Tutorial

Version 1.6.0

Creating a Middleware Application using CMSIS Components

ARM KEIL Microcontroller Tools

The latest version of this document is here: www.keil.com/appnotes/docs/apnt_268.asp

Abstract

This tutorial shows how to read the contents of a text file from a USB memory stick attached to a development board. After pressing an update button on the touch screen, the content is shown on the LCD. The tutorial explains the required steps to create the application on a STM32F429I-Discovery board but can be easily ported to other underlying hardware as it is using MDK-Professional Middleware and CMSIS, the Cortex Microcontroller Software Interface Standard.

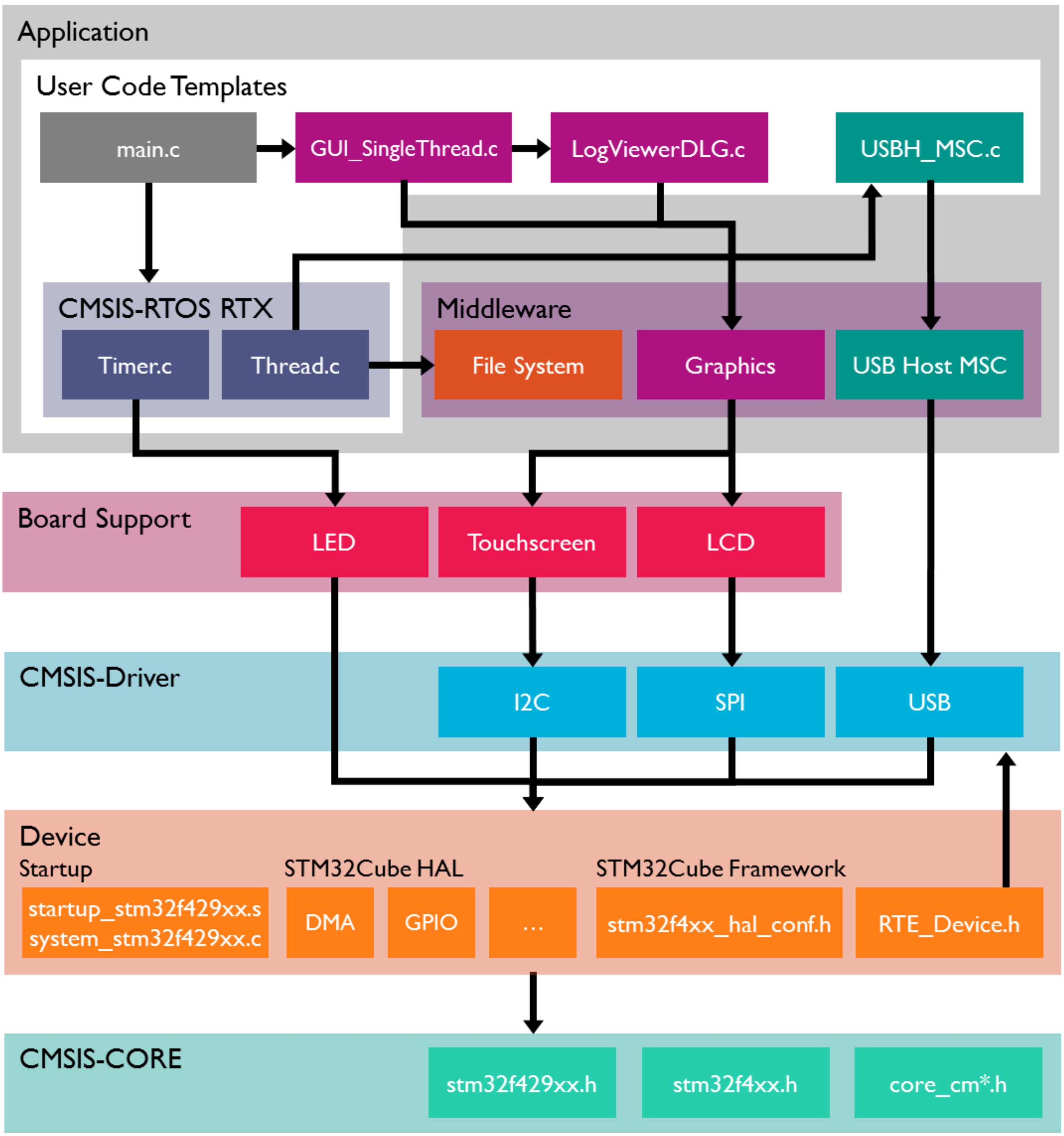
A set of videos is available that shows the steps to create this project. Please visit www.keil.com/mdk5/learn/usb_host

Contents

Introduction

This workshop explains how to create a software framework for a sophisticated microcontroller application using CMSIS and Middleware components. During this workshop a demo application is created that implements the following functions:

- Read the content of "Test.txt" file from a USB memory stick.
- Show this content on a graphical display.
- Provide an update button on a touch screen.



Software Stack

The application is created by using user code templates. These templates are part of software components such as the Middleware, CMSIS-RTOS or the STM32F4xx Device Family Pack (DFP). Some other source files are automatically generated such as the code that is creating the graphical user interface (GUI) on the external display (LogViewerDLG.c).

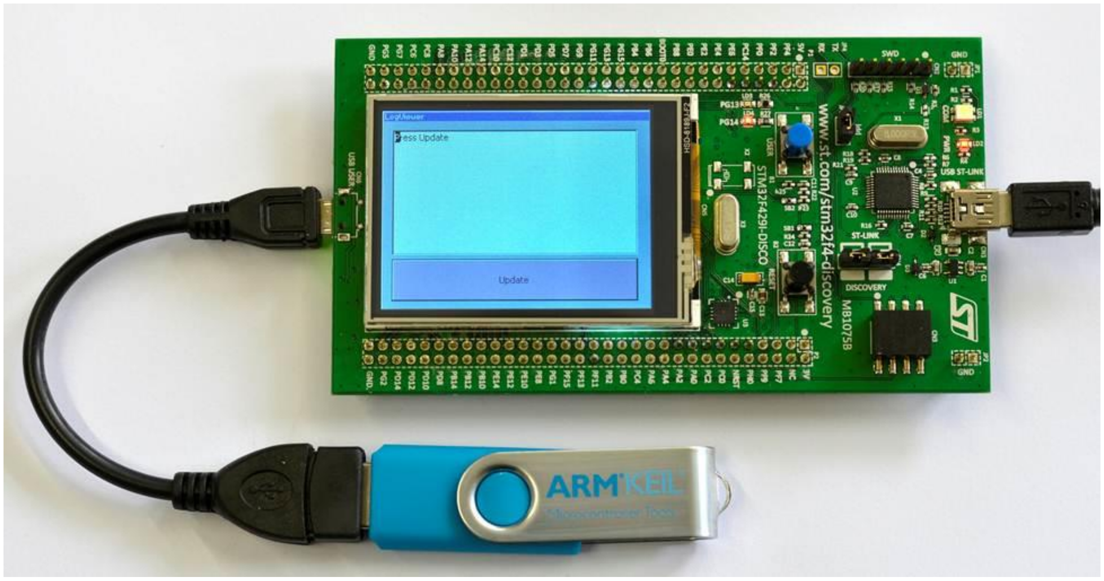
CMSIS-RTOS RTX is a real-time operating system that is part of MDK and adheres to the CMSIS specification. It is used to control the application.

The **board support** files enable the user to quickly develop code for the hardware that is used here. It provides a simple API to control LEDs, the touch screen and the LCD interface. Other components provide support for push buttons, joysticks, A/D converters or other external devices.

Middleware provides stacks for TCP/IP networking, USB communication, graphics, and file access. The Middleware used in this application is part of MDK-Professional and uses several CMSIS-Driver components.

CMSIS-Driver is an API that defines generic peripheral driver interfaces for middleware making it reusable across compliant devices. It connects microcontroller peripherals with middleware that implements for example communication stacks, file systems, or graphic user interfaces. CMSIS-Driver are available for several microcontroller families and are part of the DFPs. The DFP contains the support for the **device** in terms of startup and system code, a configuration file for the CMSIS-Driver and a device family specific software framework with hardware abstraction layer (HAL).

The basis for the software framework is **CMSIS-Core** that implements the basic run-time system for a Cortex-M device and gives the user access to the processor core and the device peripherals. The device header files adhere to the CMSIS-Core standard and help the user to access the underlying hardware.



The STM32F32F429IDiscovery Kit with the USB Stick connected to USB User OTG Connector.

The LCD displays the screen as created in the Graphical Display section in Step 4, 5 and 6. In the example given in this tutorial, the display will be rotated 90 º from that shown above.

Prerequisites

To run through the workshop you need to install the following software. Directions are given below:

- MDK-ARM Version 5.14 or later (https://www.keil.com/demo/eval/arm.htm).
- A valid MDK-Professional license.
- Keil::MDK-Middleware 6.3.0 or higher, ARM::CMSIS 4.3.0 or higher, Keil::ARM_Compiler 1.0.0 or higher
- Keil::STM32F4_DFP 2.4.0 or later which includes the STM32F429I-Discovery Board Support Package (BSP). We will download this from the Internet using Pack Installer.
- STM32F429I-Discovery Kit (www.st.com/web/catalog/tools/FM116/SC959/SS1532/PF259090).
  Note: Solder bridge SB9 ***must*** be bridged in order for the Serial Wire Viewer (SWV) to work. A soldering iron is needed. If you do not solder SB9, the examples will work but the Event Viewer, Trace Records and Exception windows will not display any information as these require SWV for their operation. See page 24.
- Text snippets for copy and paste and completed projects are here: www.keil.com/appnotes/docs/apnt_268.asp

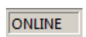
This tutorial assumes you have some experience with the MDK development tool and a basic knowledge of C.

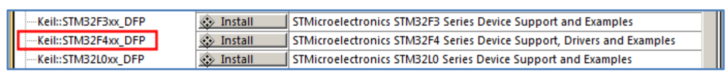
Set up the Workshop Environment

Install MDK:

1. Install MDK-ARM Version 5.14 or later. Use the default folder C:\Keil_v5 for the purposes of this tutorial.
2. After the initial MDK installation, the Pack Installer utility opens up. Read the Welcome message and close it.

Install the STM32F4xx Software Pack:

1. If Pack Installer is not open, first open µVision®: . Then open Pack Installer by clicking on its icon: 
2. The bottom right corner should display ONLINE: 

If it displays OFFLINE, connect your PC to the Internet.
3. Locate **Keil::STM32F4xx_DFP**. Click Install: The installation will commence.


4. Once the Pack is installed this will be displayed indicating a successful installation: 

Install the other required Software Packs:

5. Locate **Keil::MDK-Middleware**. Click Update
2. Locate **ARM::CMSIS**. Click Update
3. Locate **Keil::ARM_Compiler** and click Install

Install your MDK-Professional license.

1. In µVision, click on File → License Management, select the 7 day license. This button is only displayed if you are eligible for this offer. It can be used only 

once.
2. You may contact our sales team to request a time-limited license for this workshop: www.keil.com/contact
3. For more information and license installation instructions see: www.keil.com/download/license/

Install the ST-Link V2 USB Drivers:

1. Using Windows Explorer, navigate to C:\Keil_v5\ARM\STLink\USBDriver
2. Double click on **stlink_winusb_install.bat** to install the required USB drivers for the on-board ST-Link V2 debug adapter. The drivers will install in the usual fashion.
3. Update the ST-Link firmware by executing C:\Keil_v5\ARM\STLink**ST-LinkUpgrade.exe**. The best ST-Link V2 firmware to use is V2.J23.S0 or later. You can identify the version installed in your board with this Upgrade utility. You need the Discovery board connected to your PC as described below to change its firmware.

Connect the STM32F419I-Discovery Board to your PC:

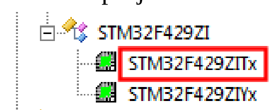
1. Use the USB-Mini cable to connect your computer and the STM32F4-Discovery board using the port labeled as "USB ST-LINK".

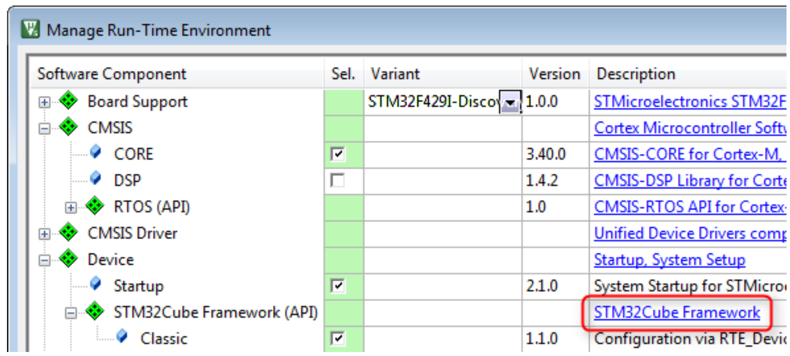
Step 1: Create a Project

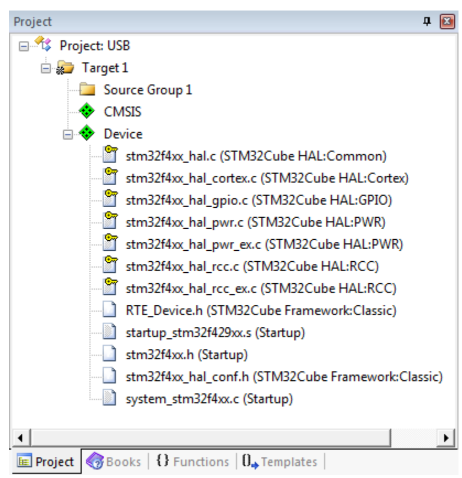
Create a New Project for the Evaluation Board

Create a project with initialization files and the main module:

1. In the main µVision menu, select **Project → New µVision Project**. The Create New Project window opens up.
2. Create a suitable folder in the normal fashion and name your project. We will use C:\USB and the project name will be **USB**. When you save the project the project file name will be USB.uvprojx.
3. The **Select Device for Target** window opens. Select **STM32F429ZITx**:
4. Click on **OK** and the Manage Run-Time Environment window opens:
5. Expand the various options as shown and select **CMSIS:Core**, **Device:Startup**. Most devices provide additional hardware abstraction layers that are listed under the Device component. The STM32Cube HAL is a list of available drivers for the STM32F429. It requires a framework. Select **STM32Cube Framework (API):Classic**. For more information, click on the link STM32Cube Framework which opens the documentation (red circle).
6. In the SEL. Column will be some orange blocks. Click on **Resolve** and these will turn to green.
7. Click **OK** to close this window
8. In the Project window expand all the items and have a look at the files µVision has added to your project:







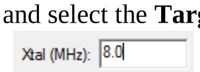
Add the main.c file:

1. Right click on Source Group 1 and select **Add New Item to Group 'Source Group 1'…**
2. In the window that opens, select **User Code Template**. Select **'main' module for STM32Cube**. It initializes the STM32Cube HAL and configures the clock system.
3. Click on **Add**.

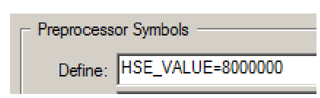
Set the CPU Clock Speed:

The external crystal oscillator on the development kit has a frequency of 8 MHz.

1. Select Target Options or ALT-F7 and select the **Target** tab.
   Enter **8 MHz** in the **Xtal (MHz)** box.



2. Select the **C/C++** tab.
3. Enter **HSE_VALUE=8000000** in the **Define** box. The HSE_VALUE represents the crystal frequency. This will set the CPU clock to 168 MHz in system_stmf4xx.c.
4. Click on **OK** to close this window.

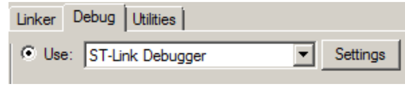


5. Select **File → Save All** or press
6. Compile the project source files: There will be no errors or warnings displayed in the Build Output window. If you get any errors or warnings, please correct this before moving on to configure the ST-Link V2 Debug Adapter.

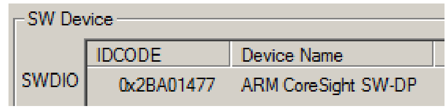
What we have at this point: We have created a new MDK 5 project called USB.uvprojx. We have set the CPU clock speed, added the CMSIS environment, a main.c file and compiled the source files to test everything.

Setup the Debug Adapter

Select the ST-Link V2 debug adapter:

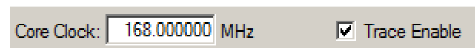


1. Select Target Options or ALT-F7. Select the **Debug** tab.
2. In the **Use** box select “ST-Link Debugger”.
3. Click on **Settings**. In the **Port** box, select **SW** (for Serial-Wire Debug SWD).
4. In the SWDIO box you must see a valid IDCODE and **ARM CoreSight SW-DP**. This indicates that µVision is connected to the STM32's debug module.



If you see an error or nothing in the SWDIO box, you must fix this before you can continue. Make sure the board is connected.

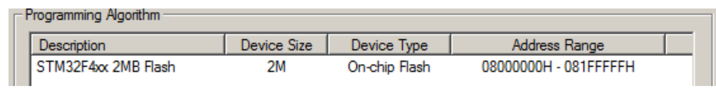
Configure the Serial Wire Viewer (SWV):



1. Select the **Trace** tab. In the **Core Clock** box, enter **168 MHz** and select **Trace Enable**. This sets the speed of the SWV UART signal and debugger timing displays. Unselect **EXCTRC** (Exception Tracing). Leave all other settings at their defaults.

Note: Solder Bridge SB9 must be bridged for SWV to function.

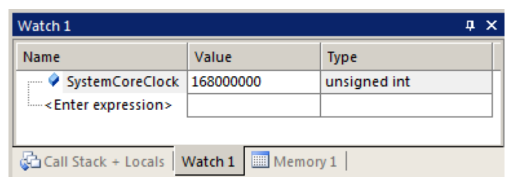
Select the Flash programming algorithm:



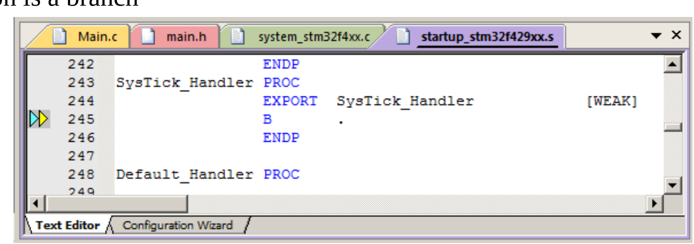
2. Select the **Flash Download** tab.
3. Confirm STM32F4xx 2 MB Flash programming algorithm is selected as shown here:
   If not, click on **Add** to choose it.
4. Click on **OK** twice to return to the main menu.
5. Compile the project source files:
6. Program the Flash and start Debugging by clicking on its icon to enter µVision's Debug mode:
7. Click on the RUN icon .
8. The program is now running now. **Note:** you may stop the program with the STOP icon .

Insert a global variable in the Watch window:

1. In the Project tab under **Device**, double-click on **system_stm32f4xx.c** to open it up.
2. Find the variable SystemCoreClock. It is declared near line 138.
3. Right click on it and select **Add SystemCoreClock to…** and select **Watch 1**. Watch 1 will automatically open if it is not already open and display this variable.
4. In the Watch 1 window, right click on SystemCoreClock in the Name column and unselect **Hexadecimal Display**. SystemCoreClock will now be displayed with the correct frequency of 168 MHz.
   Note: You can add variables to the Watch and Memory windows while your program is running.



5. Stop the program. The program counter (R15) will be at a B instruction in the SysTick_Handler. The B instruction is a branch to itself. Stopping in the SysTick Handler can be avoided by adding the user code template "Exception Handlers and Peripheral IRQ". As we are going to use CMSIS-RTOS RTX, this is not required here.



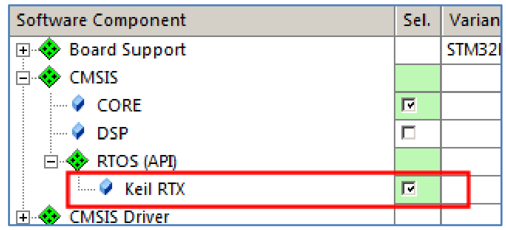
6. The yellow arrow is the program Counter (PC).
7. Exit Debug mode.

What we have at this point: We have selected the debug adapter, enabled the Serial Wire Viewer trace (SWV) and selected the Flash programmer. We also demonstrated how to display the CPU clock in a Watch window.

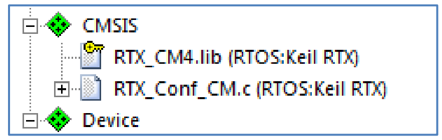
Step 2: Add CMSIS-RTOS

Add and configure CMSIS-RTOS RTX for a simple Blinky application

Select and Configure RTX RTOS:



1. Open the Manage Run-Time Environment window:
2. Under **CMSIS:RTOS (API)** select **Keil RTX** as shown here:
3. Click **OK** to close this window.
4. In the Project Window, note two new files are added under CMSIS heading: RTX_CM4.lib and RTX_Conf_CM.c
5. Double click on **RTX_Conf_CM.c** to open it.
6. Click on the **Configuration Wizard** tab at the bottom.
7. Expand RTX Kernel Timer Tick Configuration and change **RTOS Kernel Timer input clock frequency [Hz]** to 168000000 (168 MHz).



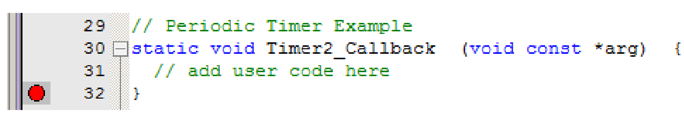
Add the Timer.c source file and add Timer Initialization Function Call:

1. In the Project window under Target 1, right click **Source Group 1** and select **Add New Item Group 'Source Group 1'**…
2. In the window that opens, select **User Code Template**. Select **CMSIS-RTOS Timer**.
3. Click on **Add**. Note Timer.c is added to the Source Group 1 in the Project window.
4. Click on the main.c tab to bring it in focus in order to edit it.
5. In main.c near line 76, add this line: `extern void Init_Timers(void);`
6. In main.c near line 103 just after SystemClock_Config();, add `Init_Timers();`
   Init_Timers creates two timers: Timer1 (a one-shot) and Timer2 which is a 1 second periodic timer. Timer2 calls a callback function.
7. Select **File → Save All** or .
8. Compile the project source files by clicking on the Rebuild icon . There will be no errors or warnings in the Build Output window. If there are any errors or warnings, please correct them before continuing.

Demonstrating the Timer is Working:

1. Program the Flash and enter Debug mode: Click on the RUN icon.

   TIP: To program the Flash manually, select the Load icon:
2. The program is running.
3. In Timer.c, near line 32, set a breakpoint by clicking on the gray box. A red circle will appear. The gray box indicates that assembly language instructions are present and a hardware breakpoint will be legal.

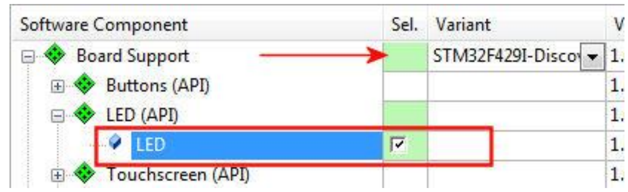


4. The program will soon stop here.
5. Click on RUN and in 1 second it will stop here again when the Timer2 is activated.
6. Remove the breakpoint for the next step.

What we have at this point: We added the RTX RTOS to your project. We enabled a periodic Timer and demonstrated that the program is running.

Blink the LED:

1. Exit Debug mode.
2. Open the Manage Run-Time Environment window:
3. Expand the Board Support (ensure that **STM32F429I-Discovery** is selected – see the red arrow)
4. Under **Board Support:LED (API)** select **LED**
5. Click **OK** to close this window.



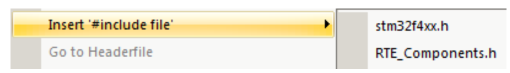
In the Project window, a header called Board Support is created containing a file LED_F429Discovery.c. This configures the I/O pins used by the LEDs with an `LED_Initialize` routine. The `LED_On` and `LED_Off` functions are used to control the LEDs.

Add C Code to Blink LED LD3:

In main.c, near line 45, add **`#include "Board_LED.h"`**

Note: An error ✕ might display on this line. Please ignore this for now. Make sure the source lines are typed in exactly as shown to avoid errors. Use your best judgment as to where the source code should be added. Line numbers can change with different versions of the software templates.

TIP: You can also select #includes from a list:



- Select a line in a source code file and right click on it.
- Select **Insert '#include file'**. A menu opens up with provided #includes that you can select from.

1. In main.c, near line 104, add **`LED_Initialize();`**
   Just after `Init_Timers();` is a good place
2. In Timer.c, near line 3, add these two lines:

```
#include "Board_LED.h"
static int timer_cnt = 0;
```

3. In Timer.c inside the Timer2_Callback function near line 32, add this code in the user code section (replace the line `//add user code here`):

```
timer_cnt++;
if (timer_cnt & 1) LED_On (0);
else               LED_Off(0);
```

4. Select File/Save All or .
5. Compile the project: There will be no errors or warnings in the Build Output window.
6. Program the Flash and enter Debug mode:
7. Click on RUN.
8. LED PG13 (green) will now blink according to the Timer you have created.
9. Leave the program running for the next steps.

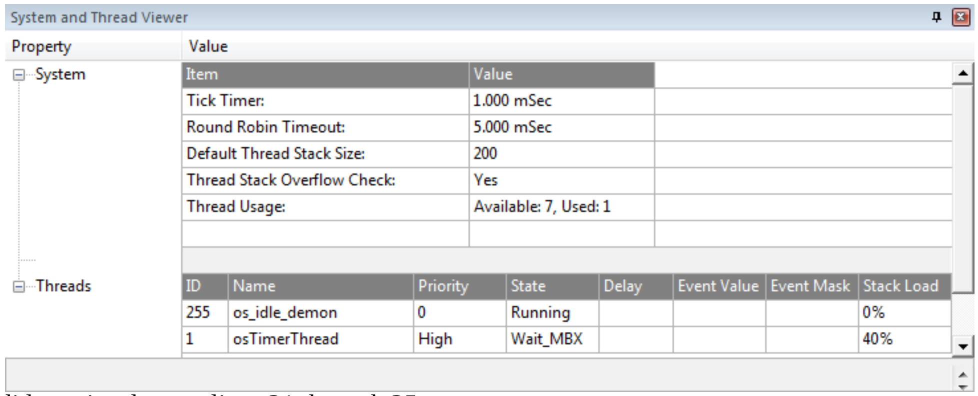
TIP: In the `LED_On` function call: (0) is the green LED. Using (1) will blink the red LED.

What we have at this point: We have selected a LED driver from the CMSIS-Pack BSP to create a blinking a LED. We have created a simple program that blinks this LED every 1 second using a timer.

RTX Kernel Awareness

System and Thread Viewer:

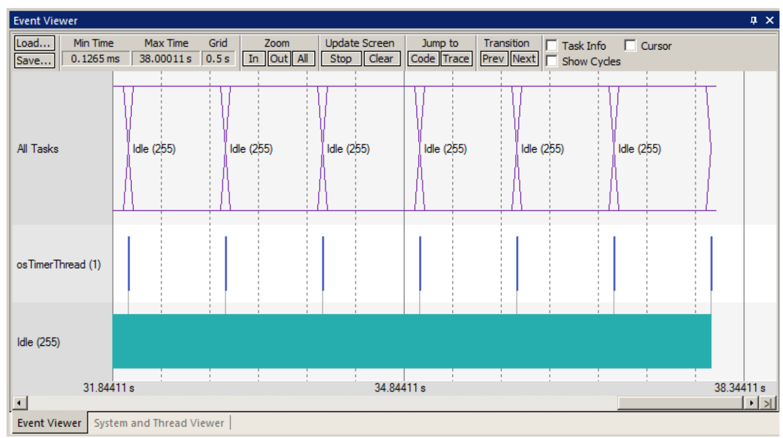
1. With the program running, open **Debug → OS Support** and select **System and Thread Viewer**. This window opens up:
   Note: os_idle_demon and osTimerThread threads have been already created.



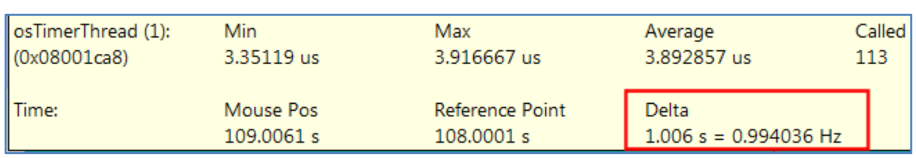
2. Set a hardware breakpoint in the Timer.c function **Timer2_Callback** as you did previously near lines 31 through 35.
3. When you click on RUN, the status of these two threads will be updated in real-time until the program stops.
4. Note the various other fields that describe RTX.
5. This is a very simple RTX implementation. We will add more threads. These threads will be automatically added to this window as you create them. This window needs no configuration or stubs in your source code.
6. Remove the breakpoint.

Event Viewer:

1. Open **Debug → OS Support** and select **Event Viewer**. The following window opens. Resize it for convenience. If this window does not display any information, the most likely cause is that the SWV is not enabled or the CPU clock frequency is incorrect. See **Serial Wire Viewer Summary** on the last page for useful SWV hints.



2. Click on RUN.
3. Using **In**, **Out** and **All** in the **Zoom** field, set the grid for about 0.5 seconds.
4. It is easy to see when the threads are running. Note most of the time the **Idle** thread is running.
5. You can tell at a glance the timing of your RTX implementation and if it is behaving as you expect.
6. As you add new tasks, they will be automatically added. The Event Viewer uses the Serial Wire Viewer (SWV).
7. Click on Stop in Update Screen.
8. Enable Task Info and Cursor.
9. Click on one of the **osTimerThread(1)** events. A red line will appear.
10. Position your mouse over the next Timer Thread event. Keep your cursor in the osTimerThread row for correct sampling.
11. The following window will open. Note the time (Delta) between the threads is about 1.006 second. This is close to the rate of the blinking LED.
    There is a minor sampling error present.

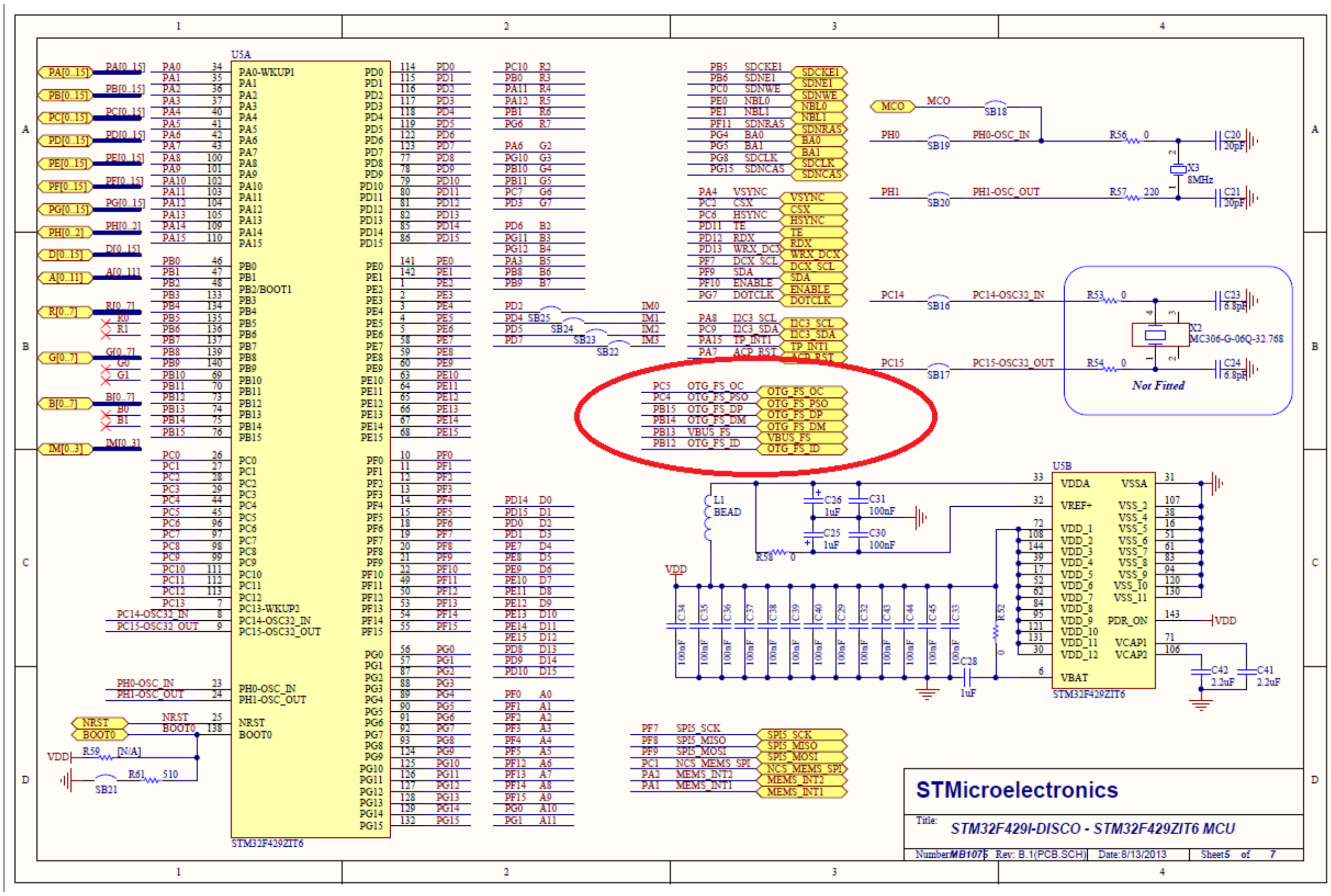


12. Stop the processor.
13. Exit Debug mode.

Step 3: Add USB Host with Mass Storage Support

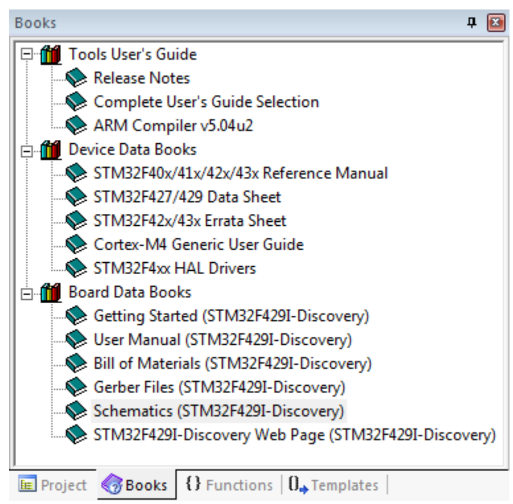
Configure the CMSIS-Driver for USB component

To correctly configure the USB Host middleware it is necessary to understand the USB User connector available on the target hardware.



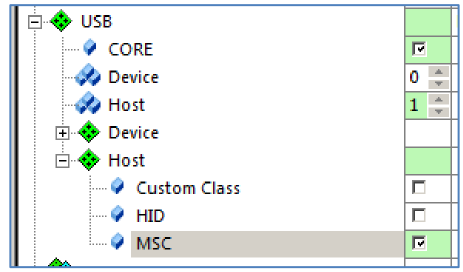
The STM32F429I Discovery Kit provides a USB connector that interfaces with the USB OTG High-speed STM32F429 peripheral via the on-chip full-speed PHY (GPIOB.14 and GPIOB.15). The VBUS power on/off pin is active low on GPIOC.4. The overcurrent detection pin is active low on GPIOC.5. Since we are only using the USB Host interface we can ignore the remaining OTG pins.

This schematic is part of the Software Pack for the STM32F4. You access these documents using the Books tab. Other documents found here are datasheets, STMicroelectronics Getting Started Guides, ARM compiler and µVision manuals and more. The Books tab is located with the Project and Functions tabs:



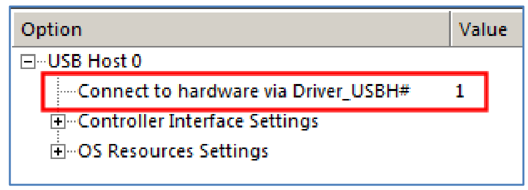
Add the USB Host middleware component to the project

As we want to connect a USB memory stick to the development board, we need to add support for the USB Mass Storage Class (MSC) to the project:



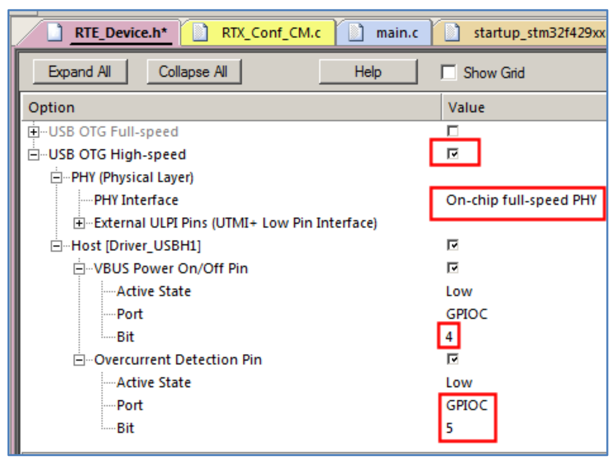
1. Open the Manage Run-Time Environment window:
2. Under **USB:Host**, select **MSC** as shown here:
   Make sure you do not accidentally select MSC in the Device header. We are setting the STM32 up as a Host and not a Device.
3. Under **CMSIS Driver:USB Host (API),** select **High-speed**
4. Click **Resolve** to add other mandatory middleware components.
5. Click **OK** to close this window.

Connect USB Host 0 to the Hardware and increase stack size:



1. In the Project window under the **USB** heading, double click on **USBH_Config_0.c (Host)** to open it.
2. Click on its **Configuration Wizard** tab and then on **Expand All**.
3. Set **Connect to hardware via Driver_USBH#** to **1**. **Note:** The USB OTG High-speed interface is represented by Driver_USBH1
4. This is the CMSIS-Driver that configured in the previous step.
5. Change the **Core Thread Stack Size** at the bottom of the configuration file to **540**. Using the default value, the program will stop with a stack overflow.
6. Select File/Save All or .

Configure the CMSIS-Driver for the USB Host

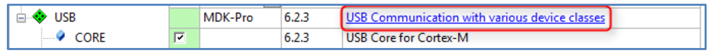


1. In the Project window, under the Device header, double click on RTE_Device.h to open it for editing.
2. Click on its Configuration Wizard tab.
3. Enable **USB OTG High-speed** as shown here:
4. Set the hardware parameters for the USB OTG High-speed interface exactly as shown here:
   - Both Ports must be **GPIOC** and first Bit is **4** and the second is **5**.
   - Change the **PHY Interface** to **On-chip Full-speed PHY**.

Next we will configure the stack, heap and thread resources for the middleware components we have just added.

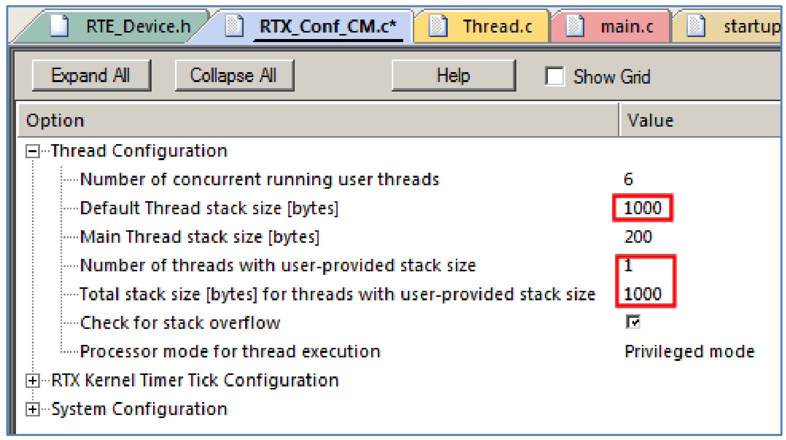
Configure the stack and thread memory resources

The resource requirements of the USB component can be found in the Middleware documentation that is accessible using the link next to the USB component in the Manage Run-Time Environment window:



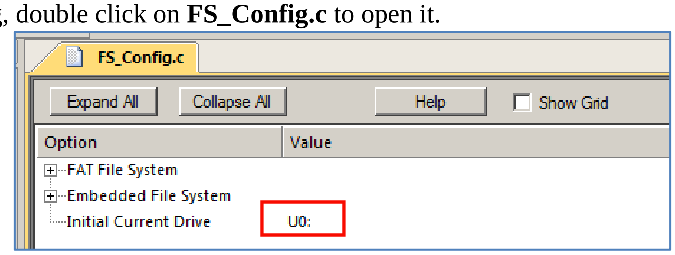
Configure Heap and Thread Stack USB sizes:

1. In the **Project** window under the **Device** heading, double click on **startup_stm32f429xx.s** to open it.
2. Select its Configuration Wizard tab. Confirm the Stack Size is set to **0x400** bytes and Heap Size is set to **0x200**.
3. Under the **CMSIS** heading, double click on **RTX_Conf_CM.c** to open it.
4. Change **Default Thread stack size [bytes]** to **1000**.
5. Set **Number of threads with user-provided stack size** to **1**.
6. Set **Total stack size [bytes] for threads with user-provided stack size** to **1000** as shown here:



Set the Default Drive Letter:

1. In the Project window under the **File System** heading, double click on **FS_Config.c** to open it.
2. Select the **Configuration Wizard** tab.
3. For a USB mass storage drive, the File System component expects the drive letter to be U0. So change **Initial Current Drive** to U0:
4. Select File/Save All or .
5. Compile the project: 



No errors or warnings will be generated as shown in the Build Output window. Please correct any errors or warnings before you continue.

Next we will add the user code to access a USB Device (the USB stick)

Add the user code that accesses the USB storage device

We will use a CMSIS-RTOS Thread to implement access to a file on the USB stick.

Add Thread.c:

1. Right click on **Source Group 1** in the Project window. Select **Add New item to Group 'Source Group1'…**
2. Select **User Code Template**.
3. Under the **CMSIS** heading and in the Name column, select **CMSIS-RTOS Thread**.
4. Click on **Add**. This adds the file **Thread.c** to your project.

Add USBH_MSC.c and USBH_MSC.h:

1. Right click on **Source Group 1** in the Project window again. Select **Add New item to Group 'Source Group1'**…
2. Select **User Code Template**.
3. Under the **USB** heading and in the Name column, select **USB Host Mass Storage Access** and click on **Add**.
4. The files **USBH_MSC.c** and **USBH_MSC.h** are now added to your project under the Source Group 1 heading.
5. These provide the relevant access functions for the USB storage device.
6. Select File/Save All or

Modify Thread.c:

To allow file access we add the following application code in the module Thread.c:

1. Double click on **Thread.c** to open it for editing.
2. Note near lines 17 and 18 there are two C lines: `return(0);` and `}`
3. Delete everything after these two lines but not including them. Start deleting with the `void Thread` (line 20). Append this code to Thread.c:

```
#include "USBH_MSC.h"
    char fbuf[200] = { 0 };

    void Thread (void const *argument) {
        static unsigned int result;
        static FILE *f;

        USBH_Initialize (0);

        while (1) {
            result = USBH_MSC_DriveMount ("U0:");
            if (result == USBH_MSC_OK)   {
                f = fopen ("Test.txt", "r");
                if (f) {
                    fread (fbuf, sizeof (fbuf), 1, f);
                    fclose (f);
                }
            }
            osDelay (1000);
        }
    }
```

4. Make sure you have at least one newline (CR) at the end of the text. Otherwise, this will generate an easily fixed warning at compilation time.

To start this new RTX Thread:

1. In **main.c** near line 77, add after `extern void Init_Timers:` **`extern void Init_Thread(void);`**
2. In **main.c** near line 112, add before `osKernelStart ();:` **`Init_Thread();`**
3. Select File/Save All.

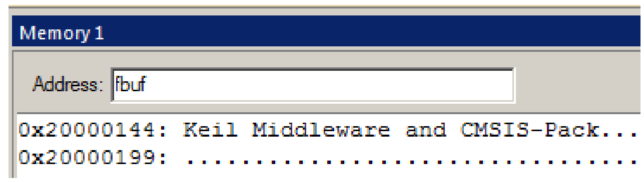
What we have at this point: On this page we added the code to open, read and close the data in file Test.txt located in a USB stick connected to USB User.

Prepare a USB memory stick:

1. Take a USB memory stick and create a file called **Test.txt** containing a short message using ASCII characters.
2. We will use the message **Keil Middleware and CMSIS-Pack**.
3. Plug this stick with an adapter cable to the STM32F429I-Dicovery board's USB connector labelled **USB USER**.

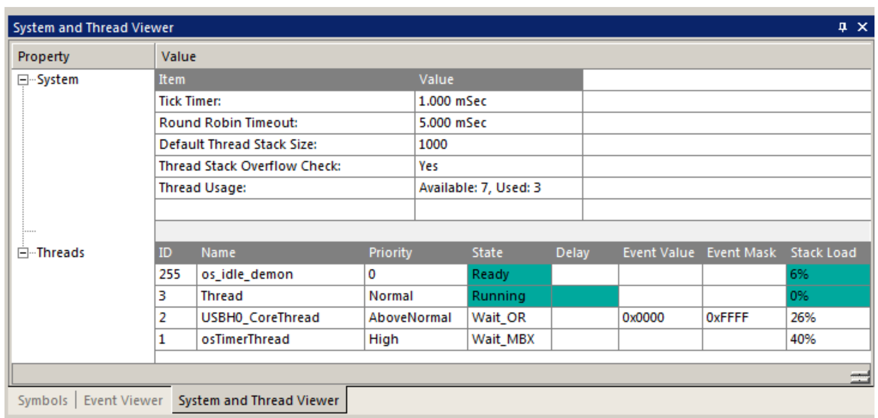
Build and RUN:

1. Compile the project: . You might get a warning from the USBH_MSC.c that can be safely ignored.
2. Enter Debug mode:
3. Click on the **Memory 1** tab. Enter **fbuf** in this window:
4. Right click anywhere in the data field area and select **Ascii**
5. Set a breakpoint in **Thread.c** on `fclose (f)` near line 35.
6. Click on RUN. In a few seconds the text will appear in the Memory 1 window.
7. The program will stop on the hardware breakpoint.
8. To repeat this sequence, click on the RESET icon and then RUN .



System and Thread Viewer:

1. Select the **System and Thread Viewer** tab or select **Debug → OS Support → System and Thread Viewer** if it is not open. Note the thread **Thread** is running and the os_idle_demon is Ready to run next. The other other two threads are in wait states.
2. Click on the RESET icon and then RUN . You will see the idle demon run as the program runs and Thread go into the running state when the breakpoint is hit.
3. Remove the breakpoint in Thread.c on the line `fclose (f)`.
4. Click on RUN.
5. Leave the program running for the next steps.

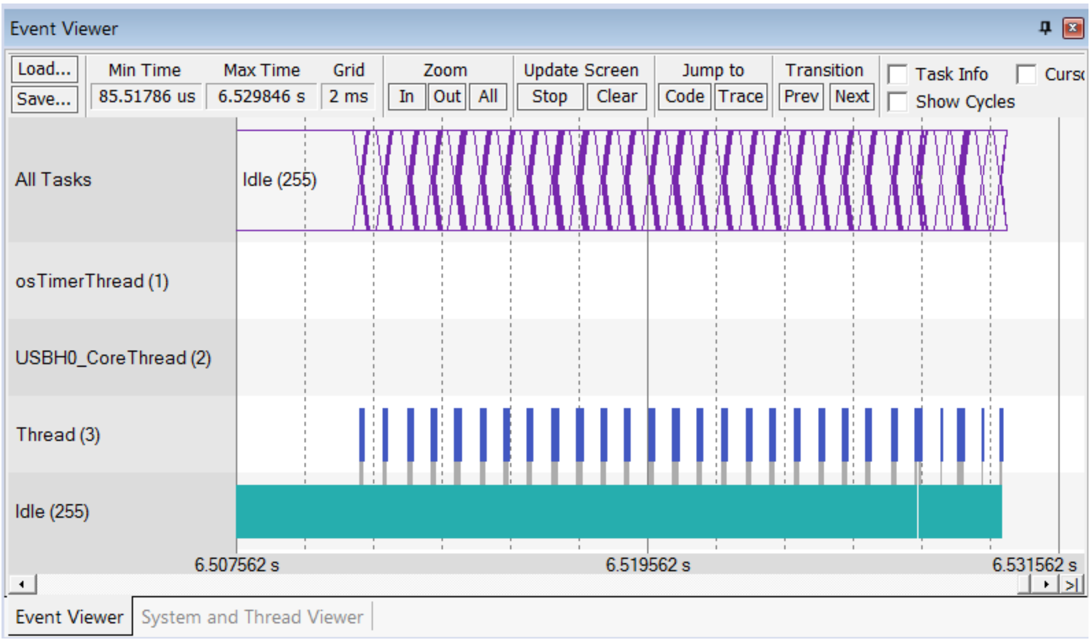


Viewing RTX Activity with the Event Viewer:

Note: If this window is blank, the Serial Wire Viewer must be configured and SB9 bridged.

1. Select the **Event Viewer** tab or if not already open: Select **Debug → OS Support → Event Viewer**.
2. Adjust the column width so the entire Thread names are visible as shown below. Data will be visible if the Serial Wire Viewer (SWV) is configured properly.
3. Set the grid to **2 ms** using **Zoom In** and **Out**. Scroll to the end of the Event Viewer as shown below.

Note the Threads visible: The **Thread (3)** data shows the activity of this thread before the breakpoint. Observer that most of the procesor time was spent in the Idle daemon. You can adjust these times to sut your application.



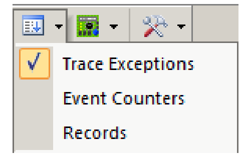
More Viewing RTX Activity with the Event Viewer:

1. Select **Stop** in the **Update Screen** box.
2. Set the grid to **10 ms**.
3. Scroll backwards in time and you can see when the other threads were active.
4. Recall you can enable the **Cursor** and **Task Info** boxes to measure timings of these events.

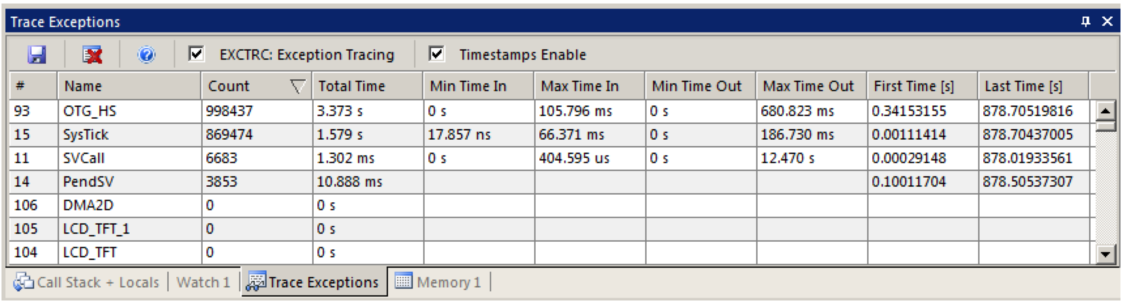
Modifying the Memory 1 Window:

1. In the **Memory 1** window displaying the text, right-click on one of the characters and select **Modify Memory *@address***.
2. Enter a **0** and press Enter.
3. The character you selected will be changed to 0 and then back to the original as Text.txt is read again by the thread **Thread**.
4. The **Memory 1** window updates in real-time and can be changed while the program is running.

Exception Trace window:

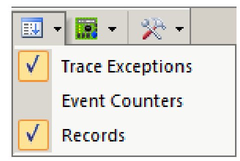


1. Open the **Trace Exception** window: click on the down arrow beside the Trace icon:
2. Select **Trace Exceptions**. Trace Exceptions window opens up with its own tab.
3. Enable **EXCTRC: Exception Tracing** as shown in the window below:
4. Click on the **Count** column header until the down triangle appears. The active exceptions will be displayed with various statistics as shown below. **Note:** this window is updated while the program is running.

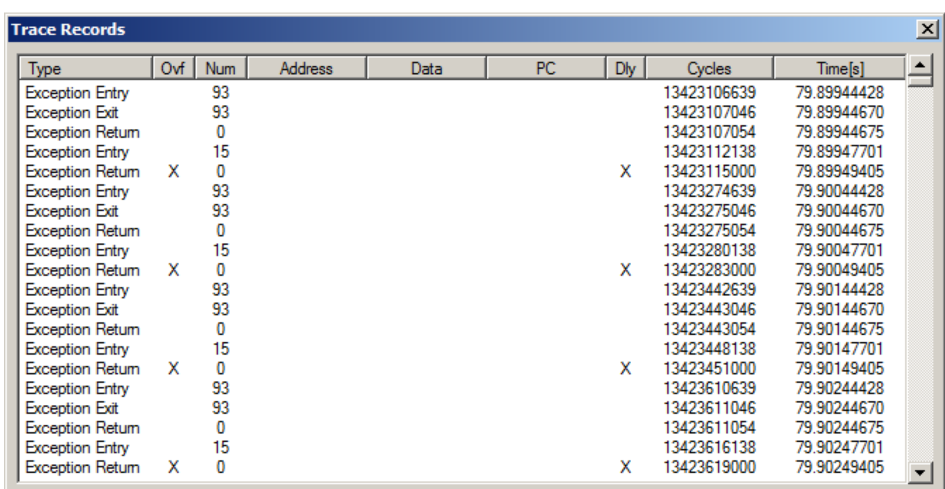


#	Name	Count	Total Time	Min Time In	Max Time In	Min Time Out	Max Time Out	First Time [s]	Last Time [s]
93	OTG_HS	998437	3.373 s	0 s	105.796 ms	0 s	680.823 ms	0.34153155	878.70519816
15	SysTick	869474	1.579 s	17.857 ns	66.371 ms	0 s	186.730 ms	0.00111414	878.70437005
11	SVCall	6683	1.302 ms	0 s	404.595 us	0 s	12.470 s	0.00029148	878.01933561
14	PendSV	3853	10.888 ms					0.10011704	878.50537307
106	DMA2D	0	0 s						
105	LCD_TFT_1	0	0 s						
104	LCD_TFT	0	0 s						

Trace Records window:



1. Open the Trace Records window: click on the down arrow beside the Trace icon:
2. Double click inside it to clear the window.
3. The exceptions will be listed as they occurred as shown below.
4. Right click in this window and you can filter out different types of events.
5. An "x" in the **Ovf** column means there was a frame lost. This is because there was too much data output on the 1 bit Serial Wire Output (SWO) pin. You can alleviate this by unselecting the Timestamps and ITM bit 31. The overflows might disappear but the Event Viewer will not function without these two attributes set.
6. An "x" in the **Dly** column means the Timestamp might not be accurate at this point. µVision recovers gracefully from such SWV trace data overflows.
7. You can also alleviate overflows by using a Keil ULINK*pro* debug adapter. ULINK*pro* can use the 4-bit ETM trace which provides more bandwidth. A board must be equipped with the CoreSight 20 pin ETM connector (not available on the STM32F429i-Discovery board).
8. Close the Trace Records window.
9. Disable **EXCTRC: Exception Tracing** in the **Trace Exceptions** window.
10. Stop the processor .
11. Close the two Trace windows.
12. Exit Debug mode. 



Type	Ovf	Num	Address	Data	PC	Dly	Cycles	Time[s]
Exception Entry		93					13423106639	79.89944428
Exception Exit		93					13423107046	79.89944670
Exception Return		0					13423107054	79.89944675
Exception Entry		15					13423112138	79.89947701
Exception Return	X	0				X	13423115000	79.89949405
Exception Entry		93					13423274639	79.90044428
Exception Exit		93					13423275046	79.90044670
Exception Return		0					13423275054	79.90044675
Exception Entry		15					13423280138	79.90047701
Exception Return	X	0				X	13423283000	79.90049405
Exception Entry		93					13423442639	79.90144428
Exception Exit		93					13423443046	79.90144670
Exception Return		0					13423443054	79.90144675
Exception Entry		15					13423448138	79.90147701
Exception Return	X	0				X	13423451000	79.90149405
Exception Entry		93					13423610639	79.90244428
Exception Exit		93					13423611046	79.90244670
Exception Return		0					13423611054	79.90244675
Exception Entry		15					13423616138	79.90247701
Exception Return	X	0				X	13423619000	79.90249405

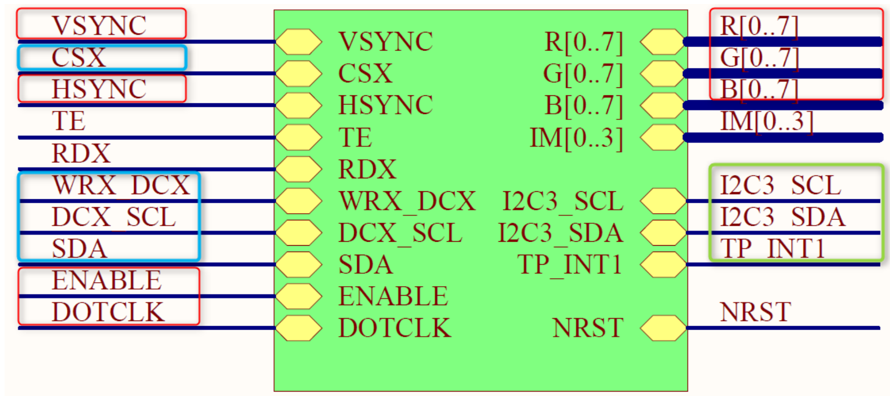
Step 4: Add the Graphical User Interface

Understanding the Hardware

To correctly configure the Graphic Interface it is necessary to understand the schematics. Here's another excerpt from the schematics showing the LCD connections.

The STM32F429 has a high-speed RGB interface (red) that is connected to the LCD. To configure the display, SPI (blue) is used which is connected to the device's SPI5 interface. The Touch Screen connects via I2C (green) to the microcontroller's I2C3 interface.

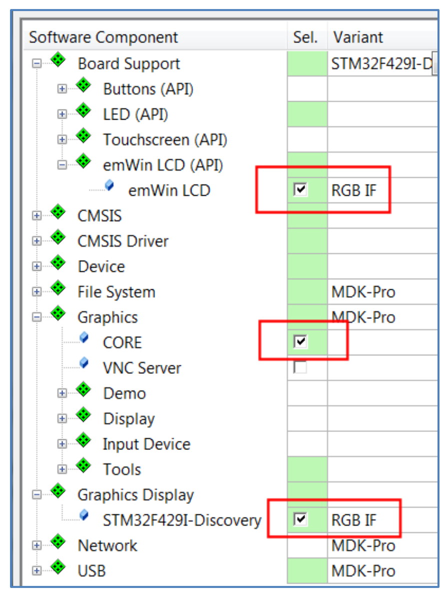
Interfaces:
RGB
SPI
I2C



Add the Graphic Core and Graphics Display Interface

Select the emWin Graphics components:

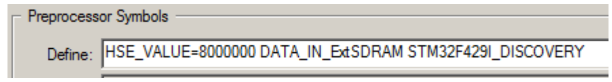
1. Open the Manage Run-Time Environment window:
2. Under **Board Support:emWin LCD (API)**, select **emWin LCD**. This component is the interface to the board LCD display.
3. Select **Graphics:Core**. This will be used for the User interface.
4. **Graphics:Core** needs a display interface configuration file where screen size and other parameters are defined. Pre-defined displays are available under **Graphics Display**. Select **STM43F429I-Discovery**.
5. Click **Resolve** to add the missing CMSIS-Drivers.
6. Click **OK** to close this window.



Modify System Clock and set Defines:

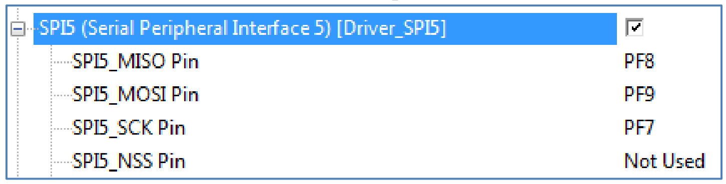
The microcontroller connects the graphics display as an external SDRAM. This SDRAM is usually configured with the CMSIS system file (system_stm32f4xx.c). The STM32Cube Framework provides `#defines` to enable the SDRAM.

1. Select Target Options  or ALT-F7.
2. Select the **C/C++** tab. Add the defines `DATA_IN_ExtSDRAM` and `STM32F429I_DISCOVERY`
3. Add a space between the three defines as shown here:
4. Click **OK** to close this window.
5. Select File/Save All or .



Configure the CMSIS-Driver SPI5 for Graphics:

1. In the Project window under the **Device** heading, double click on **RTE_Device.h** to open it.
2. Select its **Configuration Wizard** tab.
3. Enable **SPI5** and disable **SPI_NSS** pin. Set the other options as shown here:



Configure Memory for Graphics Core

The Graphics Core uses a dedicated memory for its features that needs configuration.

1. In the Project window under the **Graphics** heading, double click on **GUIConf.c** to open it. GUIConf.c configures the Graphics Core. The default configuration exceeds the memory of our system. We change the memory size to 0x4000 which is sufficient for many applications (refer to the emWin User Manual).
2. Change the `GUI_NUMBYTES` define near line 45 to **0x4000**
3. Select File/Save All or .

What we have at this point: The graphics hardware configuration is complete.

Add the code to output "Hello World" to the LCD display

Add The Graphics Thread and start the thread in main.c:

1. In the Project window under Target 1, right click **Source Group 1** and select **Add New Item to Group 'Source Group 1'...**
2. Select **User Code Template**.
3. From the Graphics heading, select **emWin GUI Thread for Single-Tasking Execution Model**.
   Note: Single-task execution is where one thread (task) calls the emWin functions. This reduces the memory footprint and is sufficient for many applications. Only one thread can call the GUI functions (refer to the Execution Model in the emWin User Manual).
4. Click on **Add**. This adds the file **GUI_Single_Thread.c** to your project.

Modify RTX for this new Thread:

The GUI Thread needs a user provided stack size of 2048 bytes:

1. Under the **CMSIS** heading, double click on **RTX_Conf_CM.c** to open it.
2. Select its **Configuration Wizard** tab and expand **Thread Configuration**.
3. Increase **Number of threads with user-provided stack size** to **2** as shown here:
4. Set **Total stack size [bytes] for threads with user provided stack size** to **4096** as shown here:

Option	Value
Thread Configuration	
Number of concurrent running user threads	6
Default Thread stack size [bytes]	1000
Main Thread stack size [bytes]	200
Number of threads with user-provided stack size	2
Total stack size [bytes] for threads with user-provided stack size	4096
Check for stack overflow	☑
Processor mode for thread execution	Privileged mode

Add the text that will display on the LCD:

1. In the Project window under the **Source Group 1** heading, double click on **GUI_SingleThread.c** to open it.
2. Near line 24, just before the `while(1)` loop, add: **`GUI_DispString("Hello World!");`**
3. Select File/Save All or .

Modify main.c:

You can now demonstrate the display of the string "Hello World!" on the LCD:

1. In **main.c** near line 79 add: **`extern Init_GUIThread (void);`**
2. In **main.c** near line 109 add: **`Init_GUIThread();`**
3. Select File/Save All or .

Build and run your project:

1. Compile the project:
2. Program the Flash and enter Debug mode:
3. Click on RUN.
4. The LCD will display **Hello World!**
5. Stop the processor . Exit Debug mode.

Step 5: Design and Add the Graphics to be Displayed on the LCD

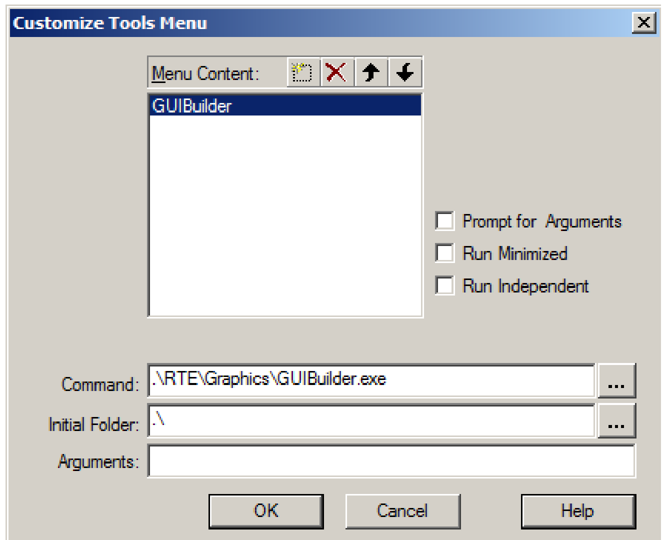
Configure GUIBuilder and Use it to Create the Graphics

emWin provides a tool called GUIBuilder to design the graphics that will display on the LCD screen. µVision allows you to execute GUIBuilder from within.

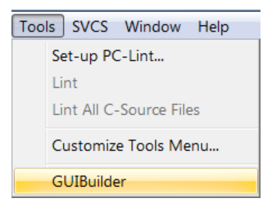
1. Open the Manage Run-Time Environment window:
2. Under **Graphics:Tools** select **GUI Builder**
3. Click **OK**

Create a shortcut on the µVision Tools menu:

1. In the main µVision menu, select **Tools → Customize Tools Menu**. The window below opens up.
2. This will allow you to add a shortcut to your tools menu to launch GUIBuilder. This only needs to be done once for every installation of MDK-ARM and not every project that you may create.
3. Click on the Insert icon (or press the Insert key).
4. Enter the text **GUIBuilder** as shown and press Enter.
5. In the Command and Initial Folder boxes enter **.\RTE\Graphics\GUIBuilder.exe** and **.** .
6. Click on **OK** to close it.



7. Click on **Tools** in µVision and the new GUIBuilder menu item will display like this:
8. Click on **GUIBuilder** and it will start.



Create the Frame:

1. Click on the Framewin icon:  A box will be created labelled Framewin.
2. With the FrameWin box selected, change the Property Name from FrameWin to **LogViewer**.
3. In the property column, enter xSize = **240** and ySize = **320**. This specifies the size of the LCD.
4. Press Enter.

Property	Value
Name	LogViewer
xPos	0
yPos	0
xSize	240
ySize	320
Extra bytes	0

Add the Multi Edit Widget

1. Click on the **Multiedit**  icon:
2. Click and drag to fill the **LogViewer** area as shown below. Leave a space at the bottom for the button.

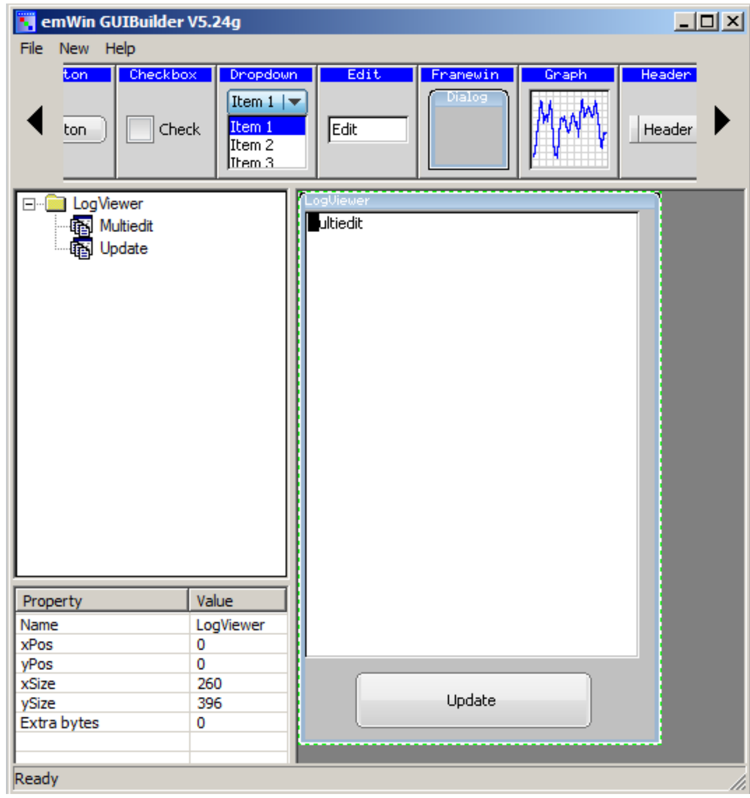
Add the Button:

1. Click on the Button icon: 
2. Using your mouse to size and position as shown below:
3. With the Button selected, change the Property Name to **Update**.
4. Click Enter to finish.

Property	Value
Name	Update
xPos	9
yPos	245
xSize	210
ySize	50
Extra bytes	0

Save and Export your GUI:

1. Select **File → Save**. A C source file with your GUI design is created and saved into your µVision project root folder. The file name is derived from your parent GUI element, and in this case the name is **LogViewerDLG.c**.
2. You will need to add this to your project. This step is done on the next page.
3. Close GUIBuilder.



Add LogViewerDLG.c to the Project and Run the GUI

Adding your GUI design file LogViewerDLG.c to Your Project:

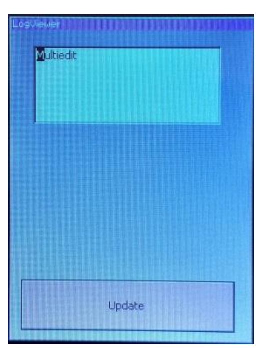
1. In the µVision Project window, right click on "Source Group 1".
2. Select **Add Existing Files to Group 'Source Group 1'**…
   Note: Choose ***Existing*** rather than ***New*** as previously.
3. In the window that opens up, select the file **LogViewerDLG.c**. Click on **Add** once and then **Close**.
4. LogViewerDLG.c is now added to your project.
5. In the Project window, under **Source Group 1**, double click on **LogViewerDLG.c** to open it for editing.
6. Near line 70, add this line to reference the file buffer fbuf: **`extern char fbuf[200];`**
   This should in between the `//User Start` near line 69 and `//User END` near line 70.

Create the GUI Design:

1. In the µVision Project window under **Source Group 1**, double click on **GUI_SingleThread.c** to edit it.
2. In GUI_SingleThread.c, near line 4 add this line: **`#include "dialog.h"`**
3. In GUI_SingleThread.c, near line 5 add this line: **`extern WM_HWIN CreateLogViewer(void);`**
4. Comment out: **`//GUI_DispString("Hello World!");`**
5. Near line 26 add this line: **`CreateLogViewer();`**

Build and RUN:

1. Select File/Save All or .
2. Compile the project: 
3. Enter Debug mode:  and click on RUN. 
4. The GUI we have just created, appears on the screen:



Step 6: Add the Touch Screen Interface

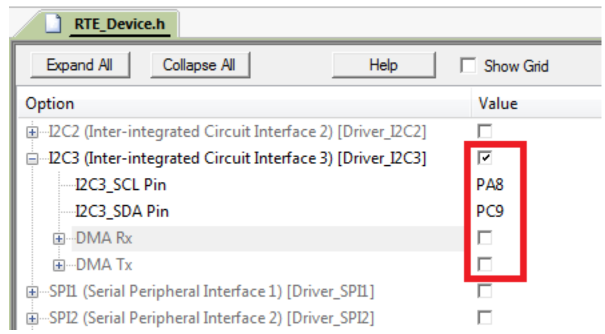
An implementation for the touch screen interface is provided as a Software Component under **Board Support**. The touch screen hardware connects via the I2C peripheral (I2C3) and therefore we will use the standard CMSIS-Driver for I2C.

Add Software Components for Touchscreen

1. Open the Manage Run-Time Environment window: 
2. Under **Graphics:Input Device**, select **Touchscreen**
3. Click **Resolve** to select other required components. This adds from the Board Support the Touchscreen Interface and from the CMSIS Driver the I2C driver.
4. Clock **OK** to close this window.

Configure the CMSIS-Driver for the I2C Interface

1. In the Project window, under the **Device** group, double click on **RTE_Device.h** to open it for editing.
2. Click on its **Configuration Wizard** tab.
3. Enable **I2C3** and configure the parameters for this driver instance as shown in the picture. Select **PA8** and **PC9** since these pins provide the interface to the touchscreen hardware.
4. Touchscreen is a low-bandwidth interface and therefore we can disable the DMA channels. This avoids DMA conflicts with other drivers.



Enable Touch support in GUI_SingleThread.c

1. In the Project window, under **Source Group 1**, double click on **LogViewerDLG.c** to open it for editing.
2. Near line 118 is case `WM_NOTIFICATION_CLICKED` for the Update button, add this code:

```
hItem = WM_GetDialogItem(pMsg->hWin, ID_MULTIEDIT_0);
MULTIEDIT_SetText(hItem, fbuf);
```

3. In the Project window, under **Source Group 1**, double click on **GUI_SingleThread.c** to open it for editing.
4. Uncomment line 33 to call the touch support of the Graphics component: `GUI_TOUCH_Exec();`

Build and RUN:

5. Select File/Save All or .
6. Compile the project: 
7. Enter Debug mode:  and click on RUN. 
8. Press the **Update** button on the LCD. The content of the file Test.txt appears on the screen:

Serial Wire Viewer Summary

Serial Wire Viewer (SWV) is a 1 bit data trace. It is output on the SWO pin which is shared with the JTAG TDO pin. This means you cannot use JTAG and SWV together. Instead, use Serial Wire Debug (SWD or SW) which is a two pin alternative to JTAG and has about the same capabilities. SWD is selected inside the µVision IDE amd is easy to use.

1. The STM329F429I Disco board ***must*** have the Solder Bridge SB9 bridged. SB9 is located on the bottom of the board close to jumper ldd. If SB9 is open, SWV will not work. The board is shipped with SB9 ***not*** bridged.
2. The Core Clock: is the CPU frequency and must be set accurately. In this tutorial, 168 MHz is used. If you see ITM frames in the Trace Records window of number other than 0 or 31, or no frames at all, the clock frequency is probably wrong.
3. SWV is configured in the Cortex-M Target Setup in the Trace tab. **In Edit mode:** Select Target Options  or ALT-F7 and select the Debug tab. Select Settings: Then select the Trace tab. **In Debug mode:** Select Debug/Debug Settings.. and then select the Trace tab.
4. Many STM32 processors need a special initialization file to get SWV and/or ETM trace to function. This file is not needed in this board as µVision accomplishes this during entry to Debug mode. If you are using a different STM32 processor and are unable to get SWV working, contact Keil tech support. SWO*xx*.ini files are provided in many µVision example projects that you can use. Insert it just below where you choose the debug adapter.
5. If SWV stops working, you can get it working by exiting and re-entering Debug mode. In rare cases, you might also have to cycle the board power. Constant improvements to the ST-Link V2 firmware are helping in this regard.
6. SWV outputs its data over a 1 bit SWO pin. Overloading can be common depending on how much information you have selected to be displayed. Reduce the information to only that which you really need helps as does limiting the activity of variables. Using a ULINK*pro* on boards equipped with a 20 CoreSight ETM connector enables the SWV information to be output on the 4 bit ETM trace port.
7. For more information on STM32F429I-Discovery board see: www.keil.com/appnotes/docs/apnt_253.asp

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Watch, Memory windows and Serial Wire Viewer can display:

- Global and Static variables. Raw addresses: i.e. *((unsigned long *)0x20000004)
- Structures.
- Peripheral registers – just read or write to them.
- Can't see local variables. (just make them global or static).
- Cannot see DMA transfers – DMA bypasses CPU and CoreSight and CPU by definition.
- You might have to fully qualify your variables or copy them from the Symbol window.

Serial Wire Viewer (SWV) displays in various ways:

- PC Samples.
- A printf facility that does not use a UART.
- Data reads. Graphical format display in the Logic Analyzer: Up to 4 variables can be graphed.
- Exception and interrupt events.
- All these are Timestamped.
- CPU counters.

Instruction Trace (ETM):

- ETM Trace records where the program has been. Assembly instructions are all recorded.
- Assembly is linked to C source when available (this is up to your program).
- A recorded history of the program execution *in the order it happened.*
- Provides Performance Analysis and Code Coverage. Higher SWV performance.
- ETM needs a Keil ULINK*pro* to provide the connection to the 4 bit Trace Port found on many STM32 processors.

Document Resources

Books

- ***NEW!*** **Getting Started MDK 5:** www.keil.com/mdk5/.
- A good list of books on ARM processors is found at: www.arm.com/support/resources/arm-books/index.php
- µVision contains a window titled **Books**. Many documents including data sheets are located there.
- A list of resources is located at: www.arm.com/products/processors/cortex-m/index.php (Resources tab).
- The Definitive Guide to the ARM Cortex-M0/M0+ by Joseph Yiu. Search the web for retailers.
- The Definitive Guide to the ARM Cortex-M3/M4 by Joseph Yiu. Search the web for retailers.
- Embedded Systems: Introduction to Arm Cortex-M Microcontrollers (3 volumes) by Jonathan Valvano.
- MOOC: Massive Open Online Class: University of Texas: http://users.ece.utexas.edu/~valvano/

Application Notes

1. Overview of application notes: www.keil.com/appnotes
2. ***NEW!*** Keil MDK for Functional Safety Applications: www.keil.com/safety
3. Using DAVE with µVision: www.keil.com/appnotes/files/apnt_258.pdf
1. Using Cortex-M3 and Cortex-M4 Fault Exceptions www.keil.com/appnotes/files/apnt209.pdf
2. CAN Primer using NXP LPC1700: www.keil.com/appnotes/files/apnt_247.pdf
3. CAN Primer using the STM32F Discovery Kit www.keil.com/appnotes/docs/apnt_236.asp
4. Segger emWin GUIBuilder with µVision™ www.keil.com/appnotes/files/apnt_234.pdf
5. Porting an mbed project to Keil MDK™ www.keil.com/appnotes/docs/apnt_207.asp
6. MDK-ARM™ Compiler Optimizations www.keil.com/appnotes/docs/apnt_202.asp
7. Using µVision with CodeSourcery GNU www.keil.com/appnotes/docs/apnt_199.asp
8. RTX CMSIS-RTOS in MDK 5 http://www.keil.com/pack/doc/cmsis_rtx/index.html
9. Lazy Stacking on the Cortex-M4 www.arm.com and search for DAI0298A
10. Sending ITM printf to external Windows applications: www.keil.com/appnotes/docs/apnt_240.asp
11. Barrier Instructions http://infocenter.arm.com/help/topic/com.arm.doc.dai0321a/index.html
12. Cortex Debug Connectors: http://www.keil.com/support/man/docs/ulinkpro/ulinkpro_cs_connectors.htm

Useful ARM Websites

1. ARM Community Forums: www.keil.com/forum and http://community.arm.com/groups/tools/content
2. ARM University Program**:** www.arm.com/university. Email: university@arm.com
3. ARM Accredited Engineer Program: www.arm.com/aae
4. mbed™: http://mbed.org
5. CMSIS standard: www.arm.com/cmsis
6. CMSIS documentation: www.keil.com/cmsis

For comments or corrections on this document please email bob.boys@arm.com.

Keil Products and Contact Information

Keil Microcontroller Development Kit (MDK-ARM™)

- MDK-Lite (Evaluation version) - $0
- MDK-ARM-CM™ (for Cortex-M series processors only – unlimited code limit)
- MDK-Standard (unlimited compile and debug code and data size Cortex-M, ARM7 and ARM9)
- MDK-Professional (Includes Flash File, TCP/IP, CAN and USB driver libraries and Graphic User Interface (GUI)
- **NEW!** ARM Compiler Qualification Kit: for Safety Certification Applications

USB-JTAG adapter (for Flash programming too)

- ULINK2 - (ULINK2 and ME - SWV only – no ETM)
- ULINK-ME – sold only with a board by Keil or OEM.
- ULINK*pro* – Faster operation and Flash programming, Cortex-Mx SWV & ETM trace.
- **NEW!** ULINK*pro* D – Faster operation and Flash programming, Cortex-Mx SWV, no ETM trace.

For special promotional or quantity pricing and offers, please contact Keil Sales.

Contact sales.us@keil.com 800-348-8051 for USA prices.

Contact sales.intl@keil.com +49 89/456040-20 for pricing in other countries.

CMSIS-RTOS RTX is now provided under a BSD license. This makes it free.

All versions, including MDK-Lite, include CMSIS-RTOS RTX *with source code!*

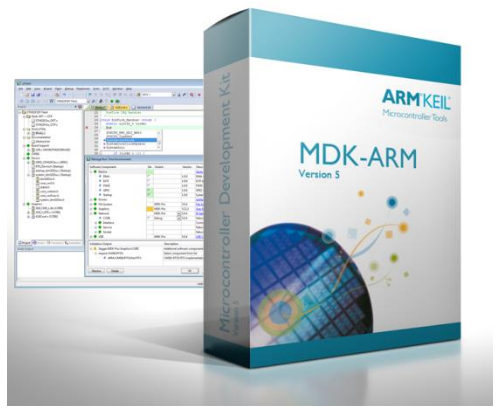
Keil includes free DSP libraries for the Cortex-M0, M0+, M3, M4 and M7.

Call Keil Sales for details on current pricing, specials and quantity discounts. Sales can also provide advice about the various tools options available to you. They will help you find various labs and appnotes that are useful.

All products are available from stock.

All products include Technical Support for 1 year. This is easily renewed.

Call Keil Sales for special university pricing. Go to www.arm.com/university to view various programs and resources.



Keil supports many other Infineon processors including 8051 and C166 series processors. See the Keil Device Database® on www.keil.com/dd for the complete list of Infineon support. This information is also included in MDK.

For more information:

Keil Sales In USA: sales.us@keil.com or 800-348-8051. Outside the US: sales.intl@keil.com or +49 89/456040-20

Keil Technical Support in USA: support.us@keil.com or 800-348-8051. Outside the US: support.intl@keil.com.

For comments or corrections please email bob.boys@arm.com.

For the latest version of this document, go to www.keil.com/appnotes/docs/apnt_268.asp

CMSIS documentation: www.arm.com/cmsis

ARM CORTEX Processor Technology

CMSIS COMPLIANT ARM® Cortex™ Microcontroller Software Interface Standard

ARM KEIL Microcontroller Tools