD_setX(), LCD_setY(), LCD_setColor(), LCD_Draw()

LCD_setCursor()

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

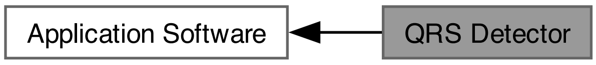
Set the cursor to line `x`, column `y`.

Parameters

in	*lineNum*	Line number to place characters. Should be in range `[0, 30)`.
in	*colNum*	Column number to place characters. Should be in range `[0, 64)`.

4.1.4 QRS Detector

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 , **STATE_BUFF_SIZE_DERFILT** = NUM_COEFF_DERFILT + BLOCK_SIZE↩_DERFILT - 1 , **BLOCK_SIZE_MOVAVG** = 1 , **NUM_COEFF_MOVAVG** = 10 ,
  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-specific Functions

- 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`	*yn*	Array containing the preprocessed ECG signal $y[n]$
`in`	*fidMarkArray*	Array to place the fiducial mark's sample indices into.
`out`	*numMarks*	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 @ fs = 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`	*yn*	Array containing the preprocessed ECG signal $y[n]$
`in`	*sigLvlPtr*	Pointer to variable holding the signal level value.
`in`	*noiseLvlPtr*	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`	*peakAmplitude*	Amplitude of the fiducial mark in signal $y[n]$
`in`	*level*	The current value of the signal level or noise level
`out`	*newLevel*	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`	*signalLevel*	Current signal level.
`in`	*noiseLevel*	Current noise level.
`out`	*threshold*	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.

Warning

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

This function originally initialized the filter `struct`s 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	*xn*	Array of raw ECG signal values.
in	*yn*	Array used to store preprocessed ECG signal values.

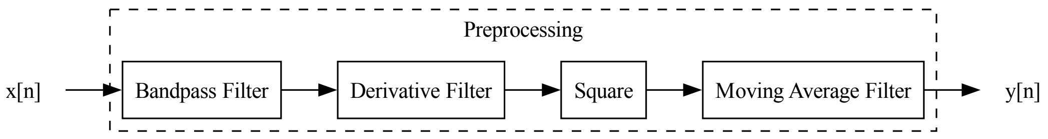
Postcondition

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.



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	*yn*	Array of preprocessed ECG signal values.
out	*heartRate*	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	*xn*	Array of raw ECG signal values.
in	*yn*	Array used to hold preprocessed ECG signal values.
out	*heartRate*	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

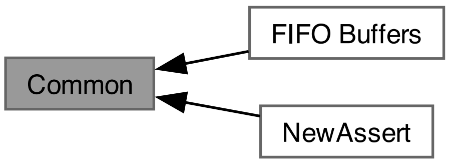
```
const float32_t COEFF_MOVAVG[NUM_COEFF_MOVAVG]  [static]
```

Initial value:

```
= {
    0.100000000149011612f, 0.100000000149011612f, 0.100000000149011612f,
    0.100000000149011612f, 0.100000000149011612f, 0.100000000149011612f,
    0.100000000149011612f, 0.100000000149011612f, 0.100000000149011612f, 0.100000000149011612f
}
```

4.2 Common

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	*condition*	Conditional to test.

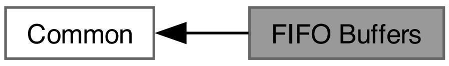
Postcondition

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.

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_TransferOne (volatile Fifo_t srcFifo, volatile Fifo_t destFifo)

  Transfer a value from one FIFO buffer to another.

Bulk Removal

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

  Empty the FIFO buffer's contents into an array.
- void FIFO_Reset (volatile Fifo_t fifo)

  Reset the FIFO buffer.
- void FIFO_TransferAll (volatile Fifo_t srcFifo, volatile Fifo_t destFifo)

  Transfer the contents of one FIFO buffer to another.

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`	*buffer*	Array of size `N` to be used as FIFO buffer
`in`	*N*	Length of `buffer`. Usable length is `N - 1`.
`out`	*fifo*	pointer to the FIFO buffer

Postcondition

The number of available FIFO buffers is reduced by 1.

TODO: Add details

FIFO_Put()

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

Add a value to the end of the buffer.

Parameters

`in`	*fifo*	Pointer to FIFO object
`in`	*val*	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.

FIFO_Get()

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

Remove the first value of the buffer.

Parameters

`in`	*fifo*	Pointer to FIFO object
`out`	*val*	First sample in the FIFO.

Postcondition

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

FIFO_TransferOne()

```
void FIFO_TransferOne (
            volatile Fifo_t srcFifo,
            volatile Fifo_t destFifo )
```

Transfer a value from one FIFO buffer to another.

Precondition

Initialize both FIFO buffers.

Parameters

`in`	*srcFifo*	Pointer to source FIFO buffer.
`in`	*destFifo*	Pointer to destination FIFO buffer.

Postcondition

A value is removed from `srcFifo` and placed in `destFifo`.

FIFO_Flush()

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

Empty the FIFO buffer's contents into an array.

Parameters

`in`	*fifo*	Pointer to source FIFO buffer.
`in`	*outputBuffer*	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.

FIFO_Reset()

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

Reset the FIFO buffer.

Parameters

in	*fifo*	Pointer to FIFO buffer.

Postcondition

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

FIFO_TransferAll()

```
void FIFO_TransferAll (
            volatile Fifo_t srcFifo,
            volatile Fifo_t destFifo )
```

Transfer the contents of one FIFO buffer to another.

Parameters

in	*srcFifo*	Pointer to source FIFO buffer.
in	*destFifo*	Pointer to destination FIFO buffer.

FIFO_PeekOne()

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

See the first element in the FIFO without removing it.

Parameters

in	*fifo*	Pointer to FIFO object
out	*val*	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`	*fifo*	Pointer to source FIFO buffer.
`in`	*outputBuffer*	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`	*fifo*	Pointer to the FIFO buffer.
`out`	*true*	The FIFO buffer is full.
`out`	*false*	The FIFO buffer is not full.

FIFO_isEmpty()

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

Check if the FIFO buffer is empty.

Parameters

`in`	*fifo*	Pointer to the FIFO buffer.
`out`	*true*	The FIFO buffer is empty.
`out`	*false*	The FIFO buffer is not empty.

FIFO_getCurrSize()

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

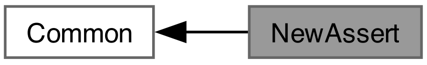
Get the current size of the FIFO buffer.

Parameters

`in`	*fifo*	Pointer to the FIFO buffer.
`out`	*size*	Current number of values in the FIFO buffer.

4.2.4 NewAssert

Collaboration diagram for NewAssert:

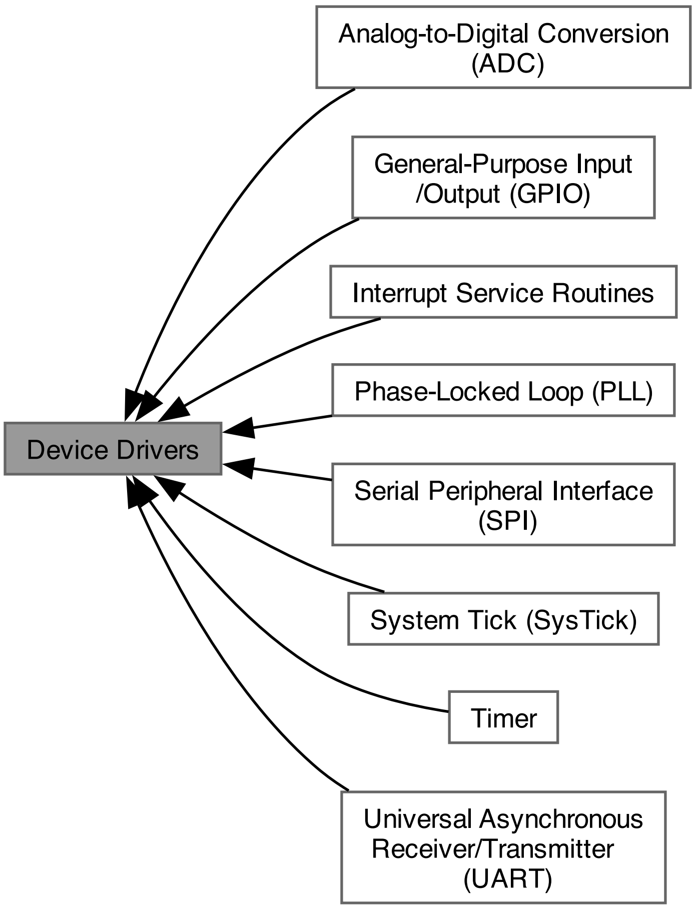


Module for using a custom `assert` implementation.

4.3 Device Drivers

Low level device driver modules.

Collaboration diagram for Device Drivers:


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

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

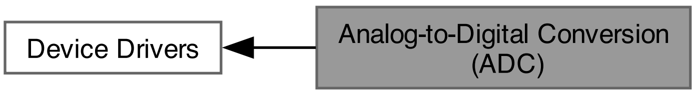
4.3.1 Detailed Description

Low level device driver modules.

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

4.3.2 Analog-to-Digital Conversion (ADC)

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



Files

- file ADC.c

  Source code ffor 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.

4.3.2.1 Detailed Description

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

4.3.2.2 Function Documentation

ADC_Init()

```
void ADC_Init (
            void  )
```

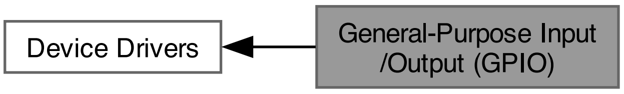
Initialize ADC0 as a single-input analog-to-digital converter.

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.

4.3.3 General-Purpose Input/Output (GPIO)

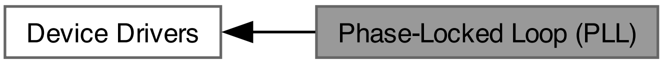
Collaboration diagram for General-Purpose Input/Output (GPIO):



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

4.3.4 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.

4.3.4.1 Detailed Description

Function for initializing the phase-locked loop.

4.3.4.2 Function Documentation

PLL_Init()

```
void PLL_Init (
             void  )
```

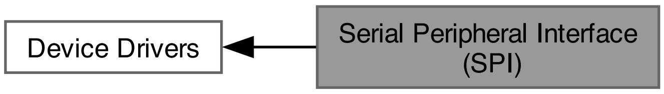
Initialize the phase-locked-loop to change the bus frequency.

Postcondition

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

4.3.5 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_SET_DC() (GPIO_PORTA_DATA_R |= 0x40)
- #define **SPI_CLEAR_DC**() (GPIO_PORTA_DATA_R &= ∼(0x40))
- #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.

4.3.5.1 Detailed Description

Functions for SPI-based communication via SSI0 peripheral.

4.3.5.2 Macro Definition Documentation

SPI_SET_DC

```
#define SPI_SET_DC( ) (GPIO_PORTA_DATA_R |= 0x40)
```

TM4C Pin	Function	ILI9341 Pin	Description
PA2	SSI0Clk	CLK	Serial clock signal
PA3	SSI0Fss	CS	Chip select signal
PA4	SSI0Rx	MISO	TM4C (M) input, LCD (S) output
PA5	SSI0Tx	MOSI	TM4C (M) output, LCD (S) input
PA6	GPIO	D/C	Data = 1, Command = 0
PA7	GPIO	RESET	Reset the display (negative logic/active `LOW`)

Clk. Polarity = steady state low (0)
Clk. Phase = rising clock edge (0)

4.3.5.3 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	*data*	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	*cmd*	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`	*data*	8-bit data to write.

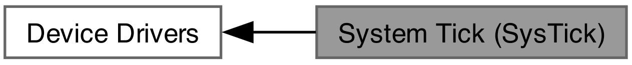
Postcondition

The D/C pin is set.

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

4.3.6 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.

4.3.6.1 Detailed Description

Functions for timing and periodic interrupts via SysTick.

4.3.6.2 Function Documentation

SysTick_Interrupt_Init()

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

Initialize SysTick for interrupts.

Parameters

time_ms	Time in [ms] between interrupts. Cannot be more than 200[ms].

4.3.7 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]

4.3.7.1 Detailed Description

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

4.3.7.2 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

4.3.7.3 Function Documentation

Timer_Init()

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

Initialize a hardware timer.

Parameters

in	*timerName*	Name of the hardware timer to use.
out	*timer*	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	*timerName*	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	*timer*	Pointer to timer object.
out	*timer↩ Name_t*	Name of the hardware timer being used.

Timer_isInit()

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

Check if a timer object is initialized.

Parameters

in	*timer*	Pointer to timer object.
out	*true*	The timer is initialized.
out	*false*	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	*timer*	Pointer to timer object.
in	*timerMode*	Mode for hardware timer to use.
in	*timerDirection*	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	*timer*	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	*timer*	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	*timer*	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	*timer*	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	*timer*	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	*timer*	Pointer to timer object.
in	*time_ms*	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`	*timer*	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`	*timer*	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	*timer*	Pointer to timer object.
out	*true*	The timer is counting.
out	*false*	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	*timer*	Pointer to timer object.
in	*time_ms*	Time in [ms] to wait for.

Postcondition

The program is delayed for the desired time.

4.3.7.4 Variable Documentation

TIMER_POOL

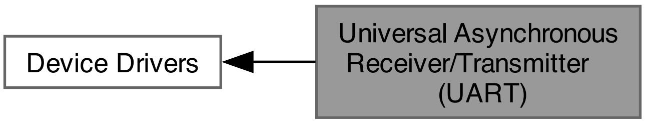
```
TimerStruct_t TIMER_POOL[6]  [static]
```

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 }
}
```

4.3.8 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 **UART_Num_t** {
  UART0 , **UART1** , **UART2** , **UART3** ,
  UART4 , **UART5** , **UART6** , **UART7** }

Functions

- UART_t ∗ UART_Init (GpioPort_t port, UART_Num_t uartNum)

  Initialize the specified UART peripheral.
- 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 UART_t UART_ARR [8]

4.3.8.1 Detailed Description

Functions for UART-based communication.

4.3.8.2 Function Documentation

UART_Init()

```
UART_t * UART_Init (
            GpioPort_t port,
            UART_Num_t uartNum )
```

Initialize the specified UART peripheral.

Parameters

in	*port*	GPIO port to use.
in	*uartNum*	UART number. Should be either one of the enumerated constants or an int in range [0, 7].
out	*UART↩ _t∗*	(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_ReadChar()

```
unsigned char UART_ReadChar (
            UART_t * uart )
```

Read a single ASCII character from the UART.

Parameters

in	*uart*	UART to read from.
out	*unsigned*	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	*uart*	UART to write to.
in	*input_char*	ASCII character to send.

UART_WriteStr()

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

Write a C string to the UART.

Parameters

in	*uart*	UART to write to.
in	*input_str*	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	*uart*	UART to write to.
in	*n*	Unsigned 32-bit `int` 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	*uart*	UART to write to.
in	*n*	Floating-point number to be converted and transmitted.
in	*num_decimals*	Number of digits after the decimal point to include.

4.3.8.3 Variable Documentation

UART_ARR

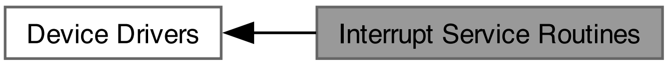
```
UART_t UART_ARR[8]  [static]
```

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 }
}
```

4.3.9 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

4.3.9.1 Detailed Description

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

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

`in`	*vectorNum*	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

`in`	*vectorNum*	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.

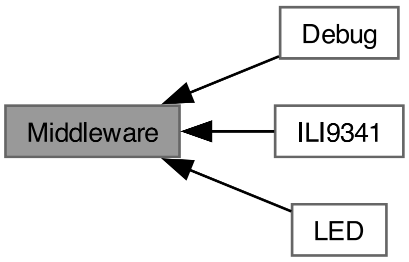
See also

ISR_clearPending()

4.4 Middleware

High-level device driver modules.

Collaboration diagram for Middleware:



Modules

- Debug
- ILI9341
- LED

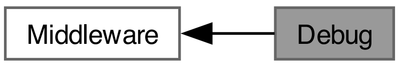
4.4.1 Detailed Description

High-level device driver modules.

These modules contain functions for interfacing with external devices/peripherals via the use of low-level drivers.

4.4.2 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 (void)

  Initialize the Debug module.

Assertions

- void Debug_Assert (bool condition)

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

4.4.2.1 Detailed Description

Module for debugging functions, including serial output and assertions.

4.4.2.2 Function Documentation

Debug_Init()

```
void Debug_Init (
             void   )
```

Initialize the Debug module.

Postcondition

An initialization message is sent to the serial port (UART0).

Debug_SendMsg()

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

Send a message to the serial port.

Precondition

Initialize the Debug module.

Parameters

message	(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

in	*msg*	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`	*value*	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

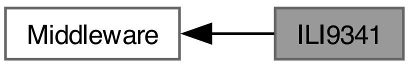
`in`	*condition*	Conditional statement to evaluate.

Postcondition

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

4.4.3 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 ,
  VSCRSADD = 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_setDispInversion (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 }

4.4.3.1 Detailed Description

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

4.4.3.2 Enumeration Type Documentation

anonymous enum

`anonymous enum`

Enumerator

ILI9341_NUM_COLS	**4.4.3.3 of columns available on the display**
ILI9341_NUM_ROWS	**4.4.3.4 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)
FRMCTR2	Frame Rate Control Set (Idle Mode)
FRMCTR3	Frame Rate Control Set (Partial Mode)
PRCTR	Blanking Porch Control.
IFCTL	Interface Control.

4.4.3.5 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	*cmd*	Command to send.

ILI9341_Init()

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

Initialize the LCD driver and the SPI module.

Currently unused commands #define RDDST (uint8_t) 0x09 /// Read Display Status #define RDDMADCTL (uint8↩_t) 0x0B /// Read Display MADCTL #define RDDCOLMOD (uint8_t) 0x0C /// Read Display Pixel Format #define RGBSET (uint8_t) 0x2D /// Color Set #define RAMRD (uint8_t) 0x2E /// Memory Read #define WRITE_MEMORY↩_CONTINUE (uint8_t) 0x3C /// Write_Memory_Continue #define READ_MEMORY_CONTINUE (uint8_t) 0x3E /// Read_Memory_Continue #define WRDISBV (uint8_t) 0x51 /// Write Display Brightness #define RDDISBV (uint8_t) 0x52 /// Read Display Brightness #define IFMODE (uint8_t) 0xB0 /// RGB Interface Signal Control (i.e. Interface Mode Control) #define INVTR (uint8_t) 0xB4 /// Display Inversion Control

Parameters

in	*timer*	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	*timer*	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	*timer*	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	*sleepMode*	`SLEEP_ON` or `SLEEP_OFF`
in	*timer*	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	*displayArea*	`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	*colorExpr*	`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	*rowStart*	
in	*rowEnd*	

See also

ILI9341_setDisplayArea()

ILI9341_setDispInversion()

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

Toggle display inversion (`OFF` by default).

Parameters

in	*invertMode*	`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`	*outputMode*	`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`	*areRowsFlipped*	
`in`	*areColsFlipped*	
`in`	*areRowsAndColsSwitched*	
`in`	*isVertRefreshFlipped*	
`in`	*isColorOrderFlipped*	
`in`	*isHorRefreshFlipped*	

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`	*colorDepth*	`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 <= `startRow` <= `endRow`

Parameters

`in`		

startRow<=endRow` < 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 <= `startCol` <= `endCol`

Parameters

in		

startCol<=endCol` $<$ 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`	*red*	5 or 6-bit `R` value
`in`	*green*	5 or 6-bit `G` value
`in`	*blue*	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.

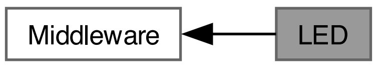
Transfer	**1**								**2**							
Bit #	7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0
Value	R4	R3	R2	R1	R0	G5	G4	G3	G2	G1	G0	B4	B3	B2	B1	B0

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	...

4.4.4 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

Functions

- Led_t Led_Init (GpioPort_t gpioPort, GPIO_Pin_t pin)

  Initialize a light-emitting diode (LED) as an `Led_t`.
- bool **Led_isInit** (Led_t led)
- GpioPort_t Led_GetPort (Led_t led)

  Get the GPIO port associated with the LED.
- GPIO_Pin_t Led_GetPin (Led_t led)

  Get the GPIO pin associated with the LED.
- bool Led_isOn (Led_t led)

  Check the LED's status.
- void Led_TurnOn (Led_t led)

  Turn the LED `ON`.
- void Led_TurnOff (Led_t led)

  Turn the LED `OFF`.
- void Led_Toggle (Led_t led)

  Toggle the LED (i.e. `OFF` -> `ON` or `ON` -> `OFF`).

Variables

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

4.4.4.1 Detailed Description

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

4.4.4.2 Function Documentation

Led_Init()

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

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

Parameters

in	*gpioPort*	Pointer to a `struct` representing a GPIO port.
in	*pin*	GPIO pin to use.
out	*Led_t**	Pointer to LED data structure.

Led_GetPort()

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

Get the GPIO port associated with the LED.

Parameters

in	*led*	Pointer to LED data structure.
out	*GPIO_Port↩ _t**	Pointer to a GPIO port data structure.

Led_GetPin()

```
GPIO_Pin_t Led_GetPin (
             Led_t led )
```

Get the GPIO pin associated with the LED.

Parameters

in	*led*	Pointer to LED data structure.
out	*GPIO_↩ Pin_t*	GPIO pin associated with the LED.

Led_isOn()

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

Check the LED's status.

Parameters

in	*led*	Pointer to LED data structure.
out	*true*	the LED is `ON`.
out	*false*	the LED is `OFF`.

Led_TurnOn()

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

Turn the LED `ON`.

Parameters

in	*led*	Pointer to LED data structure.

Led_TurnOff()

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

Turn the LED `OFF`.

Parameters

in	*led*	Pointer to LED data structure.

Led_Toggle()

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

Toggle the LED (i.e. `OFF` -> `ON` or `ON` -> `OFF`).

Parameters

in	*led*	Pointer to LED data structure.

4.5 Main

Files

- file main.c

  Main program file.

Enumerations

- enum { **DAQ_VECTOR_NUM** = INT_ADC0SS3 , **PROC_VECTOR_NUM** = INT_CAN0 , **LCD_VECTOR_↩ NUM** = INT_TIMER1A }
- enum {
  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_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) }

Functions

- static void DAQ_Handler (void)

  Reads ADC output, converts to raw voltage sample, and sends to next FIFO.
- static void Processing_Handler (void)

  Removes baseline drift and PLI from a sample, and moves it to the QRS/LCD FIFOs.
- static void LCD_Handler (void)

  Applies a 0.5-40 [Hz] bandpass filter and plots the sample to the waveform.
- 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 bool **QRS_bufferIsFull** = false
- 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 **LCD_heartRateIsReady** = false
- static float32_t **QRS_processingBuffer** [QRS_ARRAY_LEN] = { 0 }
- static uint16_t **LCD_prevSampleBuffer** [LCD_X_MAX] = { 0 }

4.5.1 Detailed Description

4.5.2 Enumeration Type Documentation

anonymous enum

`anonymous enum`

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

anonymous enum

`anonymous enum`

Enumerator

LCD_TOP_LINE	separates wavefrom from text
LCD_WAVE_NUM↩ _Y	num. of y-vals available for plotting waveform

4.5.3 Function Documentation

DAQ_Handler()

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

Reads ADC output, converts to raw voltage sample, and sends to next FIFO.

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.

Precondition

Initialize the DAQ module.

Postcondition

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

See also

DAQ_Init(), Processing_Handler()

Processing_Handler()

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

Removes baseline drift and PLI from a sample, and moves it to the QRS/LCD FIFOs.

This ISR has a priority level of 1, is triggered by the DAQ ISR, and triggers the LCD Handler. It also notifies the superloop in main() when the QRS buffer is full.

Postcondition

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

See also

DAQ_Handler(), main(), LCD_Handler()

LCD_Handler()

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

Applies a 0.5-40 [Hz] bandpass filter and plots the sample to the waveform.

This ISR has a priority level of 1 and is triggered by the Processing ISR.

Precondition

Initialize the LCD module.

Postcondition

The bandpass-filtered sample is plotted to the LCD.

See also

LCD_Init(), Processing_Handler()

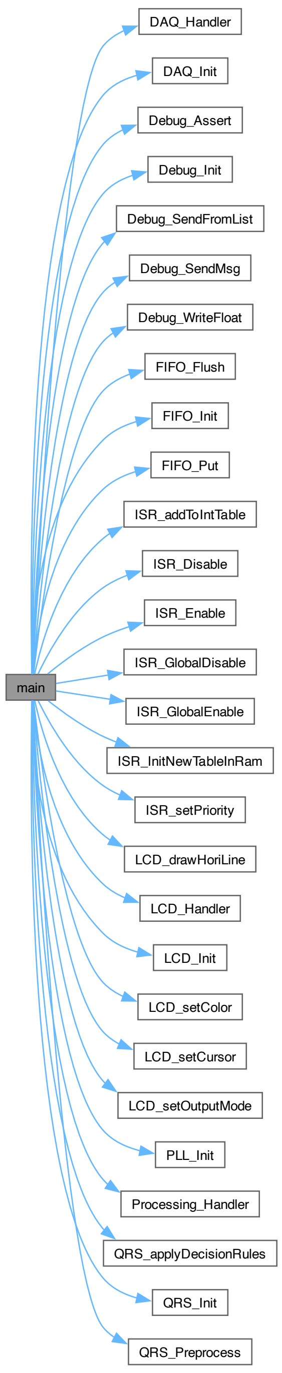
main()

```
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. Here is the call graph for this function:



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

- GPIO_Pin_t **GPIO_PIN**

  GPIO pin number.

- bool **is_ON**

  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 const **FLAG_R_ADDRESS**
- GpioPort_t **GPIO_PORT**

  pointer to GPIO port data structure
- GPIO_Pin_t **RX_PIN_NUM**

  GPIO pin number.
- GPIO_Pin_t **TX_PIN_NUM**

  GPIO pin number.
- bool **isInit**

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

- UART.c

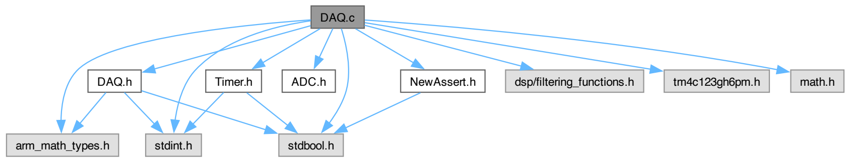
6 File Documentation

6.1 DAQ.c File Reference

Source code for DAQ module.

```
#include "DAQ.h"
#include "ADC.h"
#include "Timer.h"
#include "NewAssert.h"
#include "arm_math_types.h"
#include "dsp/filtering_functions.h"
#include "tm4c123gh6pm.h"
#include <math.h>
#include <stdbool.h>
```

`#include <stdint.h>`
Include dependency graph for DAQ.c:



Macros

- #define **SAMPLING_PERIOD_MS** 5
  sampling period in ms ($T_s = 1/f_s$)

Functions

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.

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.

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** = &notchFiltStruct
- static float32_t **stateBuffer_Bandpass** [STATE_BUFF_SIZE_BANDPASS]
- static const Filter_t bandpassFiltStruct
- static const Filter_t ∗const **bandpassFilter** = &bandpassFiltStruct

6.1.1 Detailed Description

Source code for DAQ module.

Author

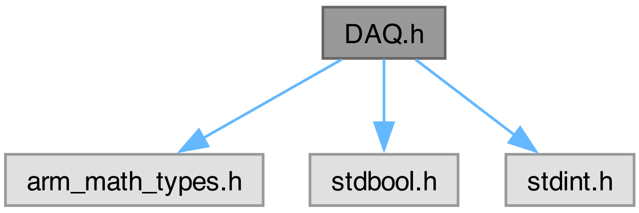
Bryan McElvy

6.2 DAQ.h File Reference

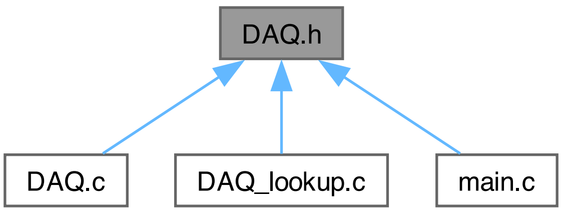
Application software for handling data acquision (DAQ) functions.

```
#include "arm_math_types.h"
#include <stdbool.h>
#include <stdint.h>
```

Include dependency graph for DAQ.h:



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



Macros

- #define **DAQ_LOOKUP_MAX** ((float32_t) 5.5f)
- #define **DAQ_LOOKUP_MIN** ((float32_t) (-5.5f))

Functions

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

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.

6.2.1 Detailed Description

Application software for handling data acquision (DAQ) functions.

Author

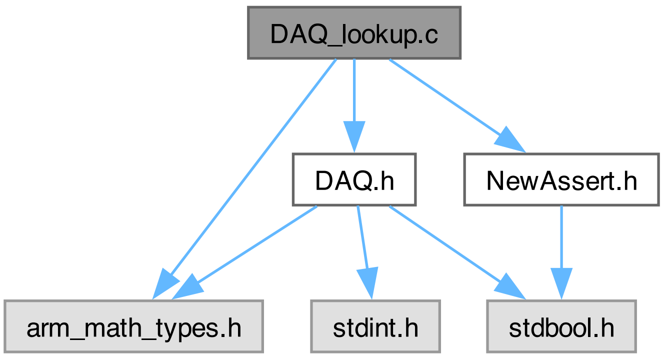
Bryan McElvy

6.3 DAQ_lookup.c File Reference

Source code for DAQ module's lookup table.

```
#include "DAQ.h"
#include "NewAssert.h"
#include "arm_math_types.h"
```

Include dependency graph for DAQ_lookup.c:



Functions

Reading Input Data

- float32_t DAQ_convertToMilliVolts (uint16_t sample)
  Convert a 12-bit ADC sample to a floating-point voltage value via LUT.

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.

6.3.1 Detailed Description

Source code for DAQ module's lookup table.

Author

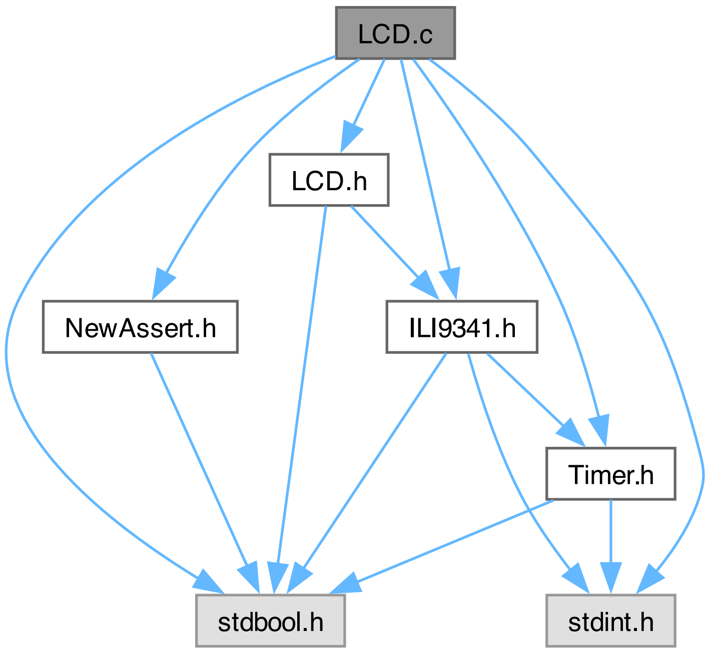
Bryan McElvy

6.4 LCD.c File Reference

Source code for LCD module.

```
#include "LCD.h"
#include "ILI9341.h"
#include "Timer.h"
#include "NewAssert.h"
#include <stdbool.h>
#include <stdint.h>
```

Include dependency graph for LCD.c:



Macros

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

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.
- static void LCD_plotSample (uint16_t x, uint16_t y, LCD_Color_t color)

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

Init./Config. Functions

- 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. $0 <= x1 <= x2 <= X_{MAX}$.
- void LCD_setY (uint16_t y1, uint16_t y2)

  Set new y-coordinates to be written to. $0 <= y1 <= y2 <= Y_{MAX}$.
- void LCD_setColor (LCD_Color_t color)

  Set the color value.

Drawing Functions

- 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, bool isFilled)

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

Writing Functions

- 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)

Variables

- 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**
  uint16_t **colNum**
  uint8_t **R_val**
  5 or 6-bit R value
  uint8_t **G_val**
  6-bit G value
  uint8_t **B_val**
  5 or 6-bit B value
  bool **isInit**
  if `true`, LCD has been initialized
  } **lcd** = { 0 }
- const uint8_t ∗const **FONT_ARRAY** [128]

6.4.1 Detailed Description

Source code for LCD module.

Author

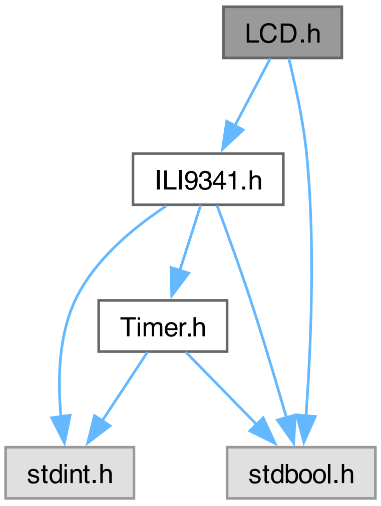
Bryan McElvy

6.5 LCD.h File Reference

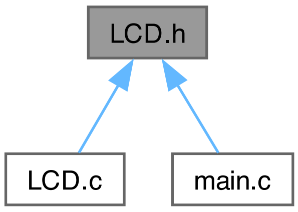
Header file for LCD module.

```
#include "ILI9341.h"
#include <stdbool.h>
```

Include dependency graph for LCD.h:



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



Functions

Drawing Functions

- 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, bool isFilled)

  Draw a rectangle of size `dx` x `dy` onto the display. The bottom-left corner will be located at `(x1, y1)`.
- static void **LCD_plotSample** (uint16_t x, uint16_t y, LCD_Color_t color)

Init./Config. Functions

- enum { **LCD_X_MAX** = ILI9341_NUM_ROWS - 1 , **LCD_Y_MAX** = ILI9341_NUM_COLS - 1 }
- enum **LCD_Color_t** {
  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. $0 <= x1 <= x2 <= X_{MAX}$.
- void LCD_setY (uint16_t y1, uint16_t y2)

  Set new y-coordinates to be written to. $0 <= y1 <= y2 <= Y_{MAX}$.
- void LCD_setColor (LCD_Color_t color)

  Set the color value.

Writing Functions

- enum { **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)

6.5.1 Detailed Description

Header file for LCD module.

Author

Bryan McElvy

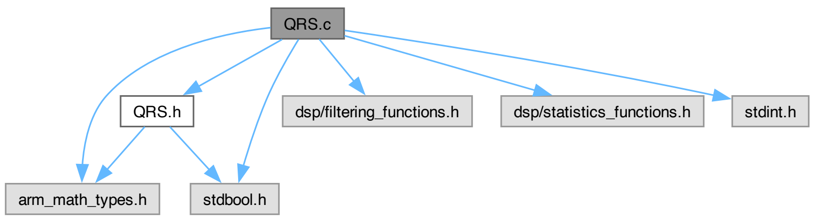
```
This module is essentially a higher-level interface to the ILI9341 module.
```

6.6 QRS.c File Reference

Source code for QRS detection module.

```
#include "QRS.h"
#include "arm_math_types.h"
#include "dsp/filtering_functions.h"
#include "dsp/statistics_functions.h"
#include <stdbool.h>
```

```
#include <stdint.h>
```
Include dependency graph for QRS.c:



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))

Functions

Implementation-specific Functions

- 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.

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 , **STATE_BUFF_SIZE_DERFILT** = NUM_COEFF_DERFILT + BLOCK_SIZE↩_DERFILT - 1 , **BLOCK_SIZE_MOVAVG** = 1 , **NUM_COEFF_MOVAVG** = 10 ,
  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

6.6.1 Detailed Description

Source code for QRS detection module.

Author

Bryan McElvy

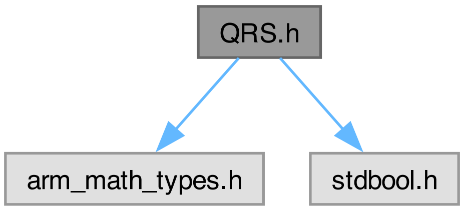
```
The algorithm used in this file is a simplified version of the Pan-Tompkins algorithm.
Specifically, this version currently only uses the integrated signal for the
thresholding, and also completely omits the searchback and T wave discrimination parts
of the original.
```

6.7 QRS.h File Reference

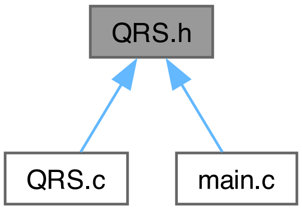
Header file for QRS detection module.

```
#include "arm_math_types.h"
#include <stdbool.h>
```

Include dependency graph for QRS.h:



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



Macros

- #define **QRS_SAMP_FREQ** ((uint32_t) 200)
- #define **QRS_SAMP_PERIOD_SEC** ((float32_t) 0.005f)
- #define **QRS_NUM_SAMP** ((uint16_t) (1 << 11))

Functions

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.

6.7.1 Detailed Description

Header file for QRS detection module.

Author

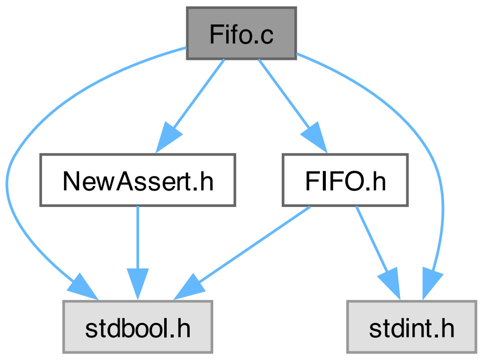
Bryan McElvy

6.8 Fifo.c File Reference

Source code for FIFO buffer module.

```
#include "FIFO.h"
#include "NewAssert.h"
#include <stdbool.h>
#include <stdint.h>
```

Include dependency graph for Fifo.c:



Data Structures

- struct Fifo_t

Functions

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

  Initialize a FIFO buffer of length N.

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_TransferOne (volatile Fifo_t srcFifo, volatile Fifo_t destFifo)
  Transfer a value from one FIFO buffer to another.

Bulk Removal

- void FIFO_Flush (volatile Fifo_t fifo, uint32_t outputBuffer[ ])
  Empty the FIFO buffer's contents into an array.
- void FIFO_Reset (volatile Fifo_t fifo)
  Reset the FIFO buffer.
- void FIFO_TransferAll (volatile Fifo_t srcFifo, volatile Fifo_t destFifo)
  Transfer the contents of one FIFO buffer to another.

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.

Variables

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

6.8.1 Detailed Description

Source code for FIFO buffer module.

Author

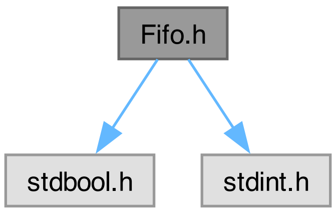
Bryan McElvy

6.9 Fifo.h File Reference

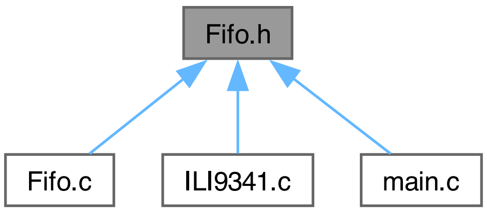
Header file for FIFO buffer implementation.

```
#include <stdbool.h>
#include <stdint.h>
```

Include dependency graph for Fifo.h:



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



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*.*

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_TransferOne (volatile Fifo_t srcFifo, volatile Fifo_t destFifo)

  Transfer a value from one FIFO buffer to another.

Bulk Removal

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

  Empty the FIFO buffer's contents into an array.
- void FIFO_Reset (volatile Fifo_t fifo)

  Reset the FIFO buffer.
- void FIFO_TransferAll (volatile Fifo_t srcFifo, volatile Fifo_t destFifo)

  Transfer the contents of one FIFO buffer to another.

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.

6.9.1 Detailed Description

Header file for FIFO buffer implementation.

Author

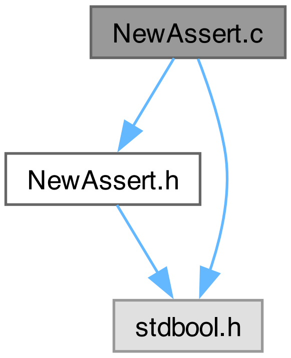
Bryan McElvy

6.10 NewAssert.c File Reference

Source code for custom `assert` implementation.

```
#include "NewAssert.h"
#include <stdbool.h>
```

Include dependency graph for NewAssert.c:



Functions

- void Assert (bool condition)

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

6.10.1 Detailed Description

Source code for custom `assert` implementation.

Author

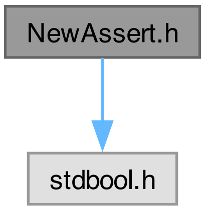
Bryan McElvy

6.11 NewAssert.h File Reference

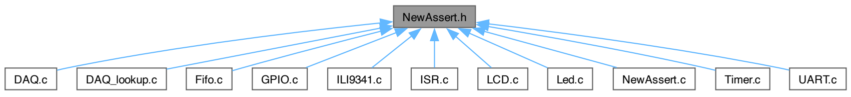
Header file for custom `assert` implementation.

```
#include <stdbool.h>
```

Include dependency graph for NewAssert.h:



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



Functions

- void Assert (bool condition)

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

6.11.1 Detailed Description

Header file for custom `assert` implementation.

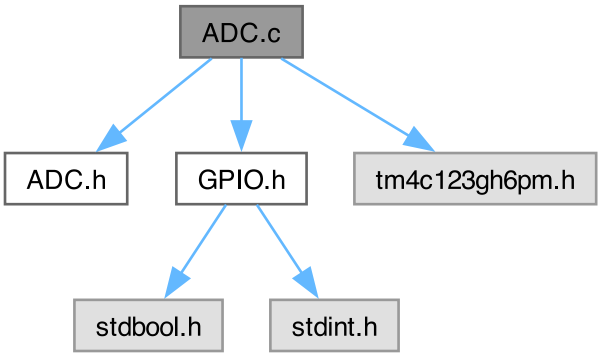
Author

Bryan McElvy

6.12 ADC.c File Reference

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

```
#include "ADC.h"
#include "GPIO.h"
#include "tm4c123gh6pm.h"
```
Include dependency graph for ADC.c:



Functions

- void ADC_Init (void)

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

6.12.1 Detailed Description

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

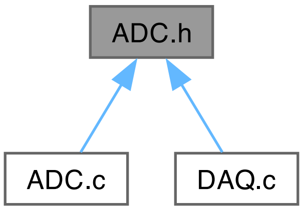
Author

Bryan McElvy

6.13 ADC.h File Reference

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

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



Functions

- void ADC_Init (void)

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

6.13.1 Detailed Description

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

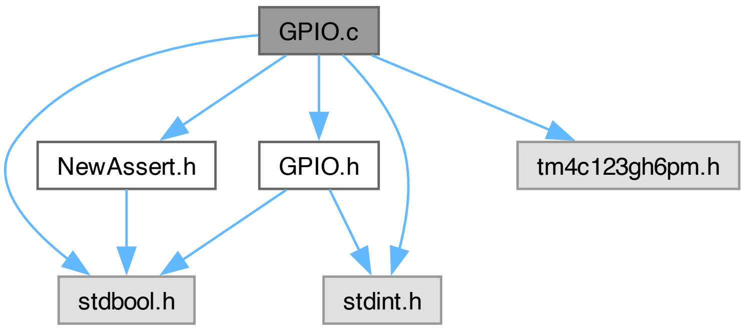
Author

Bryan McElvy

6.14 GPIO.c File Reference

Source code for GPIO module.

```
#include "GPIO.h"
#include <NewAssert.h>
#include "tm4c123gh6pm.h"
#include <stdbool.h>
#include <stdint.h>
```
Include dependency graph for GPIO.c:



Data Structures

- struct GpioPort_t

Macros

- #define **GPIO_NUM_PORTS** 6

Enumerations

- enum {
  GPIO_PORTA_BASE_ADDRESS = (uint32_t) 0x40004000 , **GPIO_PORTB_BASE_ADDRESS** = (uint32↩_t) 0x40005000 , **GPIO_PORTC_BASE_ADDRESS** = (uint32_t) 0x40006000 , **GPIO_PORTD_BASE_↩ADDRESS** = (uint32_t) 0x40007000 ,
  GPIO_PORTE_BASE_ADDRESS = (uint32_t) 0x40024000 , **GPIO_PORTF_BASE_ADDRESS** = (uint32_t) 0x40025000 }
- enum {
  GPIO_DATA_R_OFFSET = (uint32_t) 0x03FC , **GPIO_DIR_R_OFFSET** = (uint32_t) 0x0400 , **GPIO_IS_R↩_OFFSET** = (uint32_t) 0x0404 , **GPIO_IBE_R_OFFSET** = (uint32_t) 0x0408 ,
  GPIO_IEV_R_OFFSET = (uint32_t) 0x040C , **GPIO_IM_R_OFFSET** = (uint32_t) 0x0410 , **GPIO_ICR_R_↩OFFSET** = (uint32_t) 0x041C , **GPIO_AFSEL_R_OFFSET** = (uint32_t) 0x0420 ,
  GPIO_DR2R_R_OFFSET = (uint32_t) 0x0500 , **GPIO_DR4R_R_OFFSET** = (uint32_t) 0x0504 , **GPIO_↩DR8R_R_OFFSET** = (uint32_t) 0x0508 , **GPIO_PUR_R_OFFSET** = (uint32_t) 0x0510 ,
  GPIO_PDR_R_OFFSET = (uint32_t) 0x0518 , **GPIO_DEN_R_OFFSET** = (uint32_t) 0x051C , **GPIO_↩LOCK_R_OFFSET** = (uint32_t) 0x0520 , **GPIO_COMMIT_R_OFFSET** = (uint32_t) 0x0524 ,
  GPIO_AMSEL_R_OFFSET = (uint32_t) 0x0528 , **GPIO_PCTL_R_OFFSET** = (uint32_t) 0x052C }

Functions

- GpioPort_t GPIO_InitPort (GPIO_PortName_t portName)

  Initialize a GPIO Port and return a pointer to its `struct`.
- bool GPIO_isPortInit (GpioPort_t gpioPort)

  Check if the GPIO port is initialized.
- uint32_t GPIO_getBaseAddr (GpioPort_t gpioPort)

  Get the base address of a GPIO port.
- void GPIO_ConfigDirOutput (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Configure the direction of the specified GPIO pins. All pins are configured to `INPUT` by default, so this function should only be called to specify `OUTPUT` pins.
- void GPIO_ConfigDirInput (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Configure the specified GPIO pins as `INPUT` pins. All pins are configured to `INPUT` by default, so this function is technically unnecessary, but useful for code readability.
- void GPIO_ConfigPullUp (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Activate the specified pins' internal pull-up resistors.
- void GPIO_ConfigPullDown (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Activate the specified pins' internal pull-down resistors.
- void GPIO_ConfigDriveStrength (GpioPort_t gpioPort, GPIO_Pin_t pinMask, uint8_t drive_mA)

  Configure the specified pins' drive strength. Pins are initialized with 2[mA] drive strength, so this is only needed for a drive strength of 4[mA] or 8[mA].
- void GPIO_EnableDigital (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Enable digital I/O for the specified pins.
- void GPIO_DisableDigital (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Disable digital I/O for the specified pins.
- void GPIO_ConfigInterrupts_Edge (GpioPort_t gpioPort, GPIO_Pin_t pinMask, bool risingEdge)

  Configure the specified GPIO pins to trigger an interrupt on the rising or falling edge of an input.
- void GPIO_ConfigInterrupts_BothEdges (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Configure the specified GPIO pins to trigger an interrupt on both edges of an input.
- void GPIO_ConfigInterrupts_LevelTrig (GpioPort_t gpioPort, GPIO_Pin_t pinMask, bool highLevel)

  Configure the specified GPIO pins to trigger an interrupt on a high level or low level pulse.
- void GPIO_ConfigNVIC (GpioPort_t gpioPort, uint8_t priority)

  Configure interrupts for the selected port in the NVIC.
- uint32_t GPIO_getDataRegister (GpioPort_t gpioPort)

  Get the address of a GPIO port's data register.
- uint8_t GPIO_ReadPins (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Read from the specified GPIO pin.
- void GPIO_WriteHigh (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Write a `1` to the specified GPIO pins.
- void GPIO_WriteLow (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Write a `0` to the specified GPIO pins.
- void GPIO_Toggle (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Toggle the specified GPIO pins.
- void GPIO_ConfigAltMode (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Activate the alternate mode for the specified pins.
- void GPIO_ConfigPortCtrl (GpioPort_t gpioPort, GPIO_Pin_t pinMask, uint8_t fieldEncoding)

  Specify the alternate mode to use for the specified pins.
- void GPIO_ConfigAnalog (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Activate analog mode for the specified GPIO pins.

Variables

- static GpioPortStruct_t GPIO_PTR_ARR [6]

6.14.1 Detailed Description

Source code for GPIO module.

Author

Bryan McElvy

6.14.2 Function Documentation

GPIO_InitPort()

```
GpioPort_t GPIO_InitPort (
            GPIO_PortName_t portName )
```

Initialize a GPIO Port and return a pointer to its `struct`.

Parameters

`in`	*portName*	Name of the chosen port.

Returns

GPIO_Port_t∗ Pointer to the GPIO port's `struct`.

GPIO_isPortInit()

```
bool GPIO_isPortInit (
            GpioPort_t gpioPort )
```

Check if the GPIO port is initialized.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`out`	*true*	The GPIO port is initialized.
`out`	*false*	The GPIO port has not been initialized.

GPIO_getBaseAddr()

```
uint32_t GPIO_getBaseAddr (
            GpioPort_t gpioPort )
```

Get the base address of a GPIO port.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`out`	*baseAddress*	Base address of the GPIO port.

GPIO_ConfigDirOutput()

```
void GPIO_ConfigDirOutput (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask )
```

Configure the direction of the specified GPIO pins. All pins are configured to `INPUT` by default, so this function should only be called to specify `OUTPUT` pins.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`in`	*bitMask*	Bit mask corresponding to the intended `OUTPUT` pin(s).

GPIO_ConfigDirInput()

```
void GPIO_ConfigDirInput (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask )
```

Configure the specified GPIO pins as `INPUT` pins. All pins are configured to `INPUT` by default, so this function is technically unnecessary, but useful for code readability.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`in`	*bitMask*	Bit mask corresponding to the intended `INPUT` pin(s).

GPIO_ConfigPullUp()

```
void GPIO_ConfigPullUp (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask )
```

Activate the specified pins' internal pull-up resistors.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`in`	*pinMask*	Bit mask corresponding to the intended pin(s).

GPIO_ConfigPullDown()

```
void GPIO_ConfigPullDown (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask )
```

Activate the specified pins' internal pull-down resistors.

Parameters

in	*gpioPort*	Pointer to the specified GPIO port.
in	*pinMask*	Bit mask corresponding to the intended pin(s).

GPIO_ConfigDriveStrength()

```
void GPIO_ConfigDriveStrength (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask,
            uint8_t drive_mA )
```

Configure the specified pins' drive strength. Pins are initialized with 2[mA] drive strength, so this is only needed for a drive strength of 4[mA] or 8[mA].

Parameters

in	*gpioPort*	Pointer to the specified GPIO port.
in	*pinMask*	Bit mask corresponding to the intended pin(s).
in	*drive_mA*	Drive strength in [mA]. Should be 2, 4, or 8 [mA].

GPIO_EnableDigital()

```
void GPIO_EnableDigital (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask )
```

Enable digital I/O for the specified pins.

Parameters

in	*gpioPort*	Pointer to the specified GPIO port.
in	*pinMask*	Bit mask corresponding to the intended pin(s).

GPIO_DisableDigital()

```
void GPIO_DisableDigital (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask )
```

Disable digital I/O for the specified pins.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`in`	*pinMask*	Bit mask corresponding to the intended pin(s).

GPIO_ConfigInterrupts_Edge()

```
void GPIO_ConfigInterrupts_Edge (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask,
            bool risingEdge )
```

Configure the specified GPIO pins to trigger an interrupt on the rising or falling edge of an input.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`in`	*pinMask*	Bit mask corresponding to the intended pin(s).
`in`	*risingEdge*	`true` for rising edge, `false` for falling edge

GPIO_ConfigInterrupts_BothEdges()

```
void GPIO_ConfigInterrupts_BothEdges (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask )
```

Configure the specified GPIO pins to trigger an interrupt on both edges of an input.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`in`	*pinMask*	Bit mask corresponding to the intended pin(s).

GPIO_ConfigInterrupts_LevelTrig()

```
void GPIO_ConfigInterrupts_LevelTrig (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask,
            bool highLevel )
```

Configure the specified GPIO pins to trigger an interrupt on a high level or low level pulse.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`in`	*pinMask*	Bit mask corresponding to the intended pin(s).
`in`	*highLevel*	`true` for high level, `false` for low level

GPIO_ConfigNVIC()

```
void GPIO_ConfigNVIC (
            GpioPort_t gpioPort,
            uint8_t priority )
```

Configure interrupts for the selected port in the NVIC.

Parameters

in	*gpioPort*	Pointer to the specified GPIO port.
in	*priority*	Priority number between 0 (highest) and 7 (lowest).

GPIO_getDataRegister()

```
uint32_t GPIO_getDataRegister (
            GpioPort_t gpioPort )
```

Get the address of a GPIO port's data register.

Parameters

in	*gpioPort*	Pointer to the specified GPIO port.
out	*dataRegister*	Address of the GPIO port's data register.

GPIO_ReadPins()

```
uint8_t GPIO_ReadPins (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask )
```

Read from the specified GPIO pin.

Parameters

in	*gpioPort*	Pointer to the specified GPIO port.
in	*pinMask*	Bit mask corresponding to the intended pin(s).

GPIO_WriteHigh()

```
void GPIO_WriteHigh (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask )
```

Write a `1` to the specified GPIO pins.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`in`	*pinMask*	Bit mask corresponding to the intended pin(s).

GPIO_WriteLow()

```
void GPIO_WriteLow (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask )
```

Write a `0` to the specified GPIO pins.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`in`	*pinMask*	Bit mask corresponding to the intended pin(s).

GPIO_Toggle()

```
void GPIO_Toggle (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask )
```

Toggle the specified GPIO pins.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`in`	*pinMask*	Bit mask corresponding to the intended pin(s).

GPIO_ConfigAltMode()

```
void GPIO_ConfigAltMode (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask )
```

Activate the alternate mode for the specified pins.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`in`	*pinMask*	Bit mask corresponding to the intended pin(s).

GPIO_ConfigPortCtrl()

```
void GPIO_ConfigPortCtrl (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask,
            uint8_t fieldEncoding )
```

Specify the alternate mode to use for the specified pins.

Parameters

in	*gpioPort*	Pointer to the specified GPIO port.
in	*pinMask*	Bit mask corresponding to the intended pin(s).
in	*fieldEncoding*	Number corresponding to intended alternate mode.

GPIO_ConfigAnalog()

```
void GPIO_ConfigAnalog (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask )
```

Activate analog mode for the specified GPIO pins.

Parameters

in	*gpioPort*	Pointer to the specified GPIO port.
in	*pinMask*	Bit mask corresponding to the intended pin(s).

6.14.3 Variable Documentation

GPIO_PTR_ARR

```
GpioPortStruct_t GPIO_PTR_ARR[6]  [static]
```

Initial value:

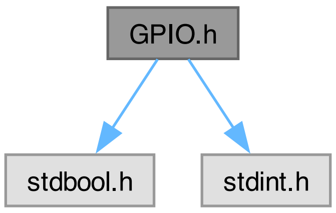
```
= {
    { GPIO_PORTA_BASE_ADDRESS, (GPIO_PORTA_BASE_ADDRESS + GPIO_DATA_R_OFFSET), false },
    { GPIO_PORTB_BASE_ADDRESS, (GPIO_PORTB_BASE_ADDRESS + GPIO_DATA_R_OFFSET), false },
    { GPIO_PORTC_BASE_ADDRESS, (GPIO_PORTC_BASE_ADDRESS + GPIO_DATA_R_OFFSET), false },
    { GPIO_PORTD_BASE_ADDRESS, (GPIO_PORTD_BASE_ADDRESS + GPIO_DATA_R_OFFSET), false },
    { GPIO_PORTE_BASE_ADDRESS, (GPIO_PORTE_BASE_ADDRESS + GPIO_DATA_R_OFFSET), false },
    { GPIO_PORTF_BASE_ADDRESS, (GPIO_PORTF_BASE_ADDRESS + GPIO_DATA_R_OFFSET), false },
}
```

6.15 GPIO.h File Reference

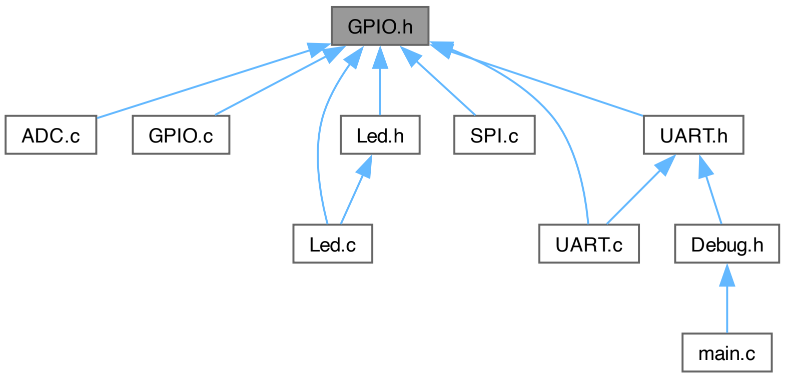
Header file for general-purpose input/output (GPIO) device driver.

```
#include <stdbool.h>
#include <stdint.h>
```

Include dependency graph for GPIO.h:



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



Enumerations

- enum **GPIO_PortName_t** {
  A , **B** , **C** , **D** ,
  E , **F** }
- enum **GPIO_Pin_t** {
  GPIO_PIN0 = ((uint8_t) 1) , **GPIO_PIN1** = ((uint8_t) (1 << 1)) , **GPIO_PIN2** = ((uint8_t) (1 << 2)) , **GPIO↩
  _PIN3** = ((uint8_t) (1 << 3)) ,
  GPIO_PIN4 = ((uint8_t) (1 << 4)) , **GPIO_PIN5** = ((uint8_t) (1 << 5)) , **GPIO_PIN6** = ((uint8_t) (1 << 6)) ,
  GPIO_PIN7 = ((uint8_t) (1 << 7)) ,
  GPIO_ALL_PINS = ((uint8_t) (0xFF)) }
- enum {
  LED_RED = GPIO_PIN1 , **LED_GREEN** = GPIO_PIN3 , **LED_BLUE** = GPIO_PIN2 , **LED_YELLOW** = (LED_RED + LED_GREEN) ,
  LED_CYAN = (LED_BLUE + LED_GREEN) , **LED_PURPLE** = (LED_RED + LED_BLUE) , **LED_WHITE** = (LED_RED + LED_BLUE + LED_GREEN) }

Functions

- GpioPort_t GPIO_InitPort (GPIO_PortName_t portName)

  Initialize a GPIO Port and return a pointer to its `struct`.
- uint32_t GPIO_getBaseAddr (GpioPort_t gpioPort)

  Get the base address of a GPIO port.
- bool GPIO_isPortInit (GpioPort_t gpioPort)

  Check if the GPIO port is initialized.
- void GPIO_ConfigDirOutput (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Configure the direction of the specified GPIO pins. All pins are configured to `INPUT` by default, so this function should only be called to specify `OUTPUT` pins.
- void GPIO_ConfigDirInput (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Configure the specified GPIO pins as `INPUT` pins. All pins are configured to `INPUT` by default, so this function is technically unnecessary, but useful for code readability.
- void GPIO_ConfigPullUp (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Activate the specified pins' internal pull-up resistors.
- void GPIO_ConfigPullDown (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Activate the specified pins' internal pull-down resistors.
- void GPIO_ConfigDriveStrength (GpioPort_t gpioPort, GPIO_Pin_t pinMask, uint8_t drive_mA)

  Configure the specified pins' drive strength. Pins are initialized with 2[mA] drive strength, so this is only needed for a drive strength of 4[mA] or 8[mA].
- void GPIO_EnableDigital (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Enable digital I/O for the specified pins.
- void GPIO_DisableDigital (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Disable digital I/O for the specified pins.
- void GPIO_ConfigInterrupts_Edge (GpioPort_t gpioPort, GPIO_Pin_t pinMask, bool risingEdge)

  Configure the specified GPIO pins to trigger an interrupt on the rising or falling edge of an input.
- void GPIO_ConfigInterrupts_BothEdges (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Configure the specified GPIO pins to trigger an interrupt on both edges of an input.
- void GPIO_ConfigInterrupts_LevelTrig (GpioPort_t gpioPort, GPIO_Pin_t pinMask, bool highLevel)

  Configure the specified GPIO pins to trigger an interrupt on a high level or low level pulse.
- void GPIO_ConfigNVIC (GpioPort_t gpioPort, uint8_t priority)

  Configure interrupts for the selected port in the NVIC.
- uint32_t GPIO_getDataRegister (GpioPort_t gpioPort)

  Get the address of a GPIO port's data register.
- uint8_t GPIO_ReadPins (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Read from the specified GPIO pin.
- void GPIO_WriteHigh (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Write a `1` to the specified GPIO pins.
- void GPIO_WriteLow (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Write a `0` to the specified GPIO pins.
- void GPIO_Toggle (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Toggle the specified GPIO pins.
- void GPIO_ConfigAltMode (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Activate the alternate mode for the specified pins.
- void GPIO_ConfigPortCtrl (GpioPort_t gpioPort, GPIO_Pin_t pinMask, uint8_t fieldEncoding)

  Specify the alternate mode to use for the specified pins.
- void GPIO_ConfigAnalog (GpioPort_t gpioPort, GPIO_Pin_t pinMask)

  Activate analog mode for the specified GPIO pins.

6.15.1 Detailed Description

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

Author

Bryan McElvy

6.15.2 Function Documentation

GPIO_InitPort()

```
GpioPort_t GPIO_InitPort (
            GPIO_PortName_t portName )
```

Initialize a GPIO Port and return a pointer to its `struct`.

Parameters

`in`	*portName*	Name of the chosen port.

Returns

GPIO_Port_t∗ Pointer to the GPIO port's `struct`.

GPIO_getBaseAddr()

```
uint32_t GPIO_getBaseAddr (
            GpioPort_t gpioPort )
```

Get the base address of a GPIO port.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`out`	*baseAddress*	Base address of the GPIO port.

GPIO_isPortInit()

```
bool GPIO_isPortInit (
            GpioPort_t gpioPort )
```

Check if the GPIO port is initialized.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`out`	*true*	The GPIO port is initialized.
`out`	*false*	The GPIO port has not been initialized.

GPIO_ConfigDirOutput()

```
void GPIO_ConfigDirOutput (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask )
```

Configure the direction of the specified GPIO pins. All pins are configured to `INPUT` by default, so this function should only be called to specify `OUTPUT` pins.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`in`	*bitMask*	Bit mask corresponding to the intended `OUTPUT` pin(s).

GPIO_ConfigDirInput()

```
void GPIO_ConfigDirInput (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask )
```

Configure the specified GPIO pins as `INPUT` pins. All pins are configured to `INPUT` by default, so this function is technically unnecessary, but useful for code readability.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`in`	*bitMask*	Bit mask corresponding to the intended `INPUT` pin(s).

GPIO_ConfigPullUp()

```
void GPIO_ConfigPullUp (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask )
```

Activate the specified pins' internal pull-up resistors.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`in`	*pinMask*	Bit mask corresponding to the intended pin(s).

GPIO_ConfigPullDown()

```
void GPIO_ConfigPullDown (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask )
```

Activate the specified pins' internal pull-down resistors.

Parameters

in	*gpioPort*	Pointer to the specified GPIO port.
in	*pinMask*	Bit mask corresponding to the intended pin(s).

GPIO_ConfigDriveStrength()

```
void GPIO_ConfigDriveStrength (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask,
            uint8_t drive_mA )
```

Configure the specified pins' drive strength. Pins are initialized with 2[mA] drive strength, so this is only needed for a drive strength of 4[mA] or 8[mA].

Parameters

in	*gpioPort*	Pointer to the specified GPIO port.
in	*pinMask*	Bit mask corresponding to the intended pin(s).
in	*drive_mA*	Drive strength in [mA]. Should be 2, 4, or 8 [mA].

GPIO_EnableDigital()

```
void GPIO_EnableDigital (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask )
```

Enable digital I/O for the specified pins.

Parameters

in	*gpioPort*	Pointer to the specified GPIO port.
in	*pinMask*	Bit mask corresponding to the intended pin(s).

GPIO_DisableDigital()

```
void GPIO_DisableDigital (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask )
```

Disable digital I/O for the specified pins.

Parameters

in	*gpioPort*	Pointer to the specified GPIO port.
in	*pinMask*	Bit mask corresponding to the intended pin(s).

GPIO_ConfigInterrupts_Edge()

```
void GPIO_ConfigInterrupts_Edge (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask,
            bool risingEdge )
```

Configure the specified GPIO pins to trigger an interrupt on the rising or falling edge of an input.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`in`	*pinMask*	Bit mask corresponding to the intended pin(s).
`in`	*risingEdge*	`true` for rising edge, `false` for falling edge

GPIO_ConfigInterrupts_BothEdges()

```
void GPIO_ConfigInterrupts_BothEdges (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask )
```

Configure the specified GPIO pins to trigger an interrupt on both edges of an input.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`in`	*pinMask*	Bit mask corresponding to the intended pin(s).

GPIO_ConfigInterrupts_LevelTrig()

```
void GPIO_ConfigInterrupts_LevelTrig (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask,
            bool highLevel )
```

Configure the specified GPIO pins to trigger an interrupt on a high level or low level pulse.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`in`	*pinMask*	Bit mask corresponding to the intended pin(s).
`in`	*highLevel*	`true` for high level, `false` for low level

GPIO_ConfigNVIC()

```
void GPIO_ConfigNVIC (
            GpioPort_t gpioPort,
            uint8_t priority )
```

Configure interrupts for the selected port in the NVIC.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`in`	*priority*	Priority number between 0 (highest) and 7 (lowest).

GPIO_getDataRegister()

```
uint32_t GPIO_getDataRegister (
             GpioPort_t gpioPort )
```

Get the address of a GPIO port's data register.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`out`	*dataRegister*	Address of the GPIO port's data register.

GPIO_ReadPins()

```
uint8_t GPIO_ReadPins (
             GpioPort_t gpioPort,
             GPIO_Pin_t pinMask )
```

Read from the specified GPIO pin.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`in`	*pinMask*	Bit mask corresponding to the intended pin(s).

GPIO_WriteHigh()

```
void GPIO_WriteHigh (
             GpioPort_t gpioPort,
             GPIO_Pin_t pinMask )
```

Write a `1` to the specified GPIO pins.

Parameters

`in`	*gpioPort*	Pointer to the specified GPIO port.
`in`	*pinMask*	Bit mask corresponding to the intended pin(s).

GPIO_WriteLow()

```
void GPIO_WriteLow (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask )
```

Write a `0` to the specified GPIO pins.

Parameters

in	*gpioPort*	Pointer to the specified GPIO port.
in	*pinMask*	Bit mask corresponding to the intended pin(s).

GPIO_Toggle()

```
void GPIO_Toggle (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask )
```

Toggle the specified GPIO pins.

Parameters

in	*gpioPort*	Pointer to the specified GPIO port.
in	*pinMask*	Bit mask corresponding to the intended pin(s).

GPIO_ConfigAltMode()

```
void GPIO_ConfigAltMode (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask )
```

Activate the alternate mode for the specified pins.

Parameters

in	*gpioPort*	Pointer to the specified GPIO port.
in	*pinMask*	Bit mask corresponding to the intended pin(s).

GPIO_ConfigPortCtrl()

```
void GPIO_ConfigPortCtrl (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask,
            uint8_t fieldEncoding )
```

Specify the alternate mode to use for the specified pins.

Parameters

in	*gpioPort*	Pointer to the specified GPIO port.
in	*pinMask*	Bit mask corresponding to the intended pin(s).
in	*fieldEncoding*	Number corresponding to intended alternate mode.

GPIO_ConfigAnalog()

```
void GPIO_ConfigAnalog (
            GpioPort_t gpioPort,
            GPIO_Pin_t pinMask )
```

Activate analog mode for the specified GPIO pins.

Parameters

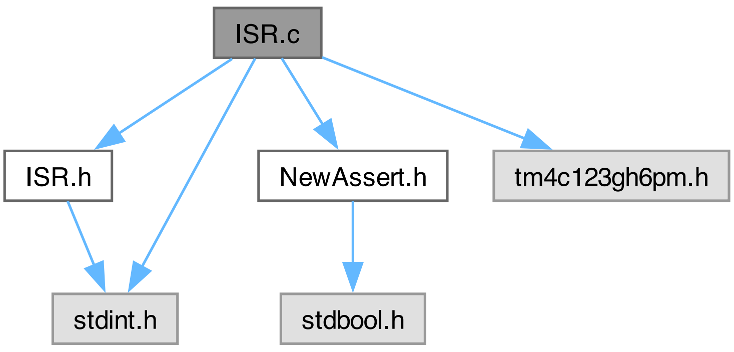
in	*gpioPort*	Pointer to the specified GPIO port.
in	*pinMask*	Bit mask corresponding to the intended pin(s).

6.16 ISR.c File Reference

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

```
#include "ISR.h"
#include "NewAssert.h"
#include "tm4c123gh6pm.h"
#include <stdint.h>
```

Include dependency graph for ISR.c:



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)

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

6.16.1 Detailed Description

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

Author

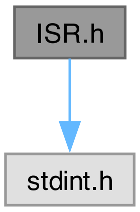
Bryan McElvy

6.17 ISR.h File Reference

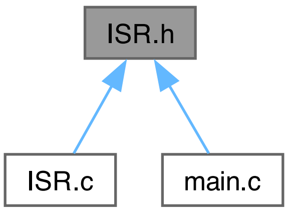
Header file for interrupt service routine (ISR) configuration module.

```
#include <stdint.h>
```

Include dependency graph for ISR.h:



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



Typedefs

- typedef void(∗ **ISR_t**) (void)

  Type definition for function pointers representing ISRs.

Functions

- void ISR_GlobalDisable (void)

  Disable all interrupts globally.
- void ISR_GlobalEnable (void)

  Enable all interrupts globally.
- 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).

6.17.1 Detailed Description

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

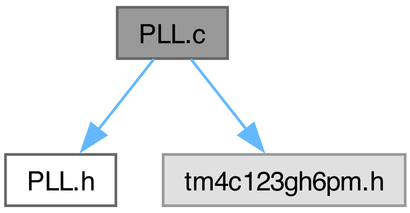
Author

Bryan McElvy

6.18 PLL.c File Reference

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

```
#include "PLL.h"
#include "tm4c123gh6pm.h"
```
Include dependency graph for PLL.c:



Functions

- void PLL_Init (void)

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

6.18.1 Detailed Description

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

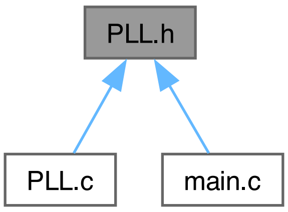
Author

Bryan McElvy

6.19 PLL.h File Reference

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

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



Functions

- void PLL_Init (void)

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

6.19.1 Detailed Description

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

Author

Bryan McElvy

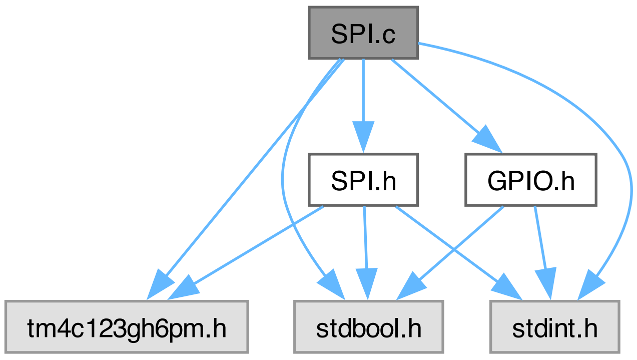
6.20 SPI.c File Reference

Source code for serial peripheral interface (SPI) module.

```
#include "SPI.h"
#include "GPIO.h"
#include "tm4c123gh6pm.h"
#include <stdbool.h>
```

```
#include <stdint.h>
```

Include dependency graph for SPI.c:



Macros

- #define SPI_SET_DC() (GPIO_PORTA_DATA_R |= 0x40)
- #define **SPI_CLEAR_DC**() (GPIO_PORTA_DATA_R &= ∼(0x40))
- #define **SPI_IS_BUSY** (SSI0_SR_R & 0x10)
- #define **SPI_TX_ISNOTFULL** (SSI0_SR_R & 0x02)

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.

6.20.1 Detailed Description

Source code for serial peripheral interface (SPI) module.

Author

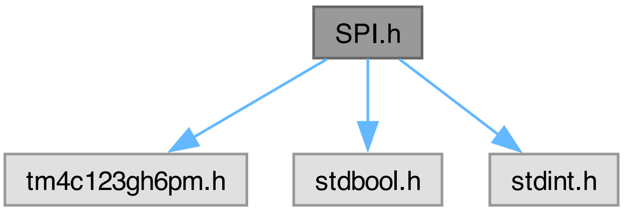
Bryan McElvy

6.21 SPI.h File Reference

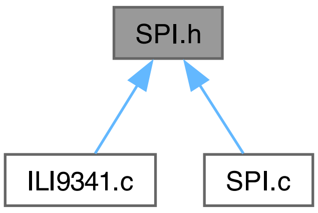
Header file for serial peripheral interface (SPI) module.

```
#include "tm4c123gh6pm.h"
#include <stdbool.h>
#include <stdint.h>
```

Include dependency graph for SPI.h:



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



Macros

- #define **SPI_CLEAR_RESET**() (GPIO_PORTA_DATA_R &= ∼(0x80))
- #define **SPI_SET_RESET**() (GPIO_PORTA_DATA_R |= 0x80)

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.

6.21.1 Detailed Description

Header file for serial peripheral interface (SPI) module.

Author

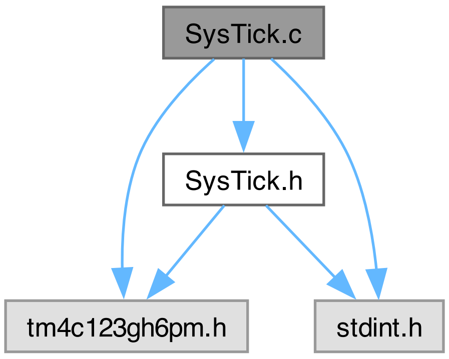
Bryan McElvy

6.22 SysTick.c File Reference

Implementation details for SysTick functions.

```
#include "SysTick.h"
#include "tm4c123gh6pm.h"
#include <stdint.h>
```

Include dependency graph for SysTick.c:



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.

6.22.1 Detailed Description

Implementation details for SysTick functions.

Author

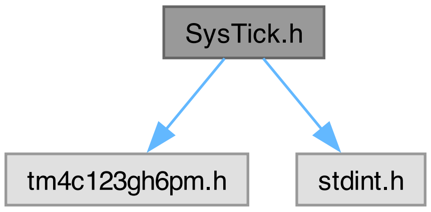
Bryan McElvy

6.23 SysTick.h File Reference

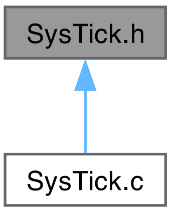
Driver module for using SysTick-based timing and/or interrupts.

```
#include "tm4c123gh6pm.h"
#include <stdint.h>
```

Include dependency graph for SysTick.h:



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



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.

6.23.1 Detailed Description

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

Author

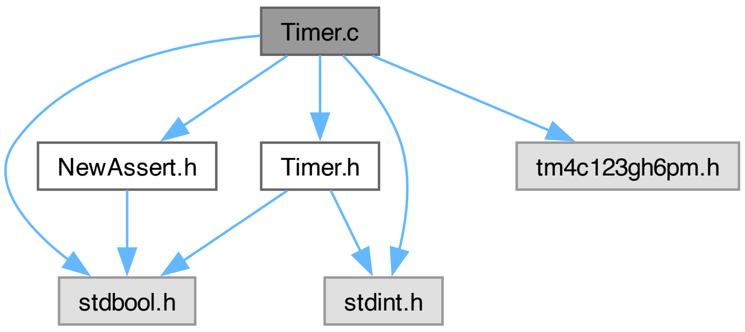
Bryan McElvy

6.24 Timer.c File Reference

Source code for Timer module.

```
#include "Timer.h"
#include "NewAssert.h"
#include "tm4c123gh6pm.h"
#include <stdbool.h>
#include <stdint.h>
```

Include dependency graph for Timer.c:



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 }

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]

6.24.1 Detailed Description

Source code for Timer module.

Author

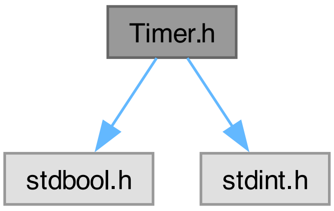
Bryan McElvy

6.25 Timer.h File Reference

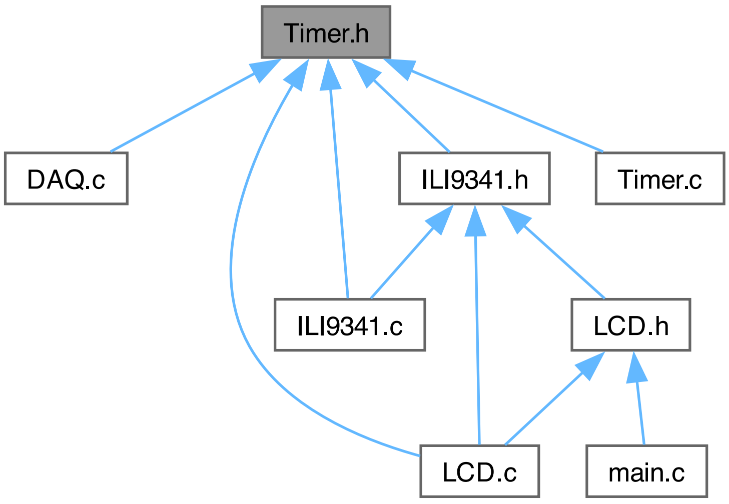
Device driver for general-purpose timer modules.

```
#include <stdbool.h>
#include <stdint.h>
```

Include dependency graph for Timer.h:



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



Enumerations

- 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.

6.25.1 Detailed Description

Device driver for general-purpose timer modules.

Author

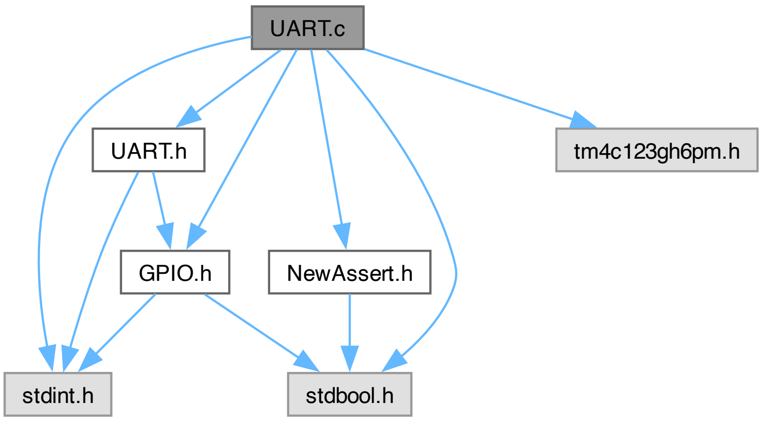
Bryan McElvy

6.26 UART.c File Reference

Source code for UART module.

```
#include "UART.h"
#include "GPIO.h"
#include "NewAssert.h"
#include "tm4c123gh6pm.h"
#include <stdbool.h>
#include <stdint.h>
```

Include dependency graph for UART.c:



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 }

Functions

- UART_t ∗ UART_Init (GpioPort_t port, UART_Num_t uartNum)

  Initialize the specified UART peripheral.
- 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 UART_t UART_ARR [8]

6.26.1 Detailed Description

Source code for UART module.

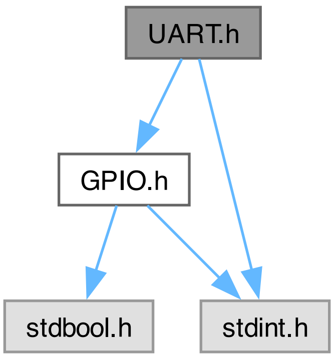
Author

Bryan McElvy

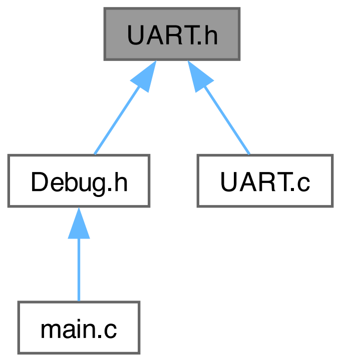
6.27 UART.h File Reference

Driver module for serial communication via UART0 and UART 1.

```
#include "GPIO.h"
#include <stdint.h>
```
Include dependency graph for UART.h:



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



Enumerations

- enum **UART_Num_t** {
  UART0 , **UART1** , **UART2** , **UART3** ,
  UART4 , **UART5** , **UART6** , **UART7** }

Functions

- UART_t ∗ UART_Init (GpioPort_t port, UART_Num_t uartNum)

  Initialize the specified UART peripheral.
- 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.

6.27.1 Detailed Description

Driver module for serial communication via UART0 and UART 1.

Author

Bryan McElvy

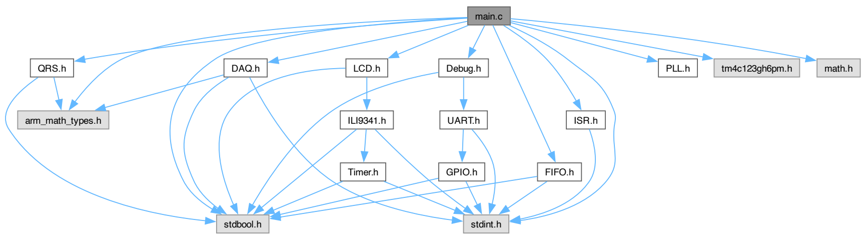
```
UART0 uses PA0 and PA1, which are not broken out but can connect
to a PC's serial port via USB.

UART1 uses PB0 (Rx) and PB1 (Tx), which are broken out but
do not connect to a serial port.
```

6.28 main.c File Reference

Main program file.

```
#include "DAQ.h"
#include "Debug.h"
#include "LCD.h"
#include "QRS.h"
#include "FIFO.h"
#include "ISR.h"
#include "PLL.h"
#include "arm_math_types.h"
#include "tm4c123gh6pm.h"
#include <math.h>
#include <stdbool.h>
#include <stdint.h>
```

Include dependency graph for main.c:



Enumerations

- enum { **DAQ_VECTOR_NUM** = INT_ADC0SS3 , **PROC_VECTOR_NUM** = INT_CAN0 , **LCD_VECTOR_NUM** = INT_TIMER1A }
- enum {
  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_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) }

Functions

- static void DAQ_Handler (void)

  Reads ADC output, converts to raw voltage sample, and sends to next FIFO.
- static void Processing_Handler (void)

  Removes baseline drift and PLI from a sample, and moves it to the QRS/LCD FIFOs.
- static void LCD_Handler (void)

  Applies a 0.5-40 [Hz] bandpass filter and plots the sample to the waveform.
- 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 bool **QRS_bufferIsFull** = false
- 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 **LCD_heartRateIsReady** = false
- static float32_t **QRS_processingBuffer** [QRS_ARRAY_LEN] = { 0 }
- static uint16_t **LCD_prevSampleBuffer** [LCD_X_MAX] = { 0 }

6.28.1 Detailed Description

Main program file.

Author

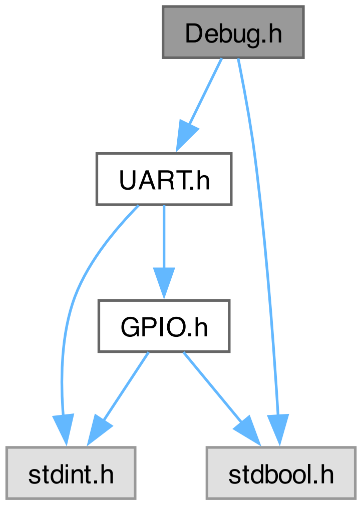
Bryan McElvy

6.29 Debug.h File Reference

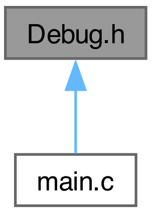
Functions to output debugging information to a serial port via UART.

```
#include "UART.h"
#include <stdbool.h>
```

Include dependency graph for Debug.h:



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



Functions

Initialization

- void Debug_Init (void)
  Initialize the Debug module.

Assertions

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

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.

6.29.1 Detailed Description

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

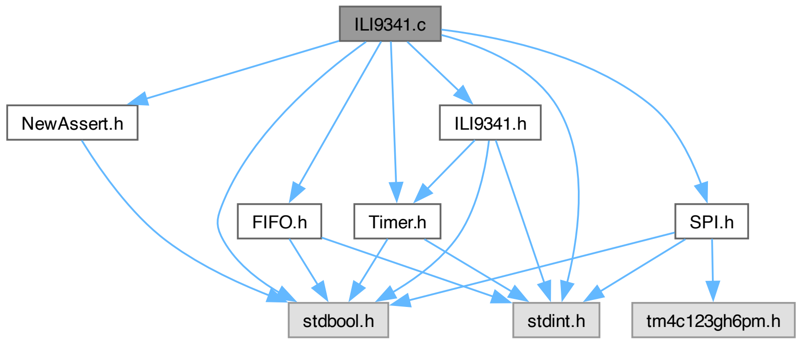
Author

Bryan McElvy

6.30 ILI9341.c File Reference

Source code for ILI9341 module.

```
#include "ILI9341.h"
#include "SPI.h"
#include "Timer.h"
#include "FIFO.h"
#include "NewAssert.h"
#include <stdbool.h>
#include <stdint.h>
```
Include dependency graph for ILI9341.c:



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_setDispInversion (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 }

6.30.1 Detailed Description

Source code for ILI9341 module.

Author

Bryan McElvy

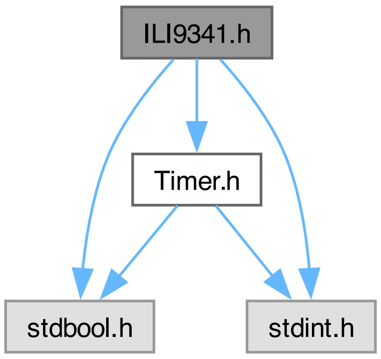
6.31 ILI9341.h File Reference

Driver module for interfacing with an ILI9341 LCD driver.

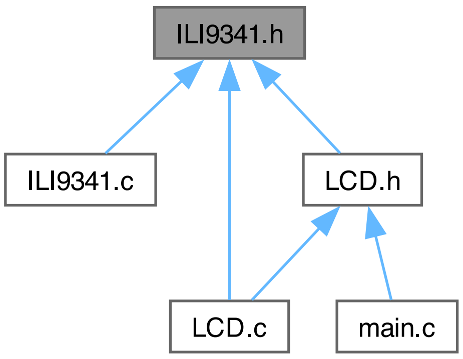
```
#include "Timer.h"
#include <stdbool.h>
```

```
#include <stdint.h>
```

Include dependency graph for ILI9341.h:



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



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 ,
  VSCRSADD = 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

- 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_setPartialArea (uint16_t rowStart, uint16_t rowEnd)

  Set the display area for partial mode. Call before activating partial mode.
- void ILI9341_setColorExpression (colorExpr_t colorExpr)

  Set the color expression (`FULL_COLORS` by default).
- void ILI9341_setDispInversion (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.

6.31.1 Detailed Description

Driver module for interfacing with an ILI9341 LCD driver.

Author

Bryan McElvy

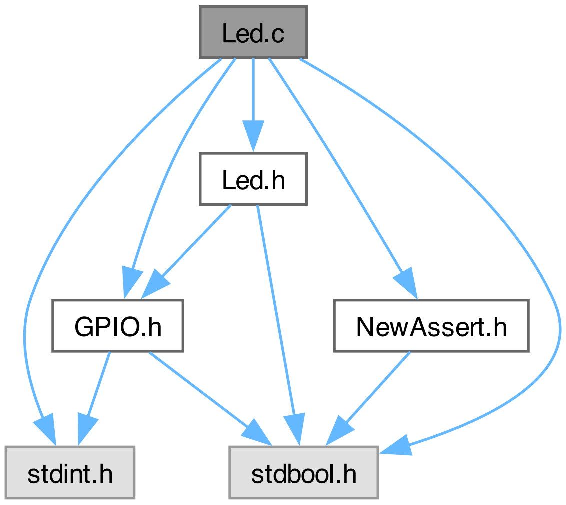
This module contains functions for initializing and outputting graphical data to a 240RGBx320 resolution, 262K color-depth liquid crystal display (LCD). The module interfaces the LaunchPad (or any other board featuring the TM4C123GH6PM microcontroller) with an ILI9341 LCD driver chip via the serial peripheral interface (SPI) protocol.

6.32 Led.c File Reference

Source code for LED module.

```
#include "Led.h"
#include "GPIO.h"
#include "NewAssert.h"
#include <stdbool.h>
#include <stdint.h>
```

Include dependency graph for Led.c:



Data Structures

- struct Led_t

Functions

- Led_t Led_Init (GpioPort_t gpioPort, GPIO_Pin_t pin)

  Initialize a light-emitting diode (LED) as an `Led_t`.
- bool **Led_isInit** (Led_t led)
- GpioPort_t Led_GetPort (Led_t led)

  Get the GPIO port associated with the LED.
- GPIO_Pin_t Led_GetPin (Led_t led)

  Get the GPIO pin associated with the LED.
- bool Led_isOn (Led_t led)

  Check the LED's status.
- void Led_TurnOn (Led_t led)

  Turn the LED `ON`.
- void Led_TurnOff (Led_t led)

  Turn the LED `OFF`.
- void Led_Toggle (Led_t led)

  Toggle the LED (i.e. `OFF` -> `ON` or `ON` -> `OFF`).

Variables

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

6.32.1 Detailed Description

Source code for LED module.

Author

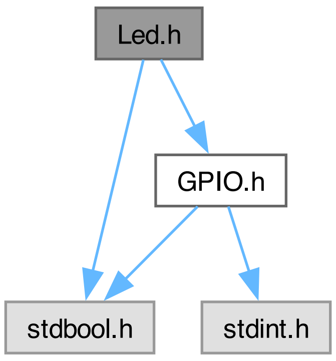
Bryan McElvy

6.33 Led.h File Reference

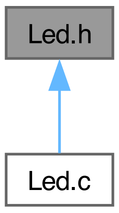
Interface for LED module.

```
#include "GPIO.h"
#include <stdbool.h>
```

Include dependency graph for Led.h:



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



Macros

- #define **LED_POOL_SIZE** 1

Functions

- Led_t Led_Init (GpioPort_t gpioPort, GPIO_Pin_t pin)

  Initialize a light-emitting diode (LED) as an `Led_t`.
- bool **Led_isInit** (Led_t led)
- GpioPort_t Led_GetPort (Led_t led)

  Get the GPIO port associated with the LED.
- GPIO_Pin_t Led_GetPin (Led_t led)

  Get the GPIO pin associated with the LED.
- bool Led_isOn (Led_t led)

  Check the LED's status.
- void Led_TurnOn (Led_t led)

  Turn the LED `ON`.
- void Led_TurnOff (Led_t led)

  Turn the LED `OFF`.
- void Led_Toggle (Led_t led)

  Toggle the LED (i.e. `OFF` -> `ON` or `ON` -> `OFF`).

6.33.1 Detailed Description

Interface for LED module.

Author

Bryan McElvy

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