FTF 2016
TECHNOLOGY FORUM

FreeRTOS SOLUTIONS FOR KINETIS MCU'S

FTF-DES-N1956

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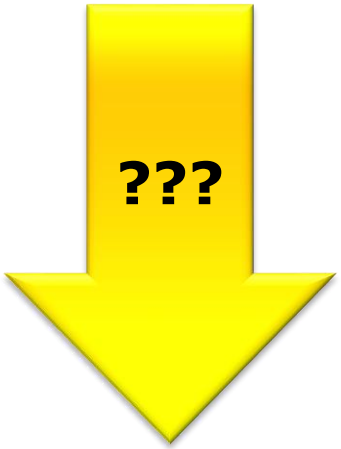
AGENDA

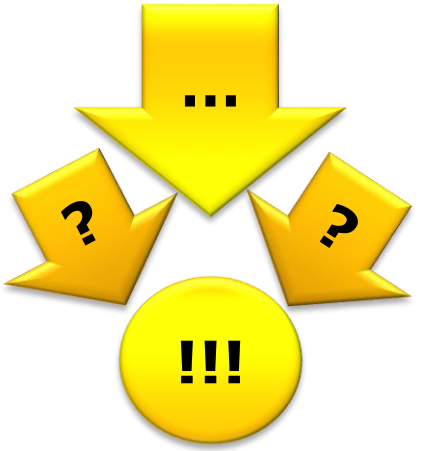
- Introduction
  - FRDM-K22F
  - FreeRTOS
  - Kinetis SDK
  - Kinetis Design Studio (KDS)
- Eclipse Kernel Awareness
- SEGGER SystemView
- Percepio FreeRTOS+Trace
- Wrap-up and Closure

Session Introduction and Objectives

- This session shows how you can use Kinetis SDK + FreeRTOS Solutions
- It shows how to debug a SDK application with FreeRTOS which includes an instrumented RTOS with Trace
- The application uses Kinetis Design Studio V3.2.0, Kinetis SDK V2.0 and the FRDM-K22F board, but the concepts are applicable to different setup as well



- After completing this session you will be able to:
  - Effectively use solutions for Kinetis SDK + FreeRTOS applications
  - Reduce debugging time
  - Improve application performance



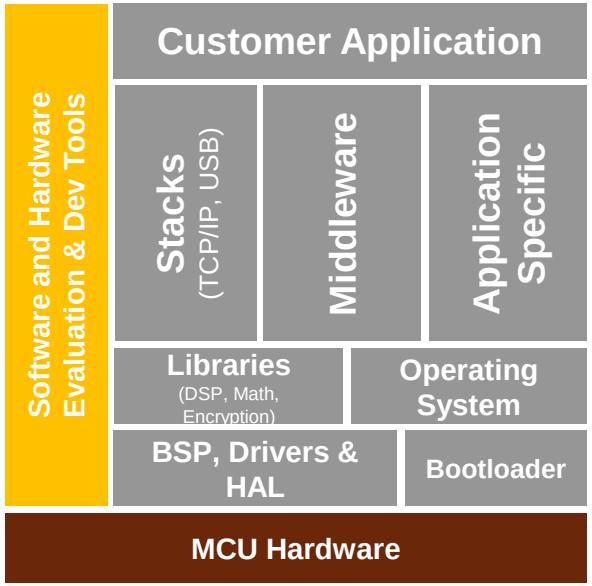
Session Philosophy

- Preinstalled software on lab computers
  - Repeat things on your own machine: installation instructions for installation at a later time
- You have received a Kinetis Design Studio + Kinetis SDK + FreeRTOS Application with the FRDM-K22F board
- Theory input with Lab in parallel
  - Going through the slide material
  - Perform the things learned with your lab computer
  - Additional information/links provided

Kinetis Design Studio

No-cost integrated development environment (IDE) for Kinetis MCUs

Eclipse and GCC-based IDE for C/C++ editing, compiling and debugging



Product Features:

- A free of charge and unlimited IDE for Kinetis MCUs
- A basic IDE that offers robust editing, compiling and debugging
- Based on Eclipse, GCC, GDB and other open-source technologies
- Includes Processor Expert with Kinetis SDK integration
- Supports all existing Kinetis devices via Processor Expert and new project wizard
- All new Kinetis devices will also feature the Kinetis SDK with Processor Expert configurability
- Code Generation for GNU, IAR and Keil
- Host operating systems:
  - Microsoft Windows 7/8/10
  - Linux (Ubuntu, Redhat, Centos) (64bit)
  - Mac OS X and Segger J-Link
- Support for SEGGER, P&E and OpenSDA/CMSIS-DAP debugger targets
- Support for Eclipse plug-ins including RTOS-awareness (i.e. MQX, FreeRTOS)
- Commercial upgrade path: Somnium DRT

Learn more at: www.nxp.com/KDS
Community: https://community.freescale.com/community/kinetis-design-studio

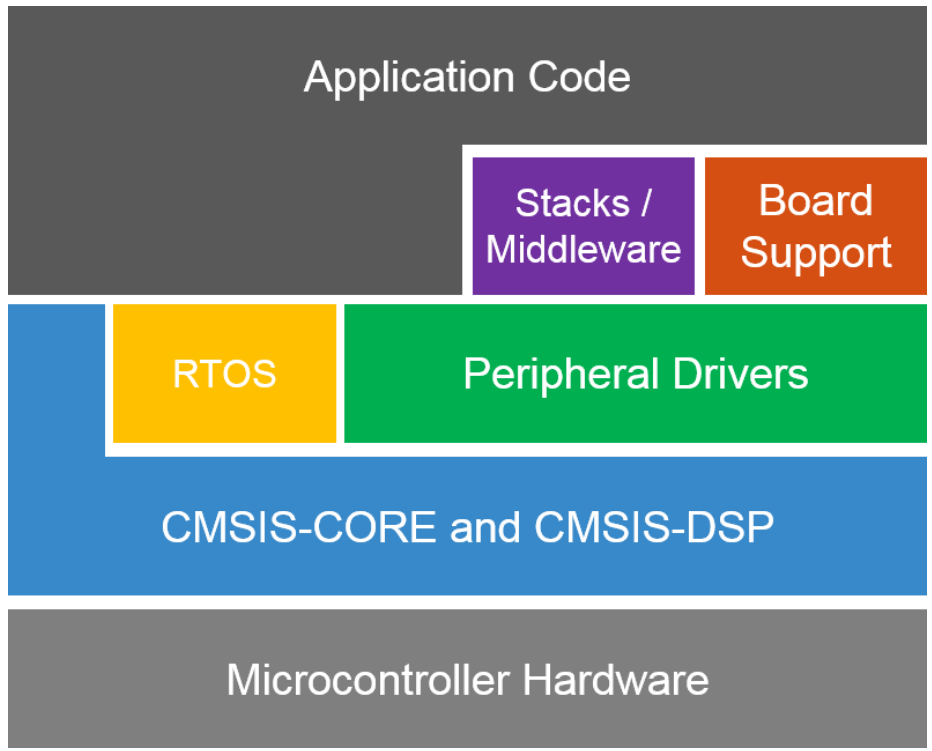
Kinetis Software Development Kit v2.x (KSDK v2)

- Architecture:
  - CMSIS-CORE compatible
  - Single driver for each peripheral
  - Transactional APIs w/ optional DMA support for communication peripherals
- Integrated RTOS:
  - FreeRTOS, Micrium uC/OS-II & -III
  - RTOS-native driver wrappers
- Integrated Stacks & Middleware
  - USB Host, Device and OTG
  - lwIP, FatFS
  - Crypto acceleration plus wolfSSL & mbedTLS
  - SD and eMMC card support
- Reference Software:
  - Peripheral Driver usage examples
  - Application Demos
  - FreeRTOS usage demos
- License:
  - BSD 3-clause for startup, drivers, USB stack
- Toolchains:
  - KDS, IAR, Keil, Atollic, GCC w/ CMake
- Quality
  - Production grade software
  - MISRA 2004 compliance
  - Checked with Coverity Static Analysis tools

Learn more at: www.nxp.com/KSDK

KSDK

The software framework and reference for Kinetis MCU application development



Freedom Development Platforms

Product Features

- Low–cost (starting at $12.95 USD)
- Designed in an industry-standard compact form factor (Arduino R3)
- Easy access to the MCU I/O pins
- Integrated open-standard serial and debug interface (OpenSDA)
- Compatible with a rich-set of third-party expansion boards

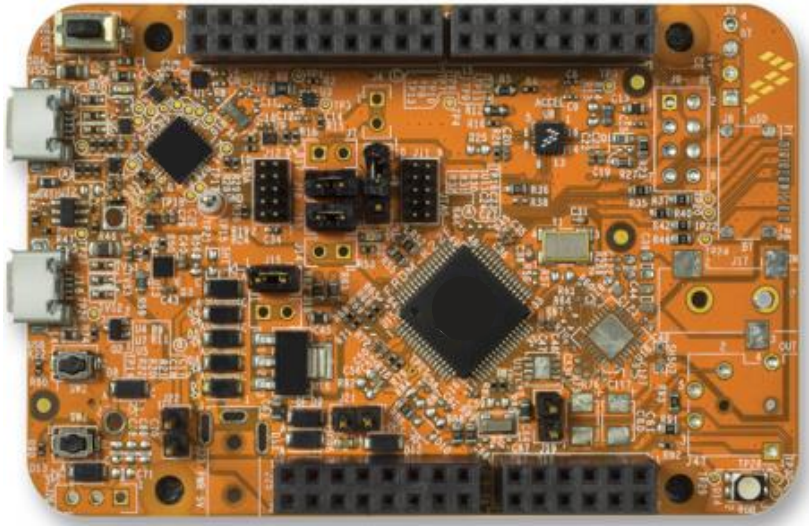
Software and Support

- Rich ARM ecosystem includes Kinetis Design Studio, Keil, IAR, SEGGER, mbed and more
- mbed-enablement through the built-in USB flash programming interface (OpenSDA)

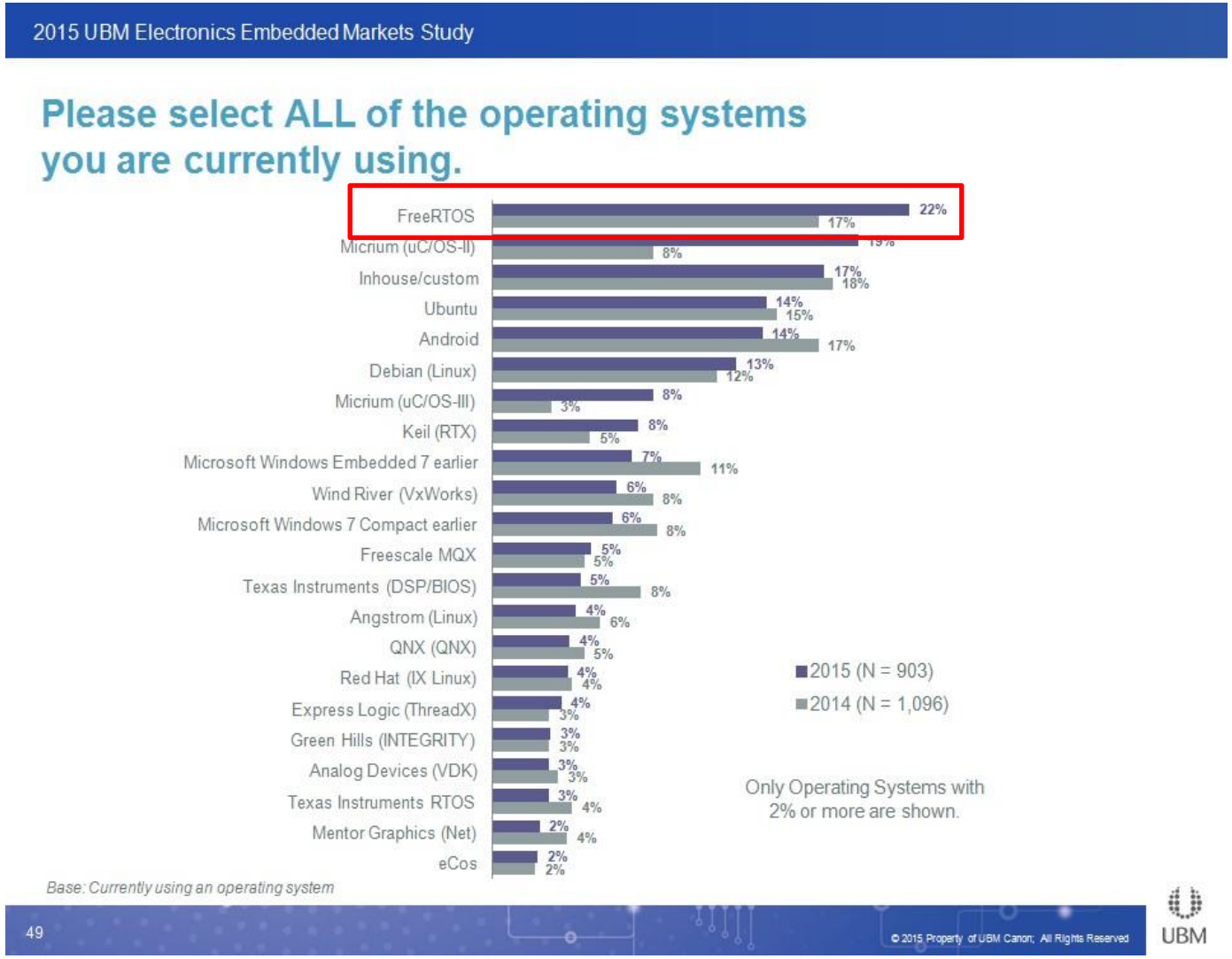
Learn more at: www.nxp.com/Freedom
www.nxp.com/mbed

Low-cost/low-power development hardware

Enables quick application prototyping and demonstration of Kinetis MCU families



UBM Embedded Market Study

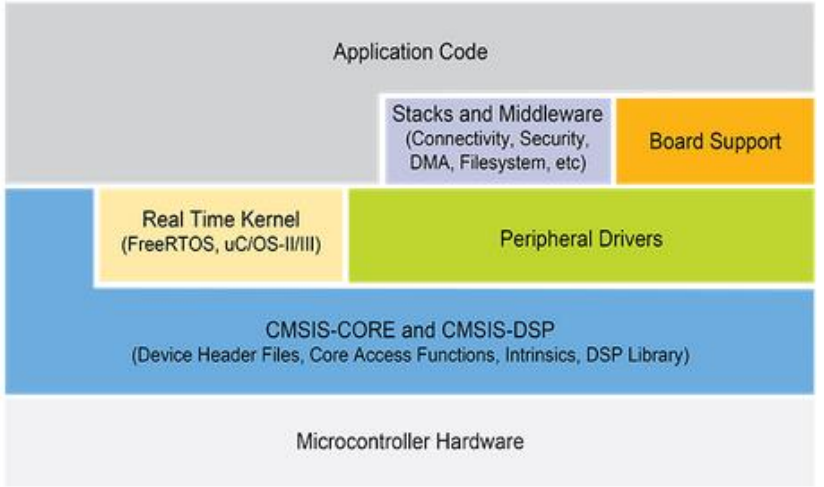


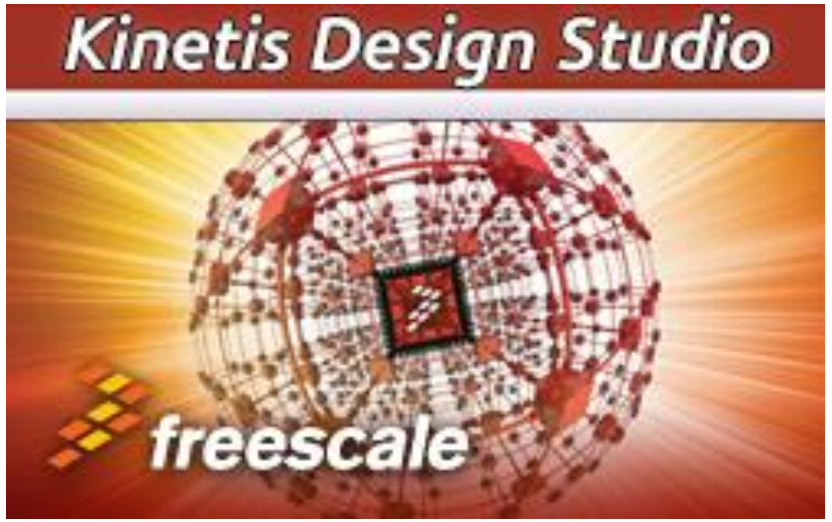
FreeRTOS and Tools

- http://www.freertos.org
- Maintained by Real Time Engineers Ltd., London (Richard Barry)
- Open Source, free-of-charge, royalty free
- >35 architectures, >113,000 downloads in 2015
- Portable, simple to learn and use
- Ecosystem and commercial supported ports available
  - OpenRTOS: commercial supported version
  - SafeRTOS: special version dedicated to safety critical systems
  - **SEGGER SystemView**: System Visibility with Segger RTT
  - **PERCEPIO Tracalizer**: Powerful Analysis Views

NXP Software and Tools for FreeRTOS

- **FreeRTOS** included in NXP Kinetis SDK:
  - http://www.nxp.com/ksdk
  - Open Source, permissible license
  - CMSIS-Core startup and drivers
  - FreeRTOS, Micrium µC/OS and bare metal support
- **Kinetis Design Studio** based on GNU/Eclipse:
  - http://www.nxp.com/kds
  - Kinetis SDK device support added with Eclipse Updates
  - Processor Expert used for Rapid Application Development
- **FreeRTOS Kernel Awareness Plugin**

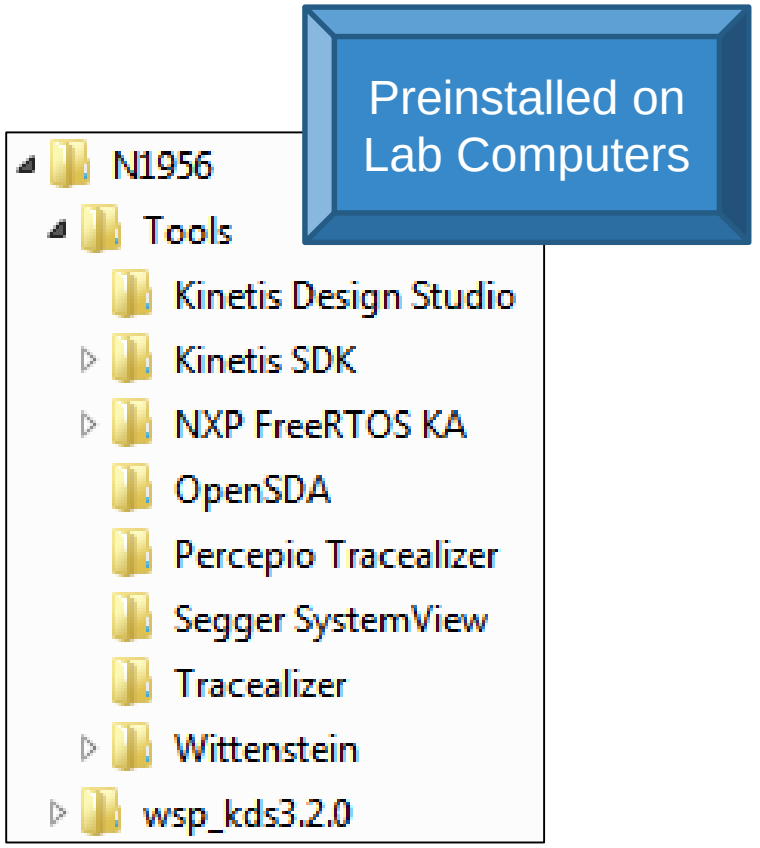




Lab Notes

- Lab Files in C:\FTF\N1956

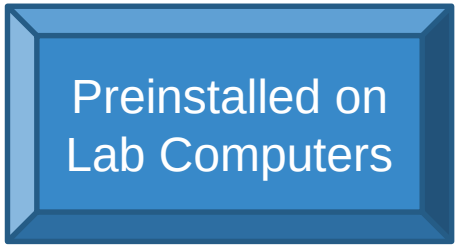
- Lab_KSDK_FreeRTOS
  - KDS Project used in labs
- Tools
  - Tools used in labs
- wsp_kds3.2.0
  - Kinetis Design Studio workspace used in labs



Please leave the boards/cables/notebooks in the room!

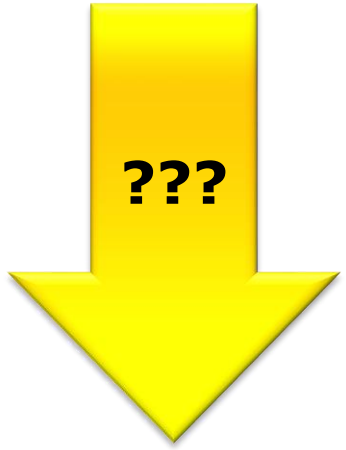
Lab Setup

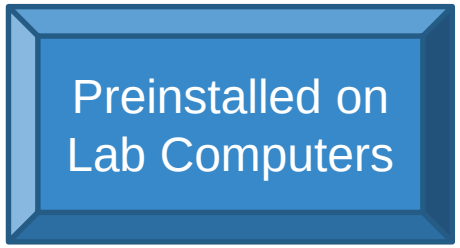
Setup and installation of the tools used in this session…



Outline: Setup

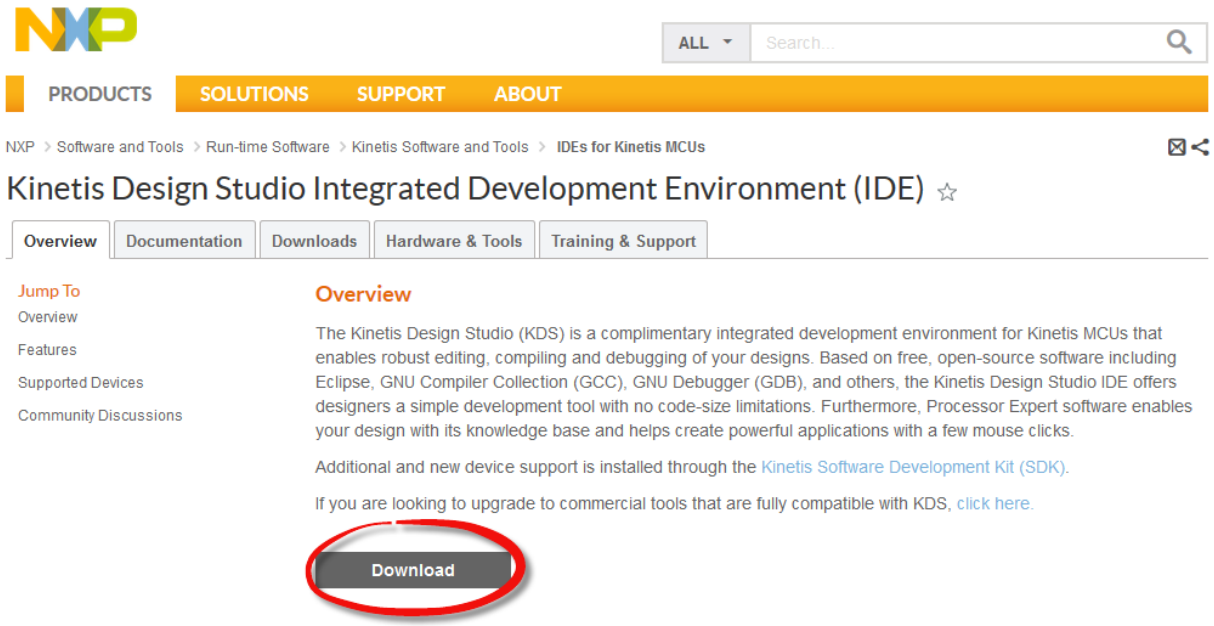
- **Problem**
  - Getting Tools and Project in place
- **Solution**
  - Installation of Kinetis Design Studio IDE, Kinetis SDK and Eclipse Update
- **Steps**
  - Installation of Kinetis Design Studio
  - Installation of Kinetis SDK
  - Adding Kinetis SDK support to Kinetis Design Studio
  - Importing existing project into workspace





Installation of Kinetis Design Studio IDE

- Download Kinetis Design Studio from http://www.nxp.com/kds
- Version used in Lab: KDS v3.2.0
- Hosts: Windows, Linux, Mac OS X
- Run the setup with default settings

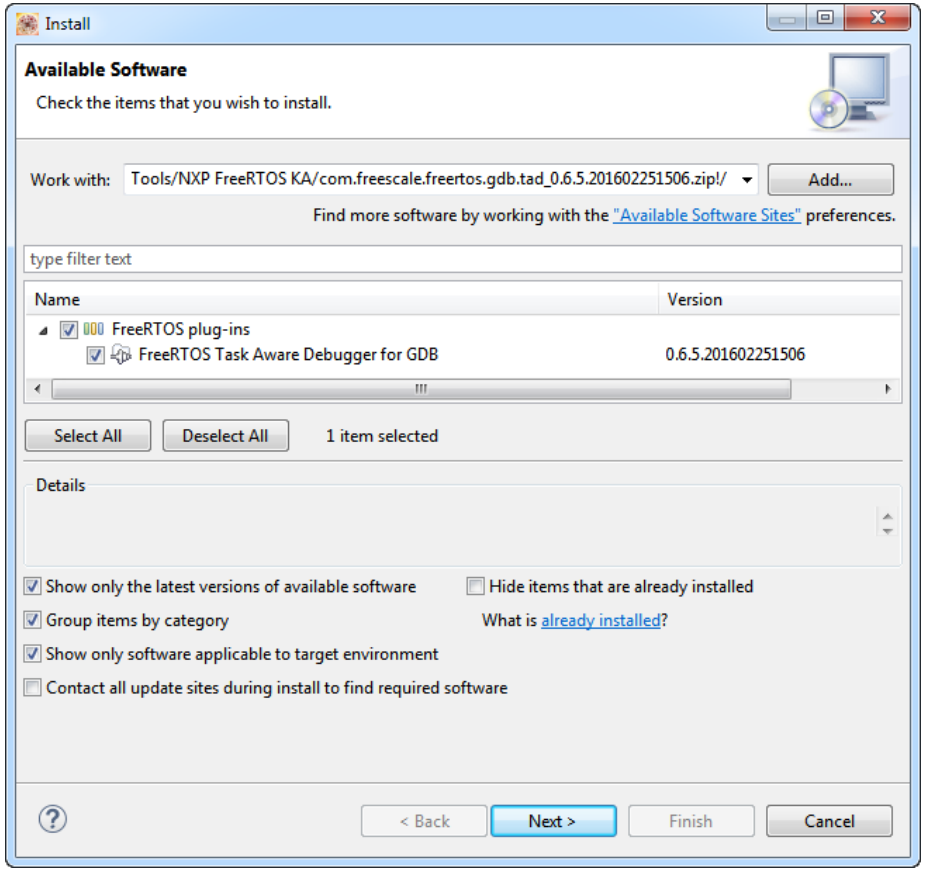


Preinstalled on Lab Computers

Kernel Awareness Installation

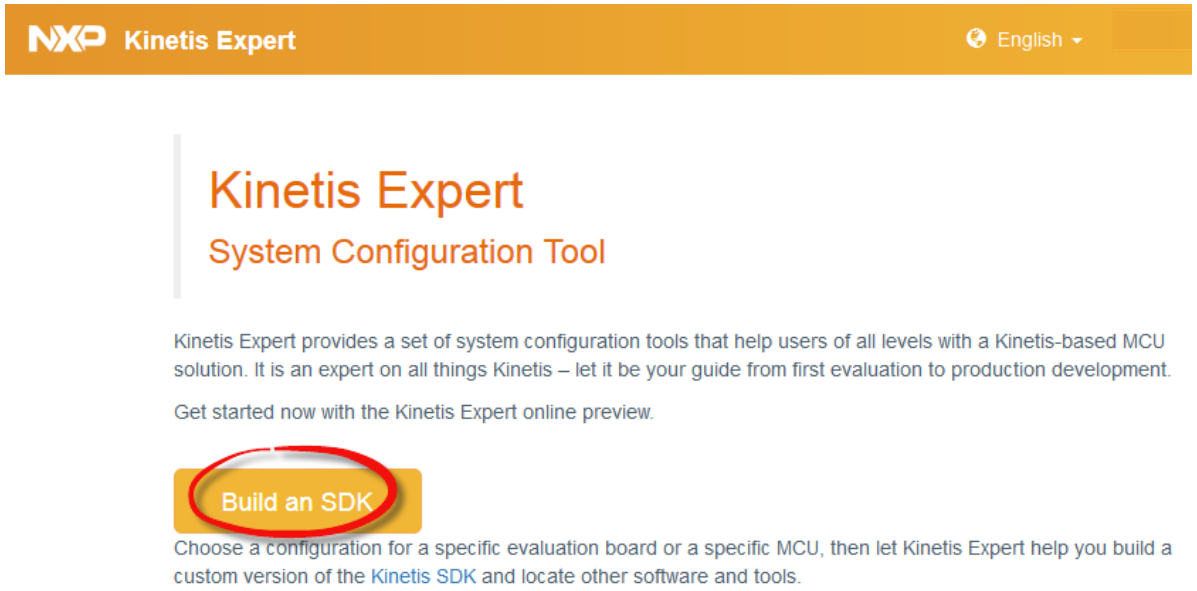
- Menu Help > Install New Software
- N1956/Tools/NXP FreeRTOS KA/*.zip

Pre-Installed on Lab Computers



Get the Kinetis SDK

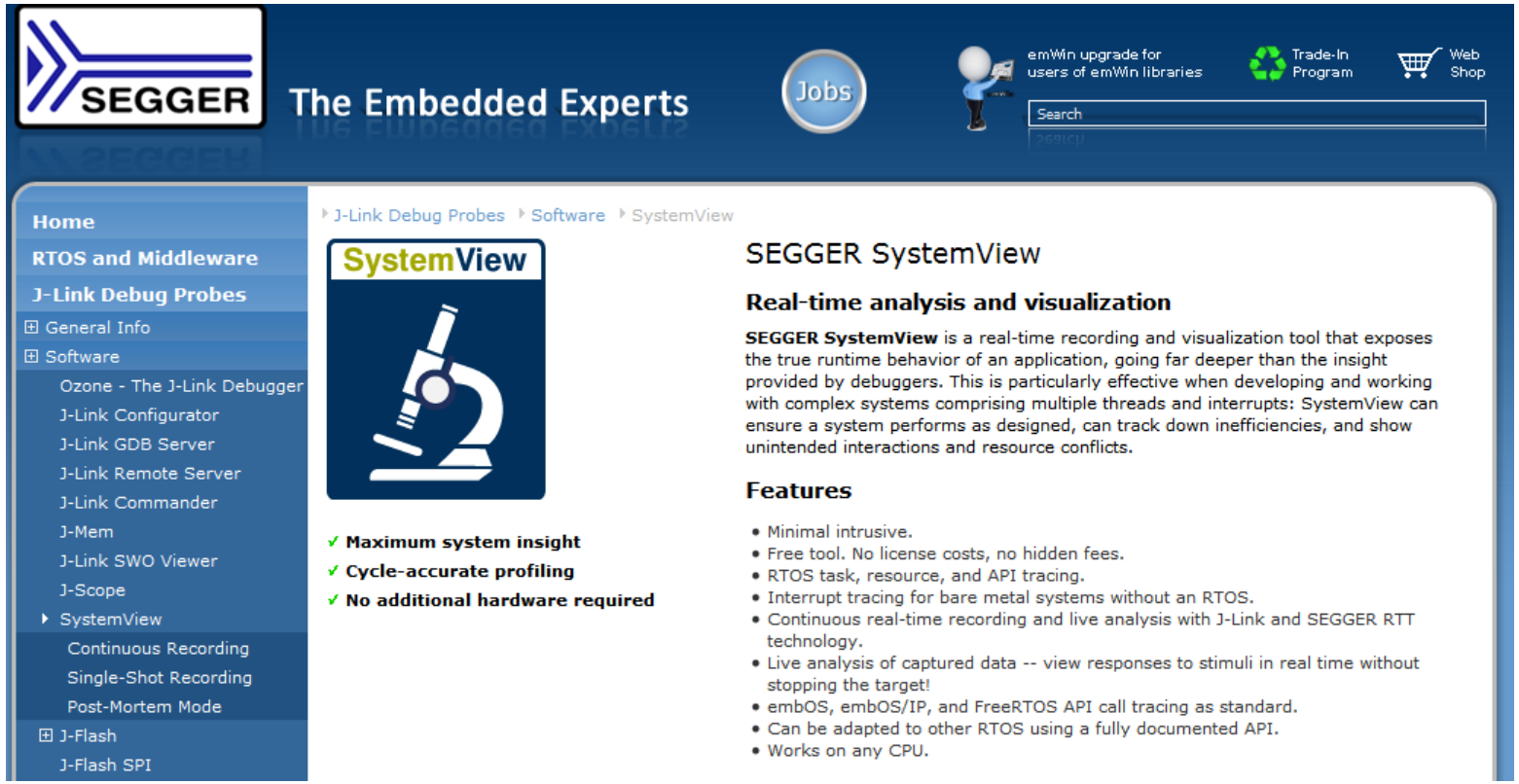
- Build the SDK on http://kex.nxp.com
- Download file from the Vault
- Extract into c:\nxp\KSDK
- ➔ Lab project has SDK inside lab project (‘standalone’)



Preinstalled on Lab Computers

Segger SystemView

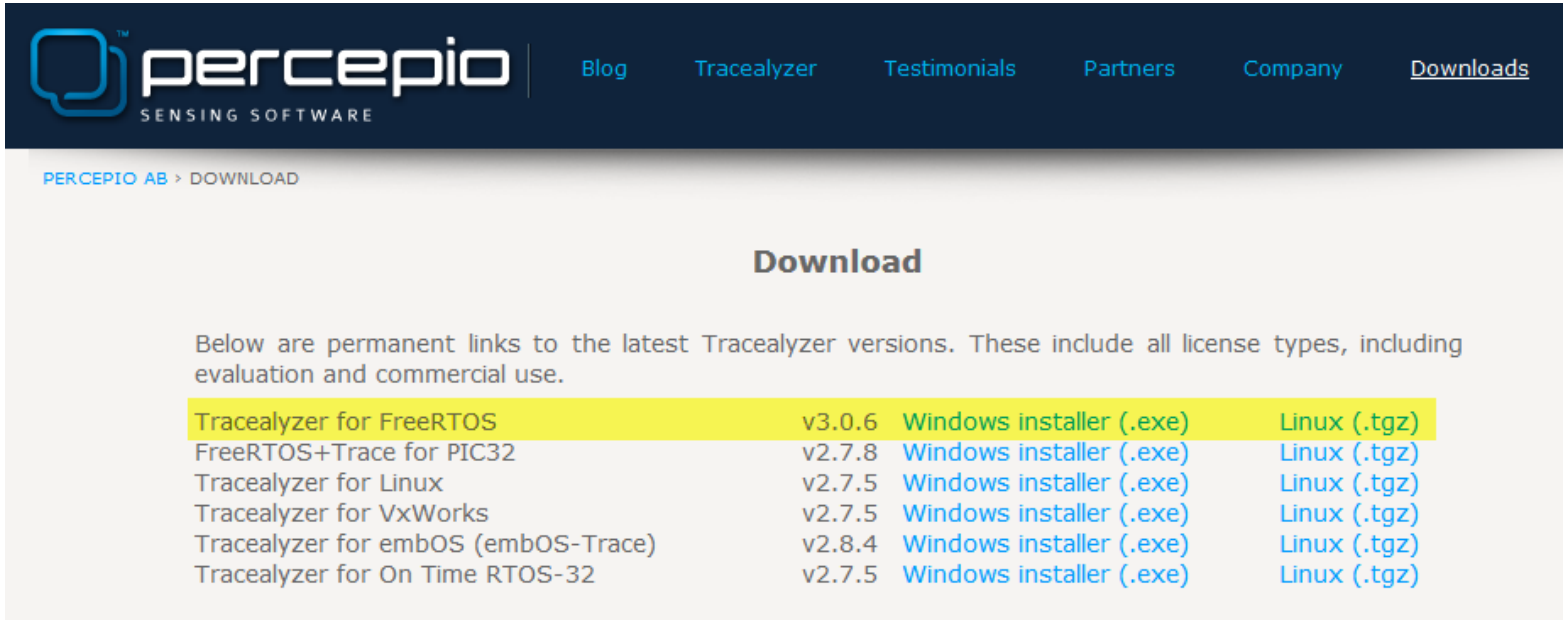
- Download SystemView from https://www.segger.com/systemview.html
- Run the setup



Preinstalled on Lab Computers

FreeRTOS+Trace Tracealizer from Percepio

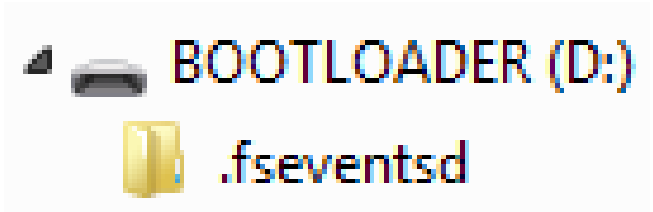
- Download Tracealyzer for FreeRTOS from http://percepio.com/download/
- Free demo version (task scheduling only)
- 30 day evaluation (Professional Edition) installed on lab computers

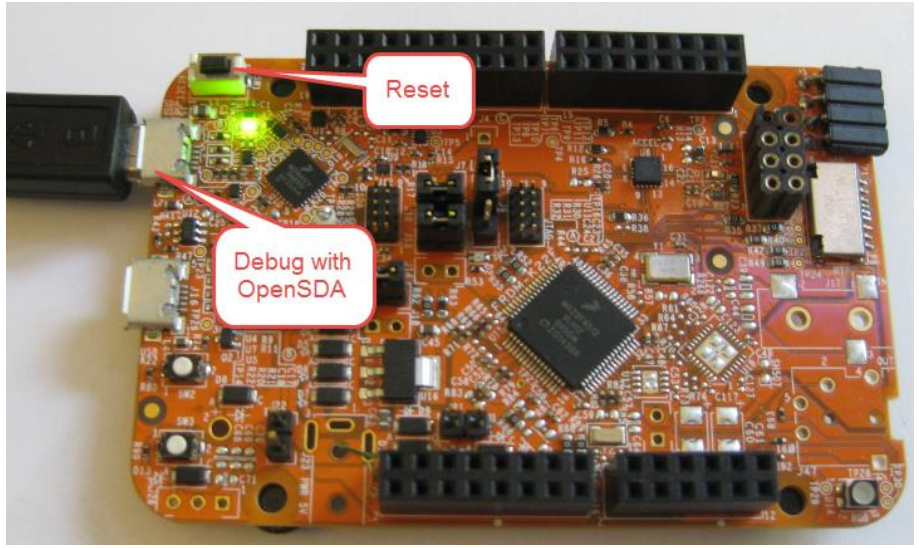


Preinstalled on Lab Computers

Lab Setup: Segger OpenSDA Firmware

- Power Board with 'SDA USB' while RESET button pressed
  - Board enumerates as BOOTLOADER
  - Copy firmware file (JLink_OpenSDA_V2_2015-10-13.bin) to BOOTLOADER drive
  - Green LED blinks fast, then mostly on
- Repower board with SDA USB port normally
  - USB drivers might enumerate
  - Green LED mostly on



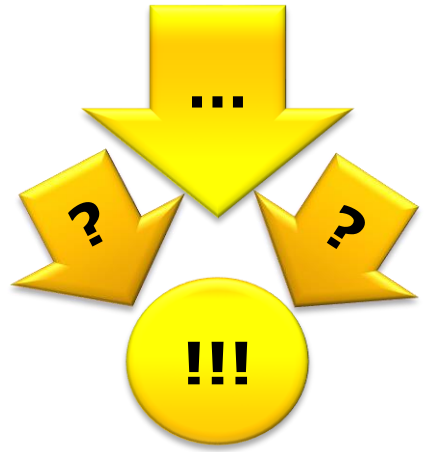


Preinstalled on Lab Boards

Summary: Lab Setup

- Setup on Lab Machines
  - FRDM-K22F Board
  - OpenSDA Debug (Segger J-Link)
  - Kinetis Design Studio
  - FreeRTOS Kernel Awareness
  - Kinetis SDK
  - Segger SystemView
  - Percepio Tracealizer

Preinstalled on Lab Boards

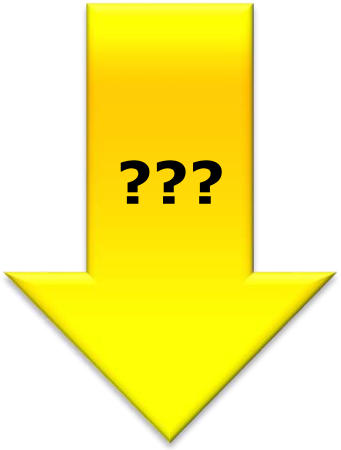


Lab Application

Go, figure it out and make it better!

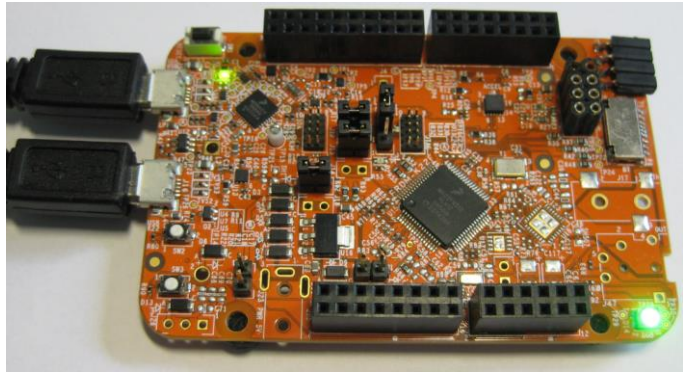
Outline: Lab Application

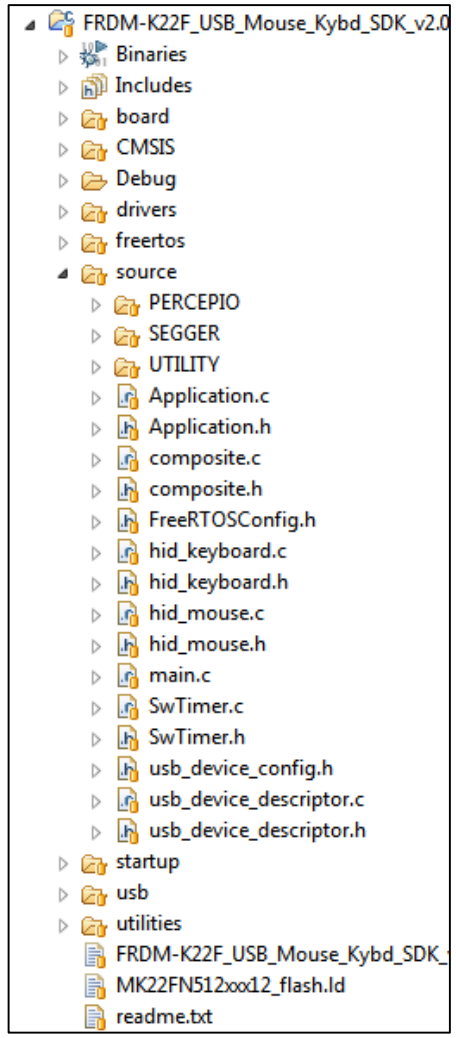
- High Level overview (Tools, board, Application)
- First steps
  - Starting Kinetis Design Studio IDE
  - New workspace
  - Importing Project
  - Building
  - Debugging



Lab Board and Application

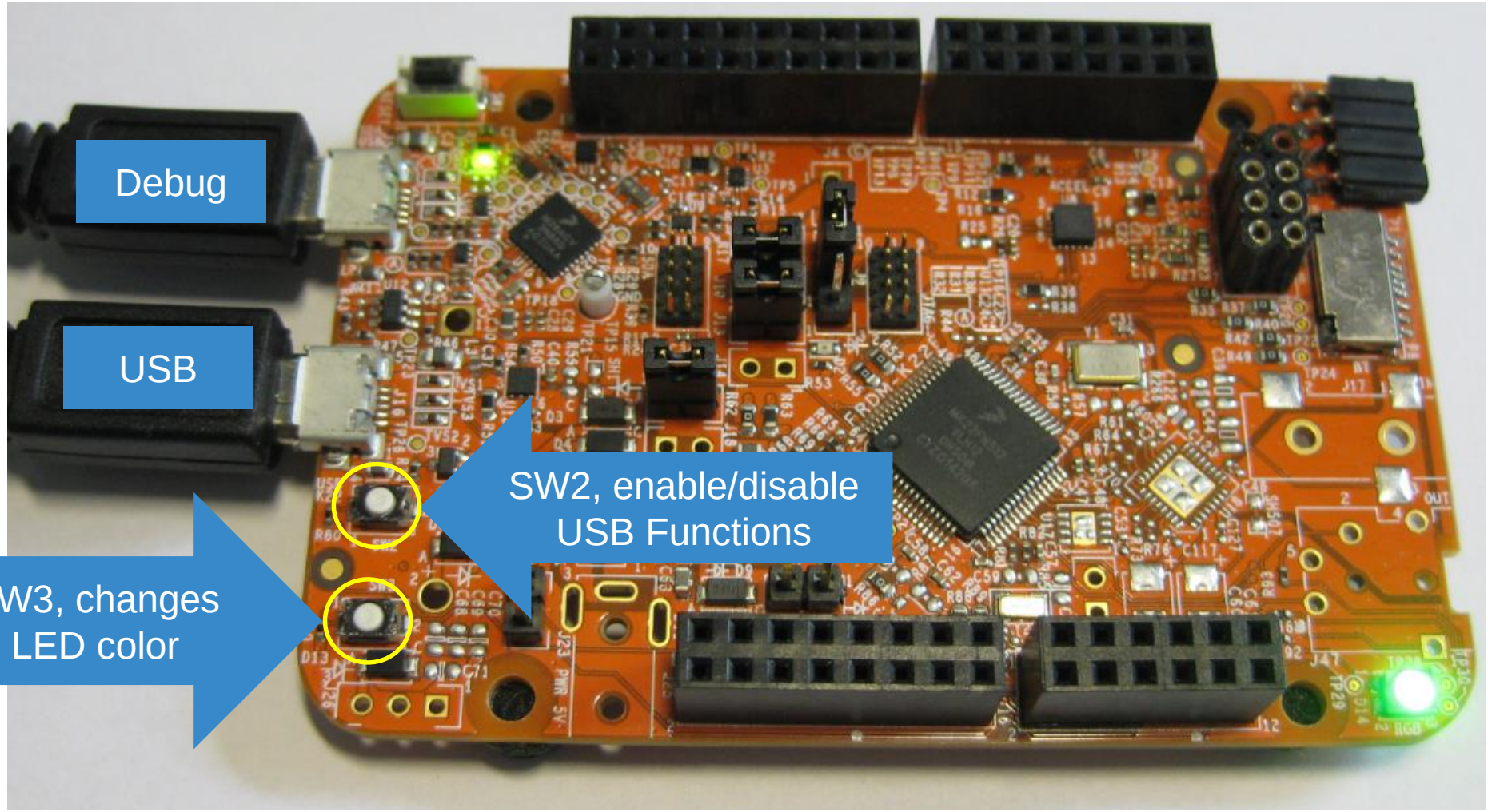
- **FRDM-K22F** (ARM Cortex M4F)
- OpenSDA v2 with **Segger J-Link** OpenSDA firmware
- **Kinetis SDK v2.0** with **FreeRTOS v8.2.3**
- USB HID Composite (Mouse + Keyboard)
- **FreeRTOS+Trace** enabled
  - **Segger SystemView** with Segger RTT
  - **Percepio Tracealizer** with Segger RTT





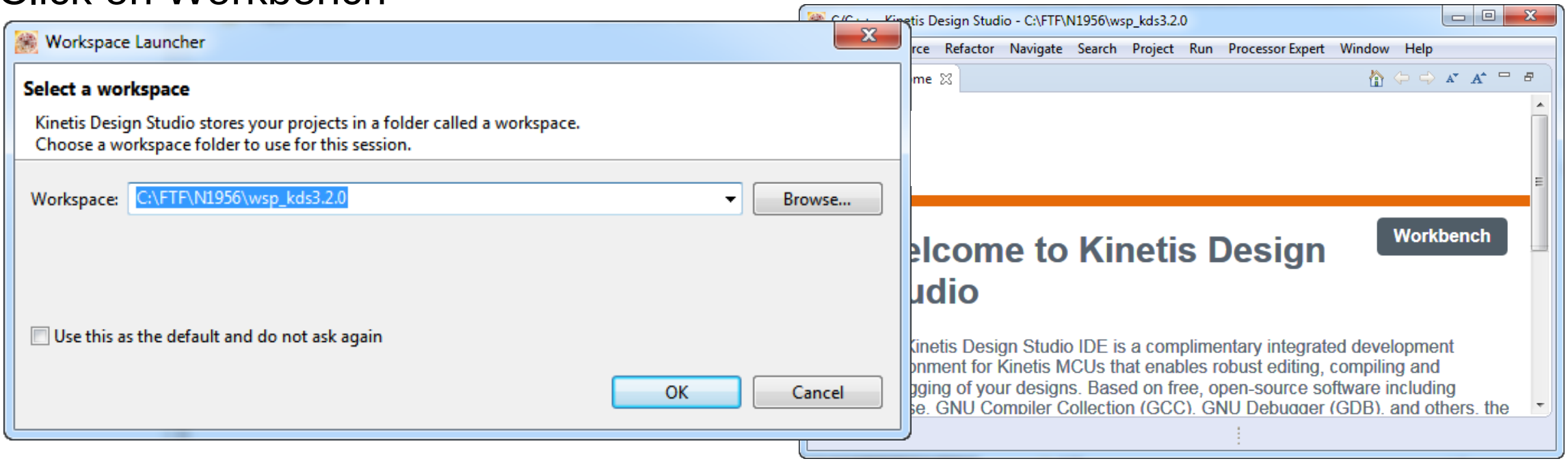
Board Functions

Connect both USB cables to host PC



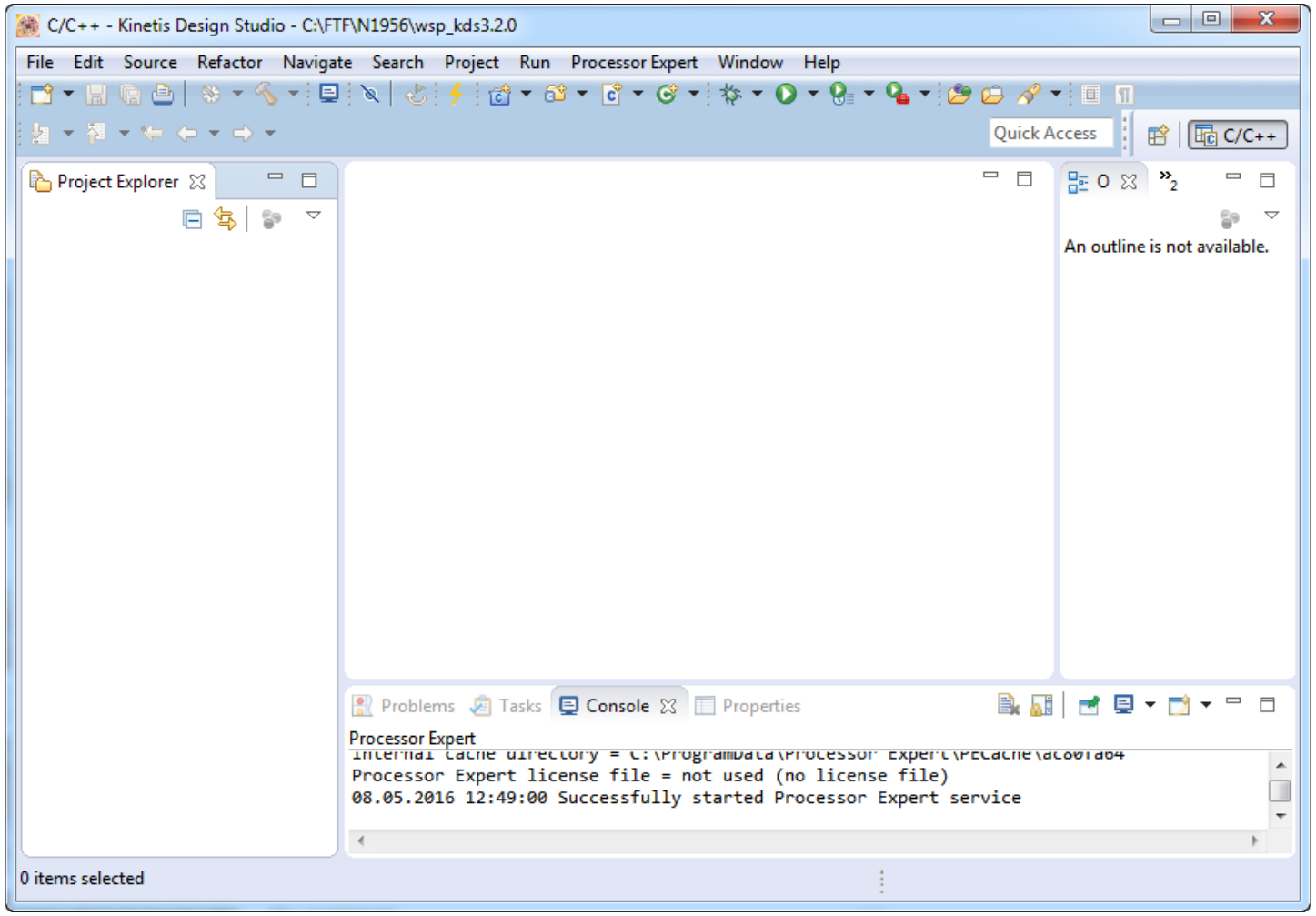
Launching Kinetis Design Studio IDE

- Launch KDS from Shortcut on Desktop
- Choose Workspace
  - C:\FTF\N1956\wsp_kds3.2.0
- Click on Workbench



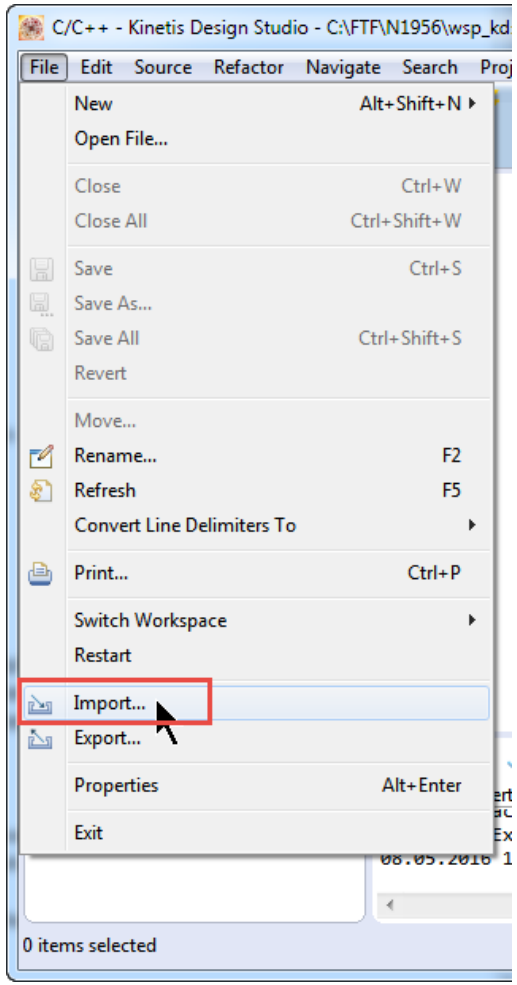
Kinetis Design Studio

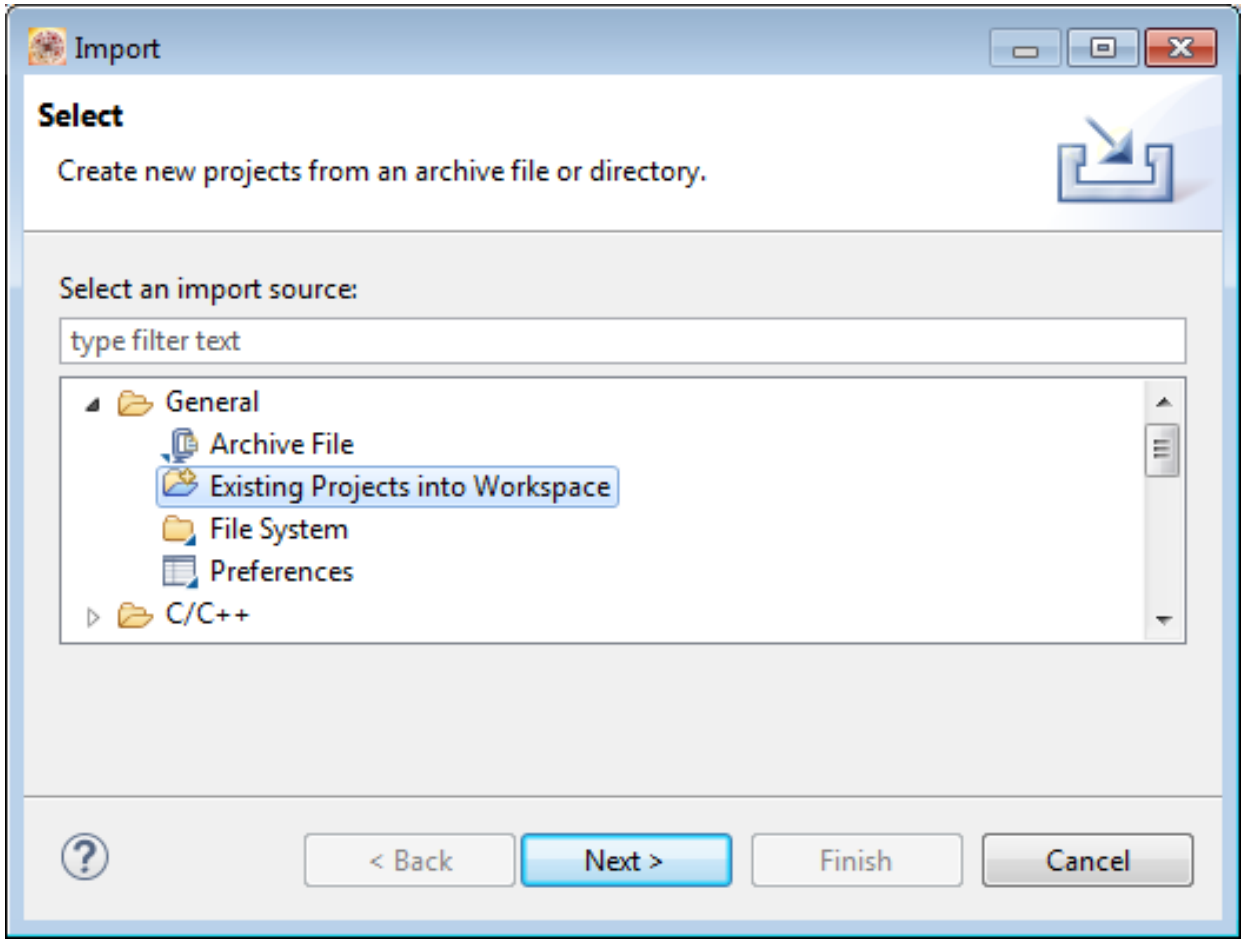
- New Workspace, no projects listed
- Importing lab project in next step



Importing Existing Project

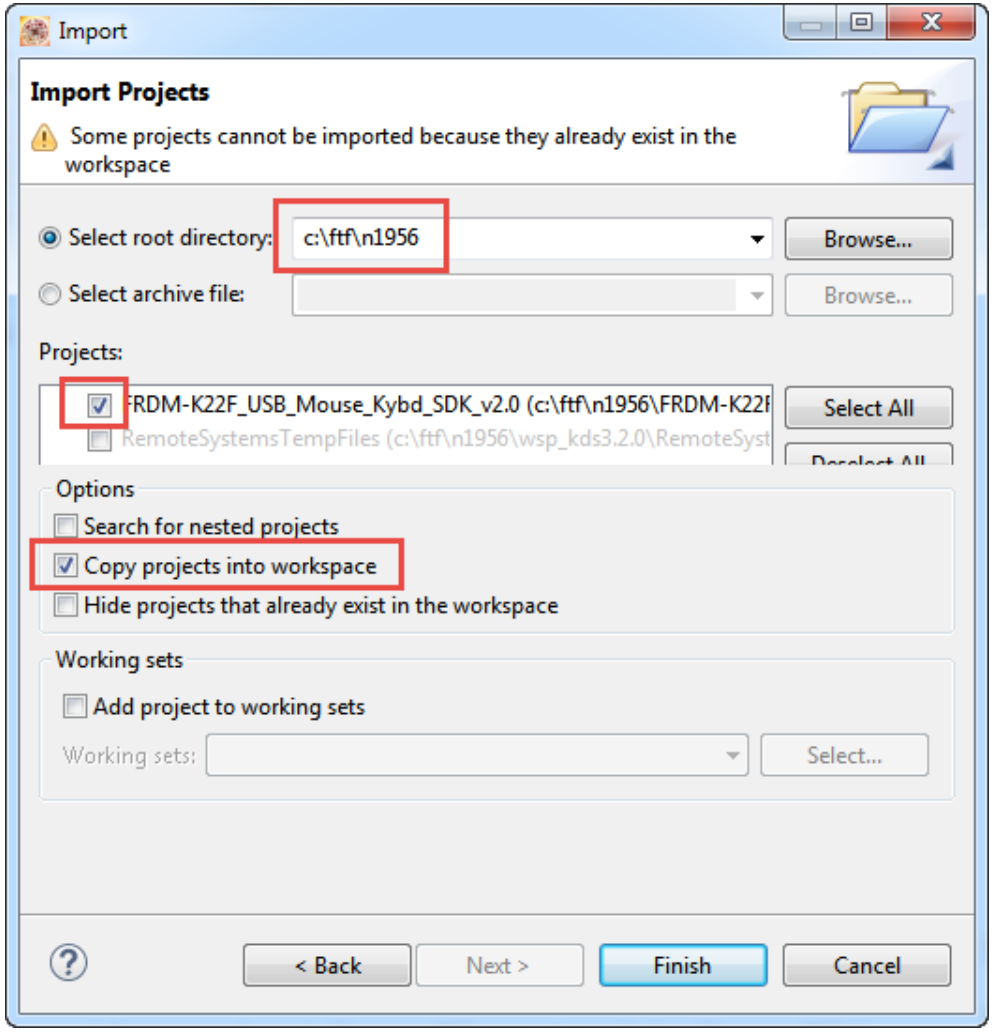
Menu File > Import > General > Existing Projects into Workspace





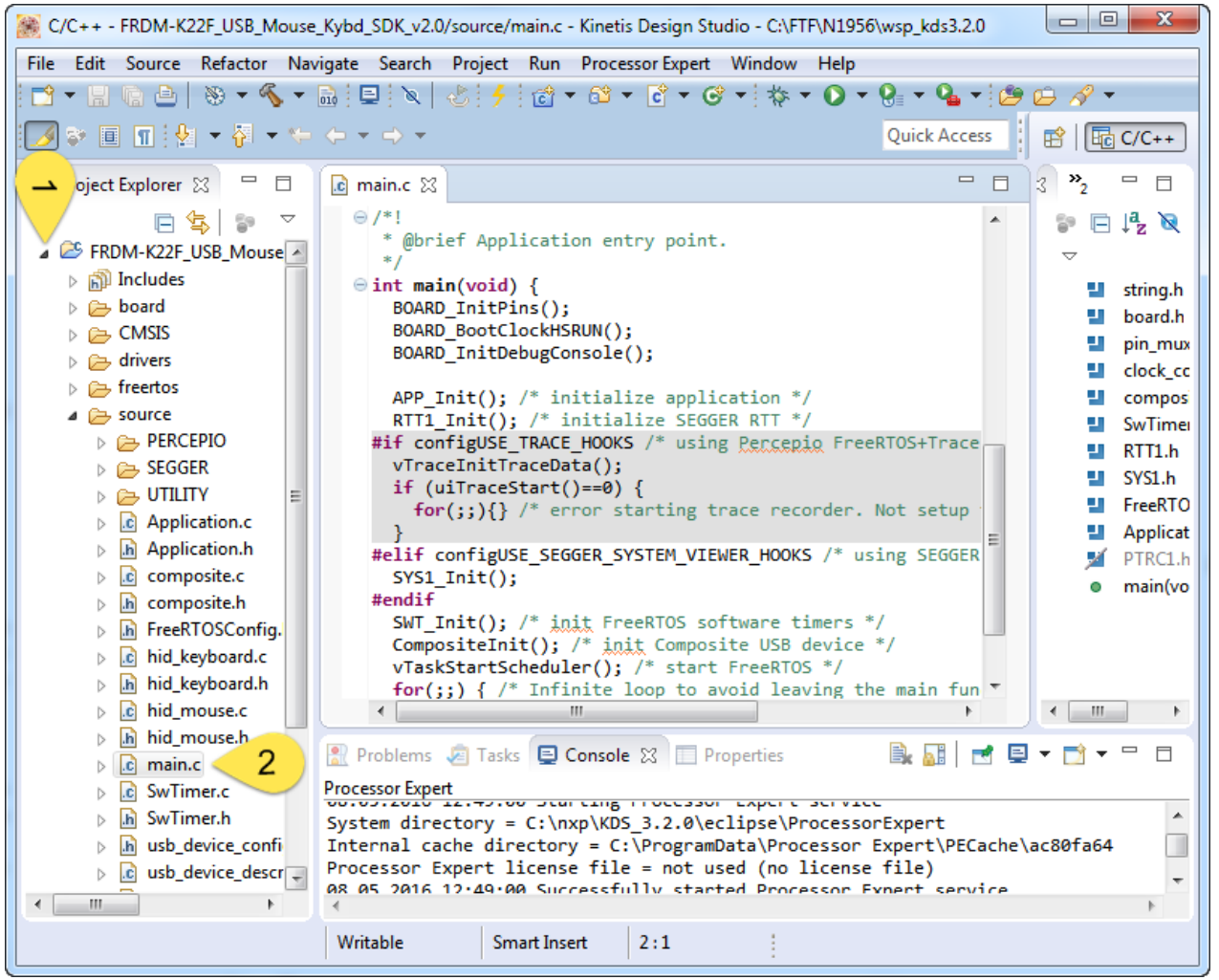
Importing Existing Project

- Enter C:\FTF\N1956
- Select project (FRDM-K22F_USB_...)
- Select Copy projects into workspace
- Press Finish to copy it

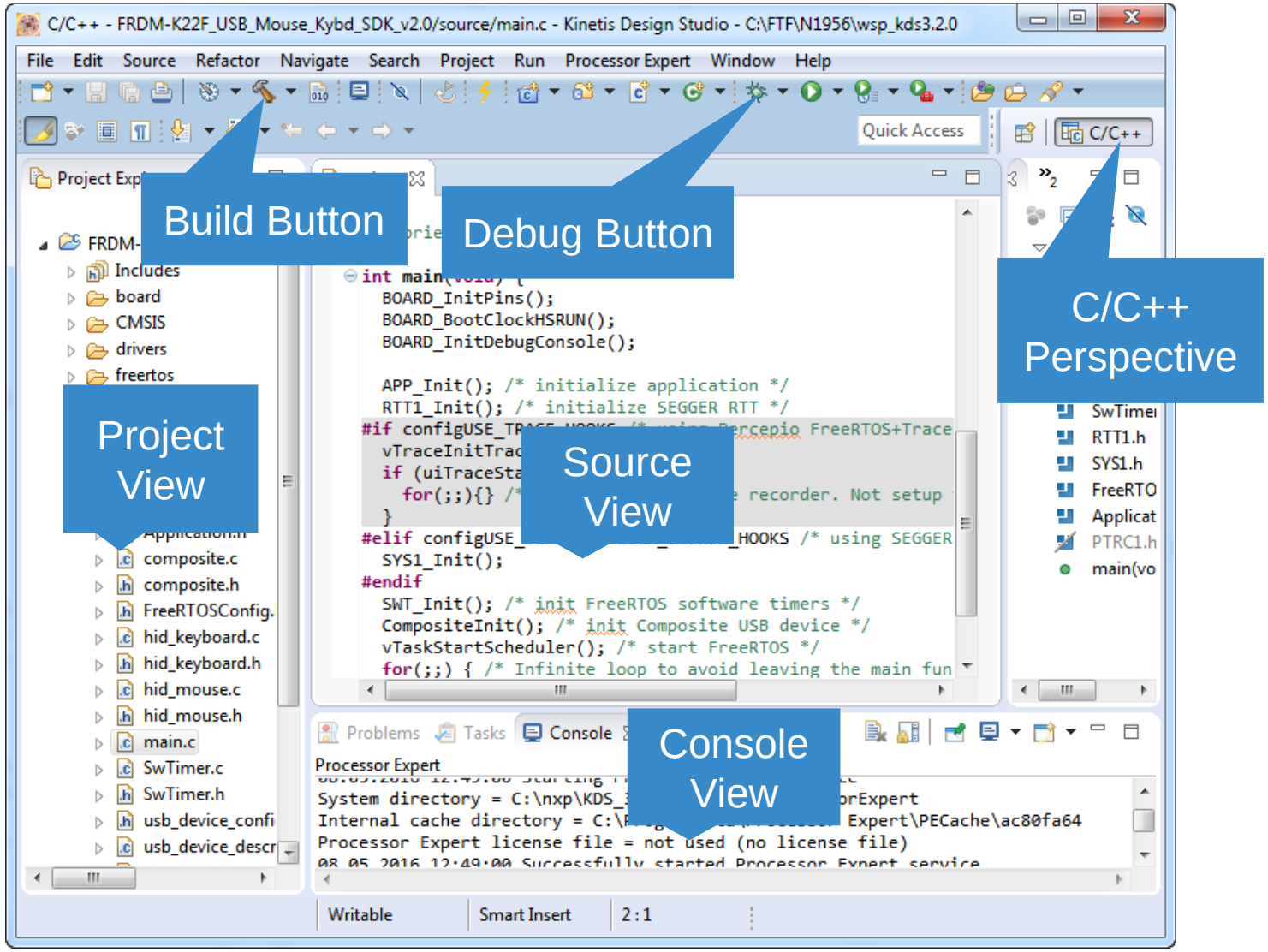


Editor View

- Expand project folder
- Double click on main to open it in editor view

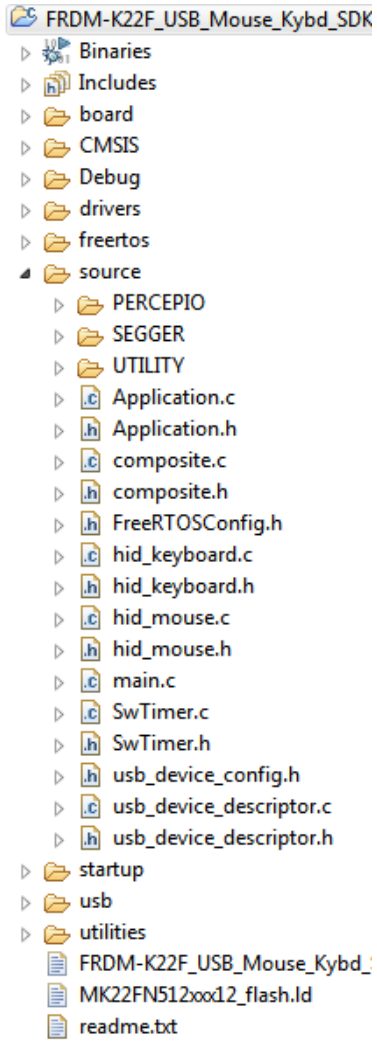


Kinetis Design Studio IDE Views



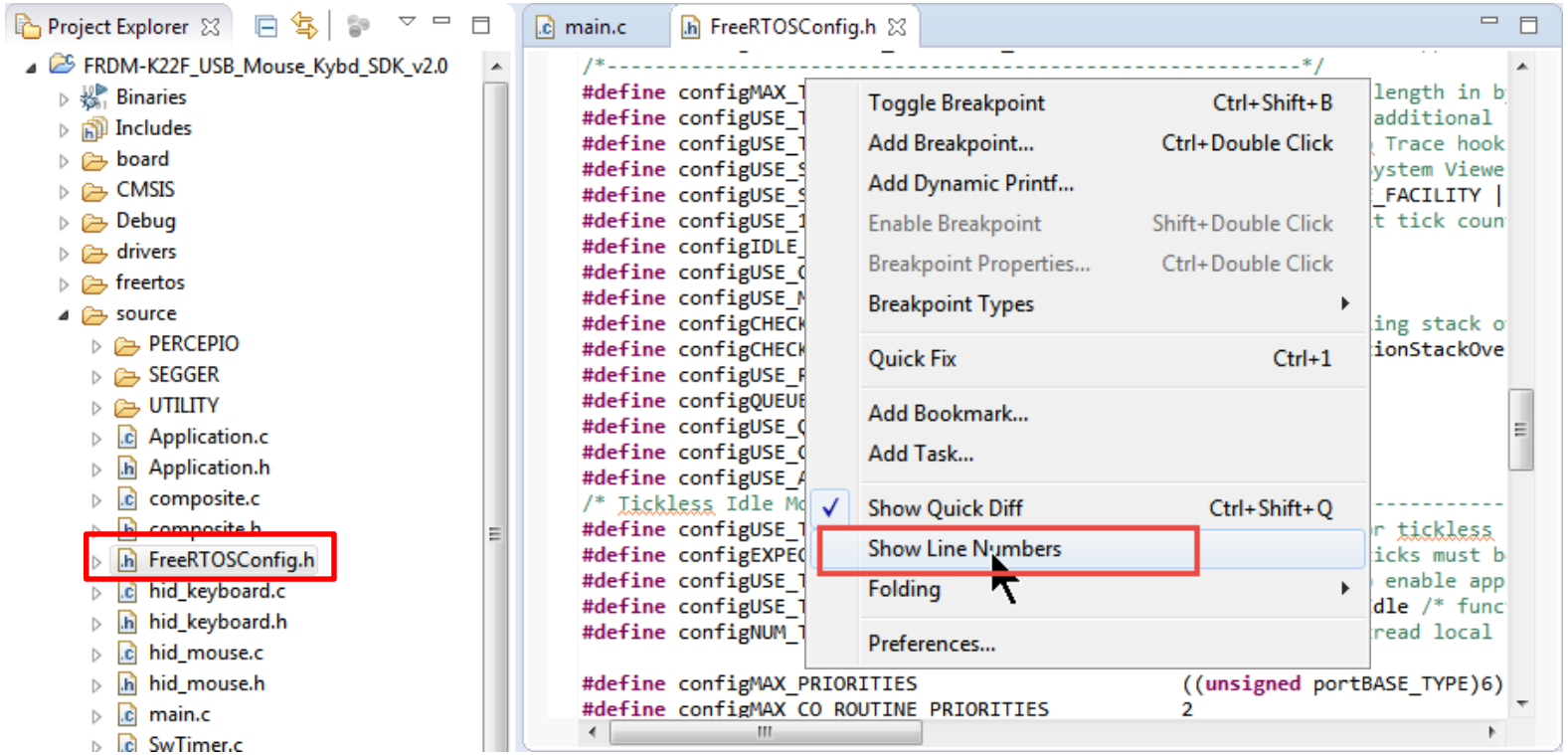
Application Project Structure

- **board**, **CMSIS** & **drivers**: Kinetis SDK
- **freertos**: RTOS
- **source**: Application sources
  - **PERCPIO**: Percepio FreeRTOS+Trace sources
  - **SEGGER**: Segger SystemView and RTT sources
  - **UTILITY**: helper routines
- **startup**: SDK startup code
- **USB**: USB stack
- **utilities**: SDK utilities



FreeRTOSConfig.h and Show Line Numbers

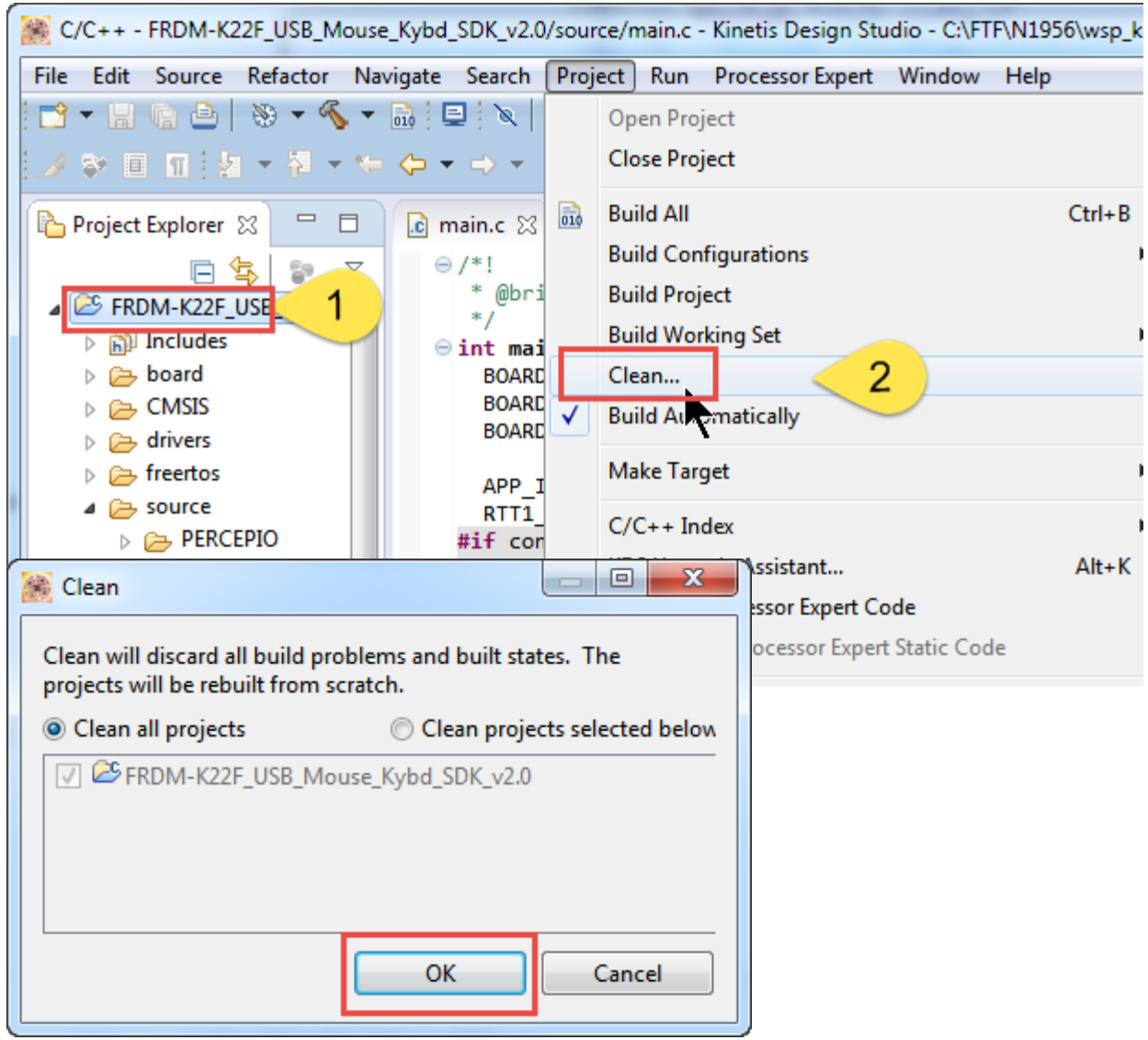
- RTOS Configuration File (FreeRTOSConfig.h)
- Will use it to turn on either Segger and Percepio Trace
- ➔ Show Line Numbers



Clean Project

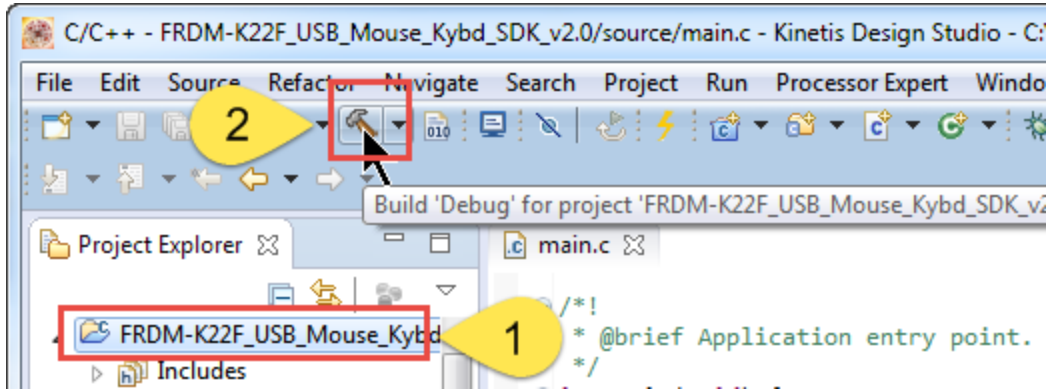
- After importing a project, a clean shall be done
  - Removes object files
  - Removes make files

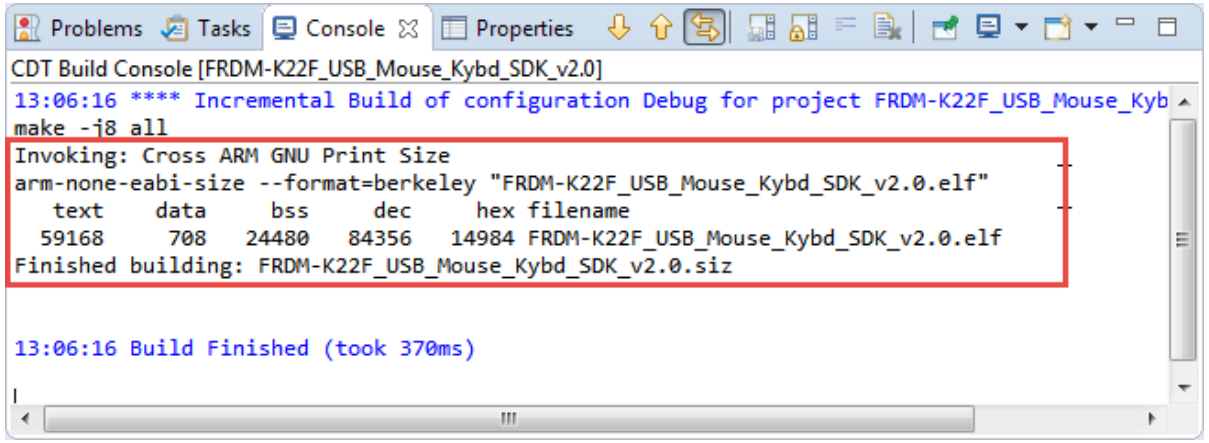
- Perform a 'Clean'
  - Select project
  - Menu **Project > Clean…**
  - Press **OK** to clean

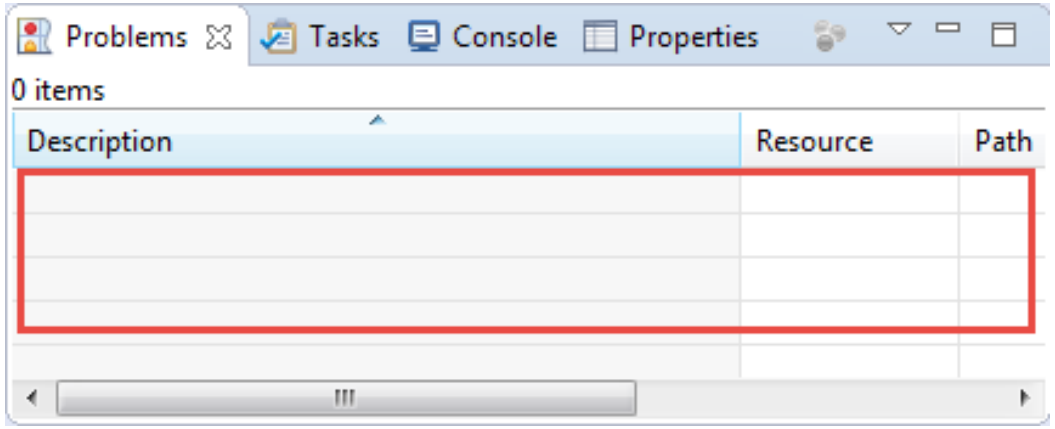


Build Project

- Select Project and Build
- Results
  - No errors in Problems view
  - Code/Data size reported in Console

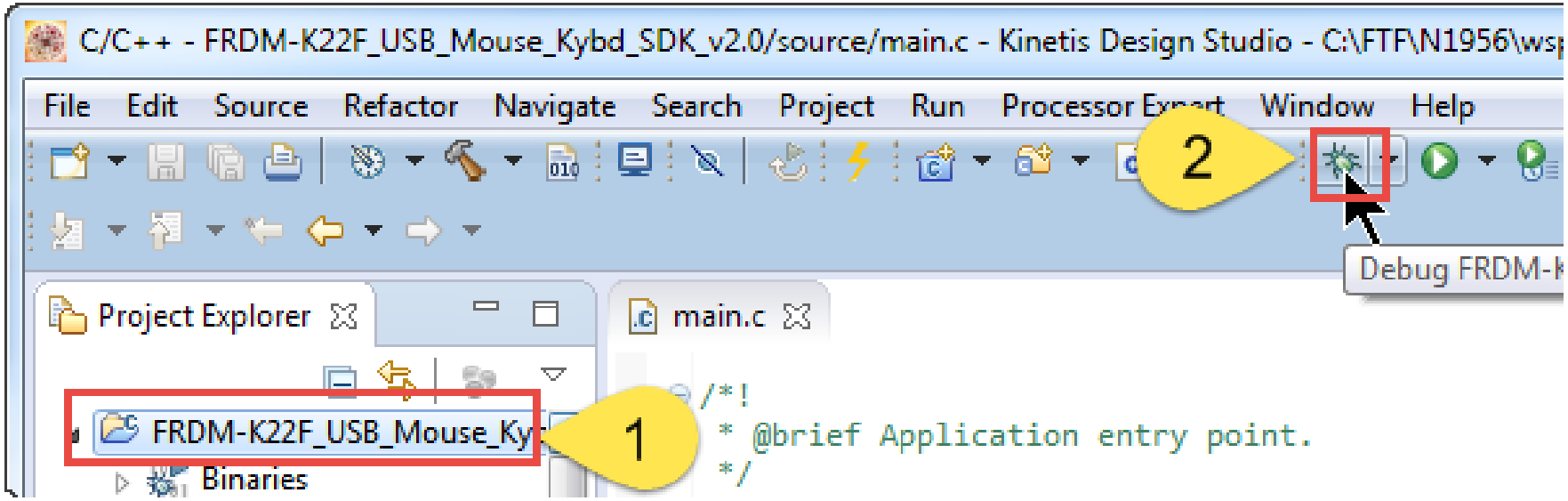






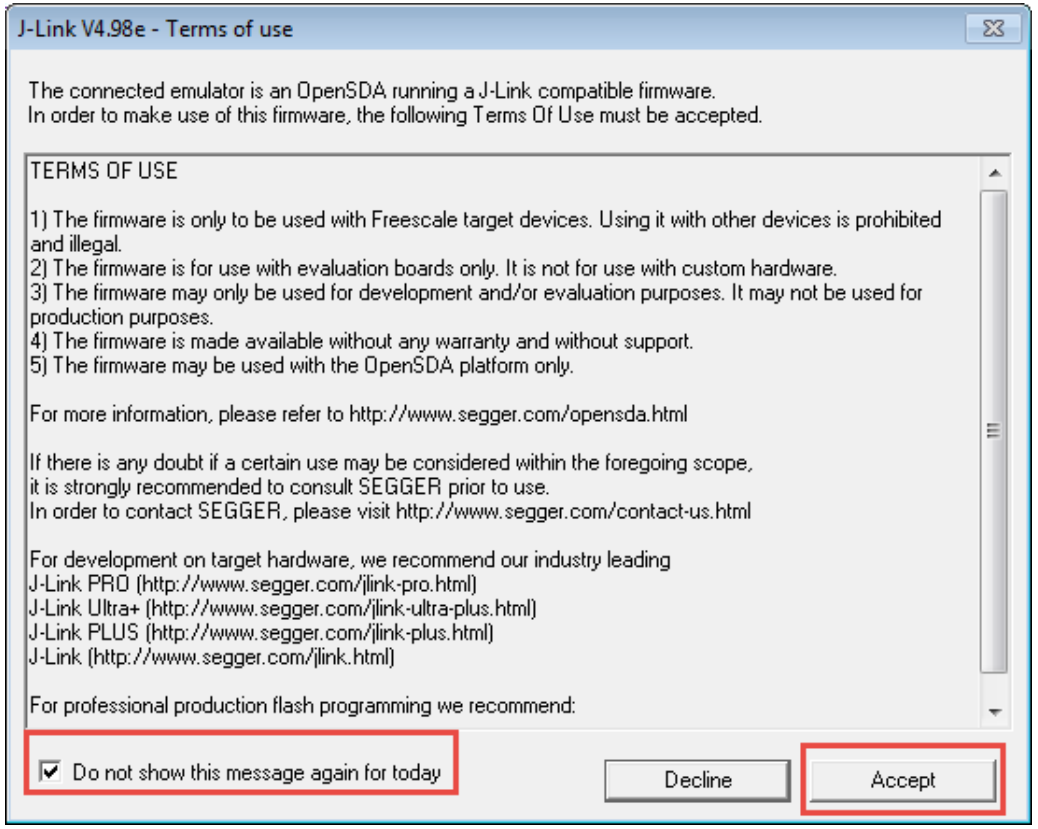
Debug Application

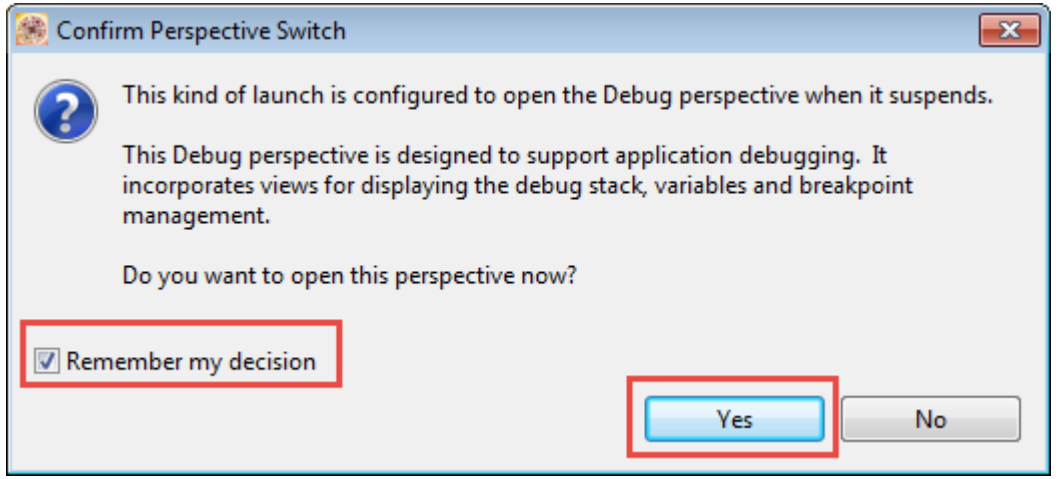
- Select **Project**
- Press **Debug Icon**



Segger Unlimited Flash Breakpoints

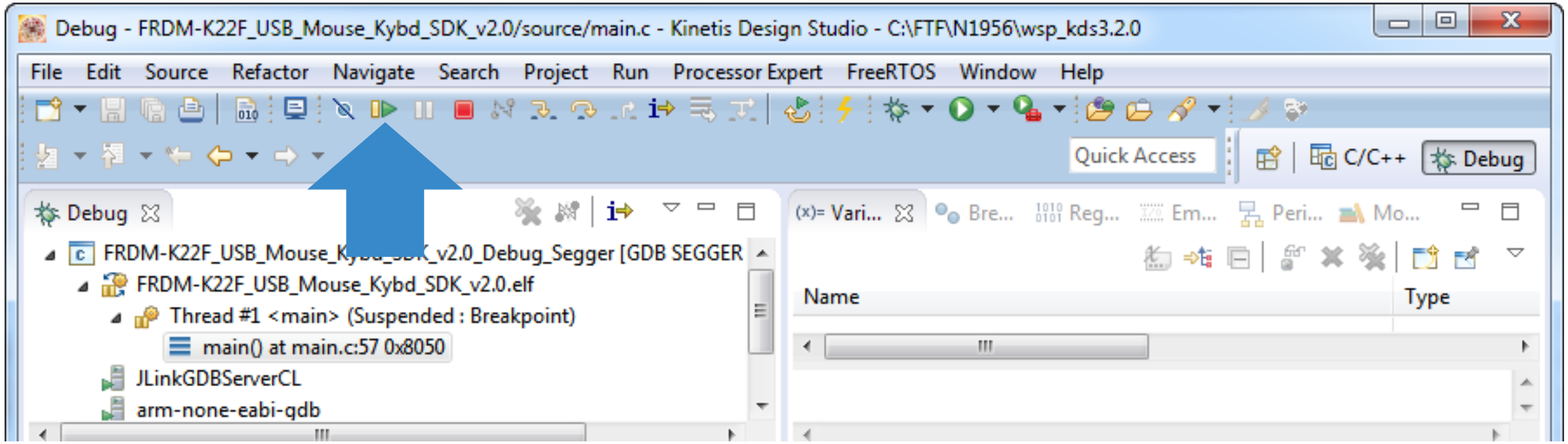
- J-Link Dialog to accept (enable checkbox and press Accept)
- Eclipse asks to switch perspective (enable checkbox and press Yes)





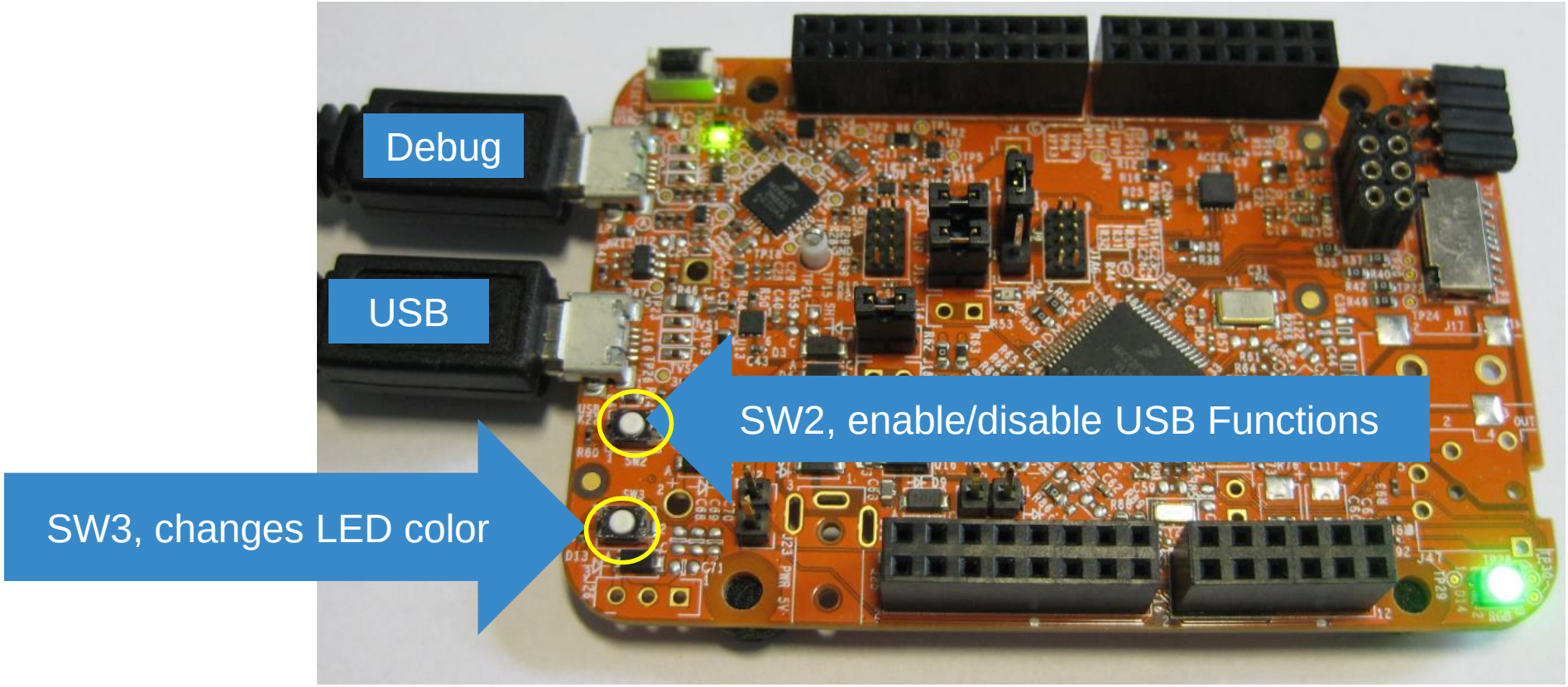
Debugging/Running Application

Run the application 



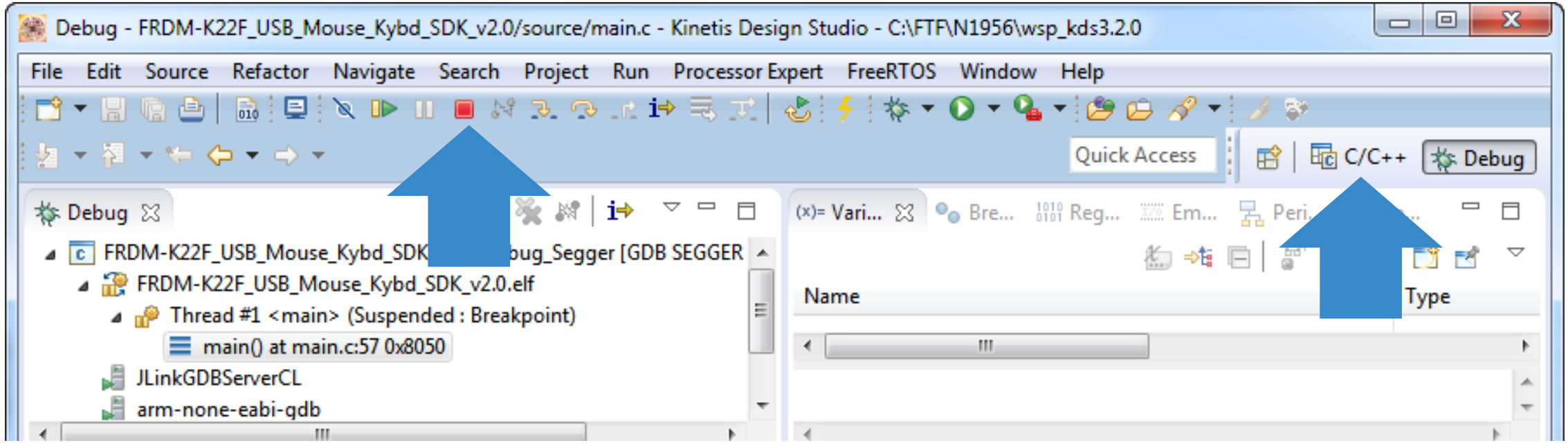
Running Lab Application

- Press SW3 to change RGB LED color
- Press SW2 to toggle USB functionality



Debugging/Running Application

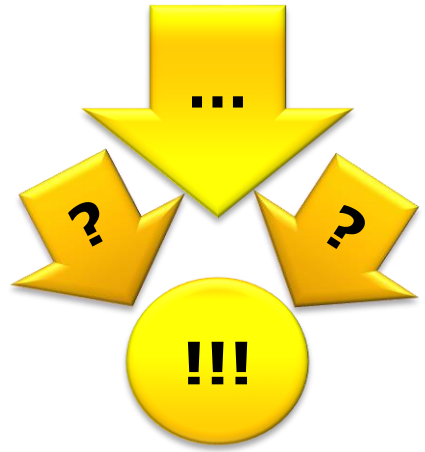
- Terminate Debug Session 
- Switch to C/C++ Perspective 



Summary: Lab Setup

- Initial version of lab application running on board
- Kinetis Design Studio IDE: Eclipse based IDE for NXP Kinetis devices
- Kinetis SDK: Suite of peripheral drivers, stacks and middleware
- Application overview: high level functions and overview

- Further Information:
  - http://www.nxp.com/kds
  - http://www.nxp.com/ksdk
  - http://www.nxp.com/freedom

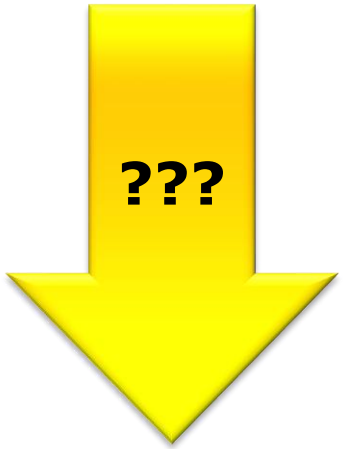


Lab: NXP FreeRTOS Kernel Awareness

Inspecting stack and runtime behavior of RTOS and Application

Outline: FreeRTOS Kernel Awareness

- **Problem**
  - Knowing tasks, queues, stack usage, system load

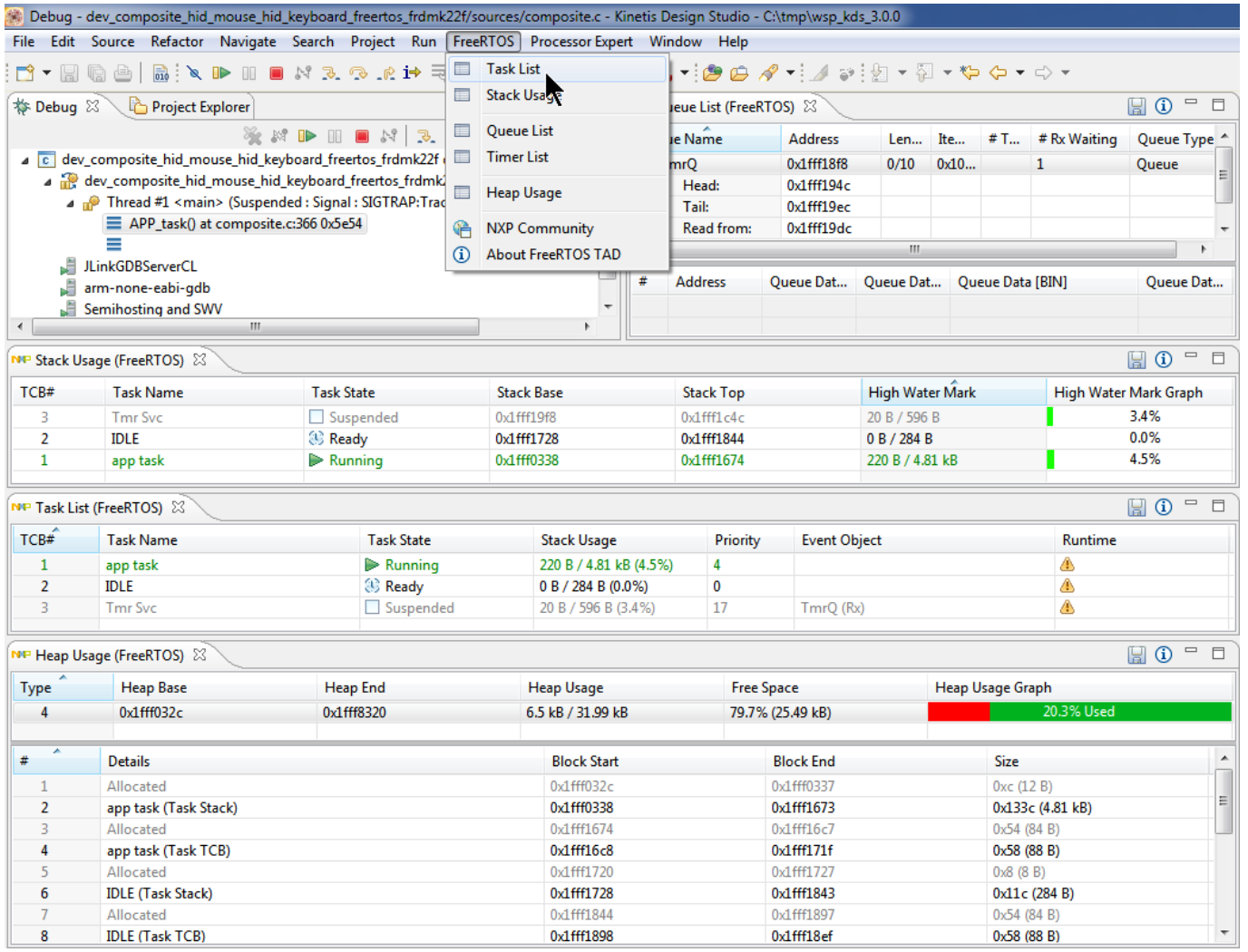


- **Solution**
  - NXP FreeRTOS Kernel Awareness with GDB

- **Steps**
  - Installation of Kernel Awareness plugins
  - Inspect RTOS state

NXP FreeRTOS Eclipse Plugins

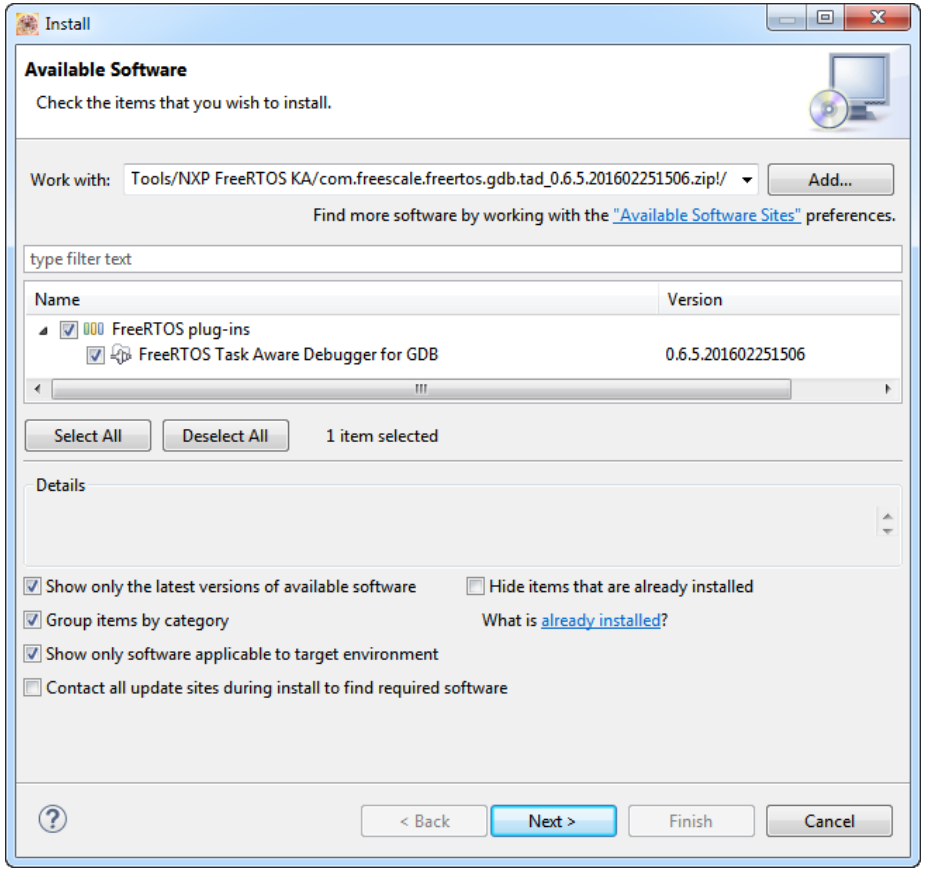
- NXP FreeRTOS Kernel Awareness plugins for Eclipse
- Views
  - Tasks
  - Stacks
  - Queues
  - Timers
  - Heap
- ‘Stop-Mode’ Views
  - Suspend debugger



Kernel Awareness Installation

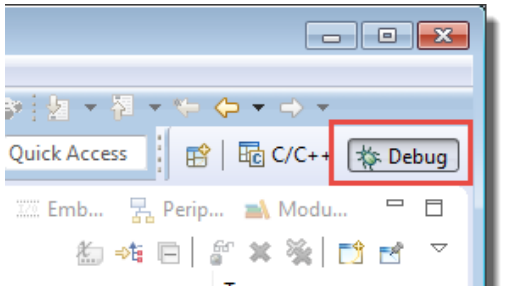
- Menu Help > Install New Software
- N1956/Tools/NXP FreeRTOS KA/*.zip

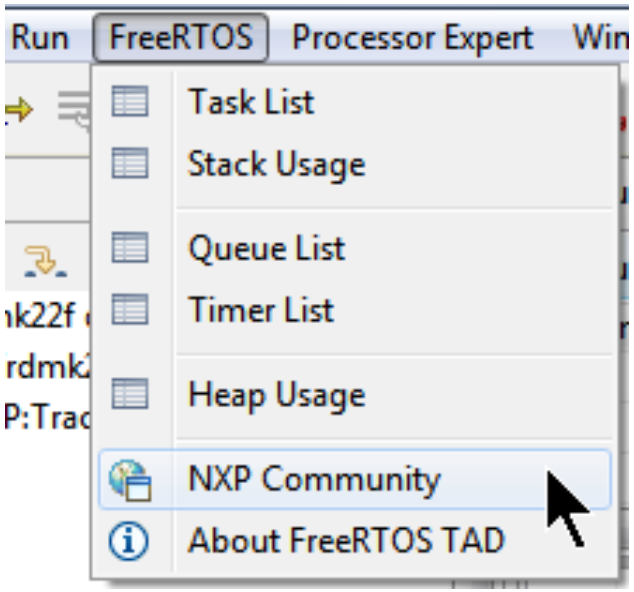
Pre-Installed on Lab Computers

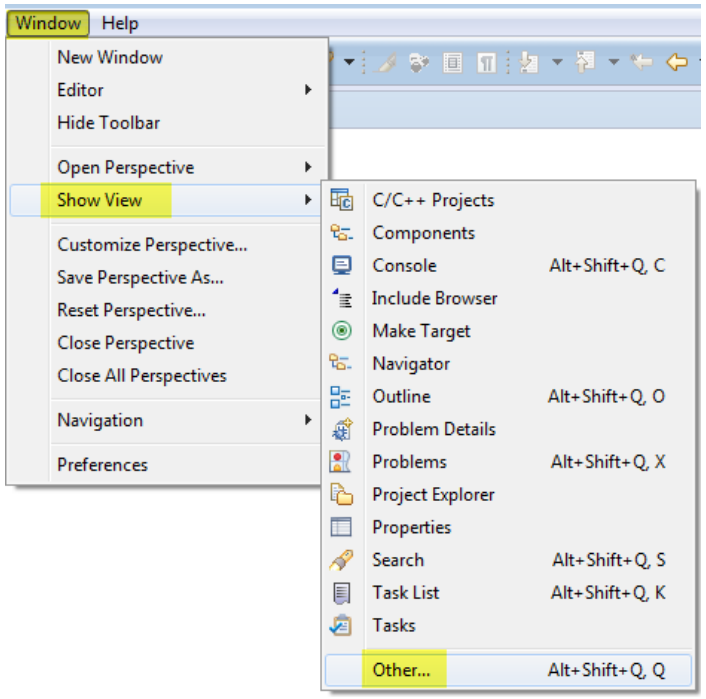


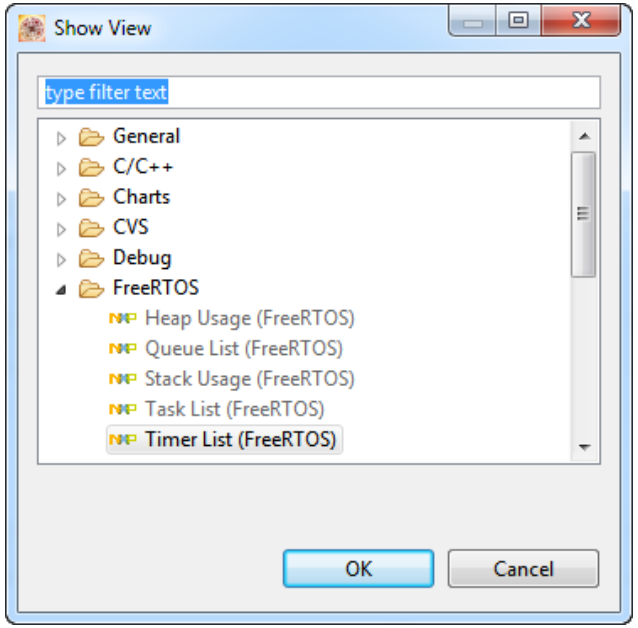
Open Views

- Press **Debug** ➔ Debug Perspective
- Menu ***FreeRTOS***
- Menu ***Window > Show View > Other..***



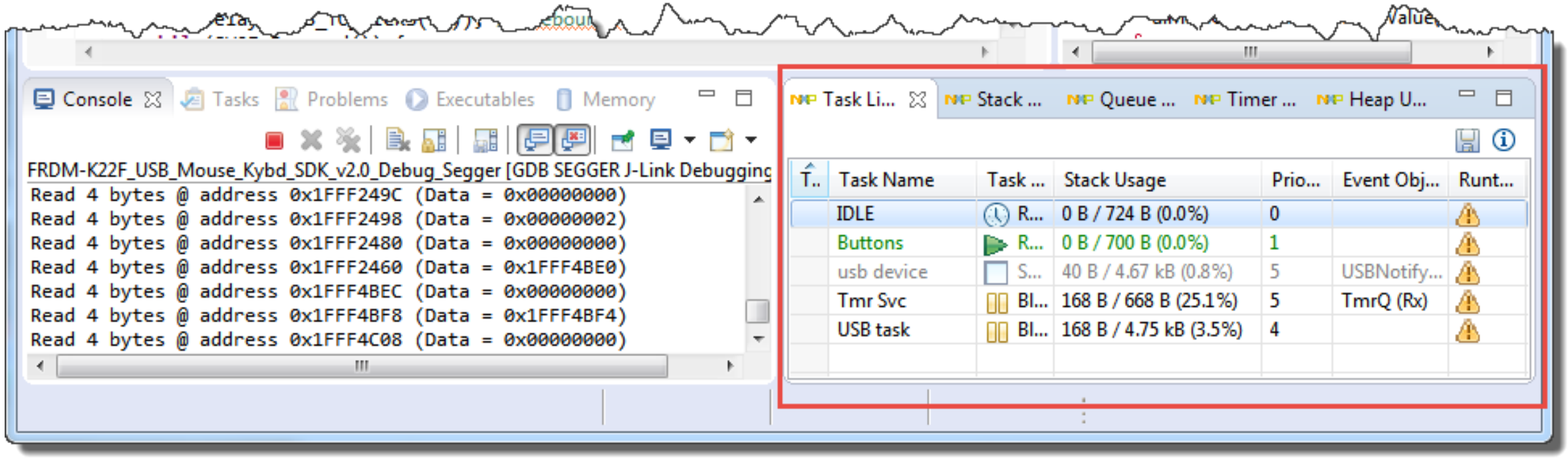






Tips & Tricks: FreeRTOS View Arrangement

- Move FreeRTOS views to the side (Drag Tab to the side and drop)
- Own stack of views
- Does not interfere with console updates



Tasks

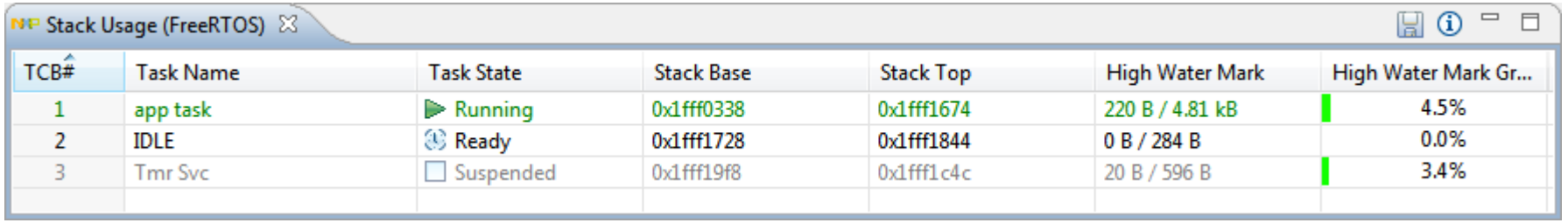
- Tasks with TCB (Task Control Block) number
- Task Name
- Task State
- Stack Usage
- Priority
- Event Object
- Runtime

Task List (FreeRTOS)

TCB#	Task Name	Task State	Stack Usage	Priority	Event Object	Runtime
1	app task	Running	220 B / 4.81 kB (4.5%)	4		
2	IDLE	Ready	0 B / 284 B (0.0%)	0		
3	Tmr Svc	Suspended	20 B / 596 B (3.4%)	17	TmrQ (Rx)	

Stack Usage

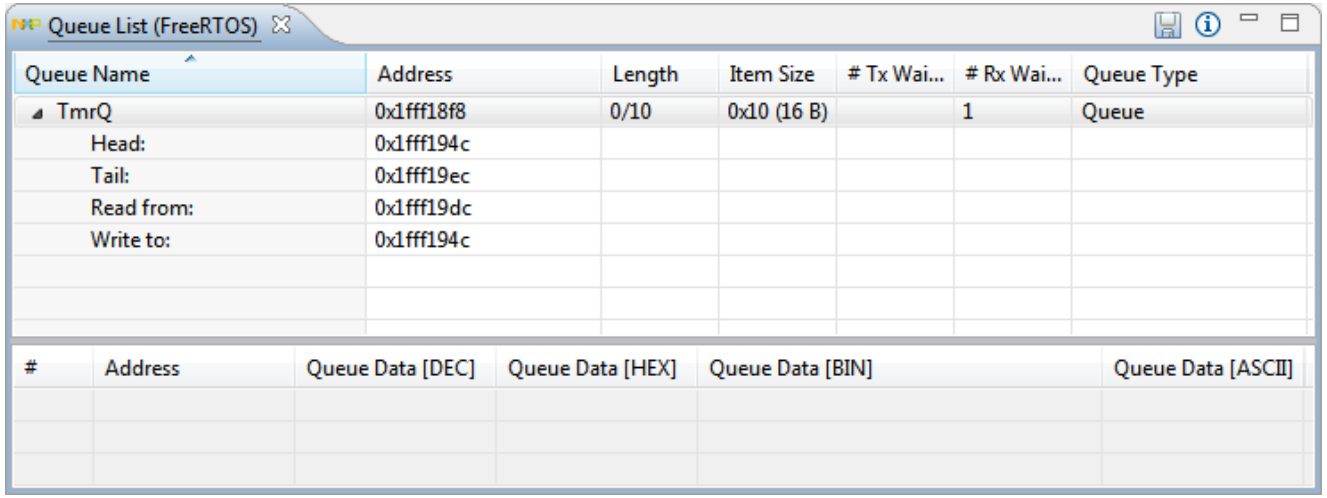
- List of tasks
  - TCB
  - Task state
  - Stack memory location
  - High Water Marks
- Can save data as .csv



TCB#	Task Name	Task State	Stack Base	Stack Top	High Water Mark	High Water Mark Gr...
1	app task	Running	0x1fff0338	0x1fff1674	220 B / 4.81 kB	4.5%
2	IDLE	Ready	0x1fff1728	0x1fff1844	0 B / 284 B	0.0%
3	Tmr Svc	Suspended	0x1fff19f8	0x1fff1c4c	20 B / 596 B	3.4%

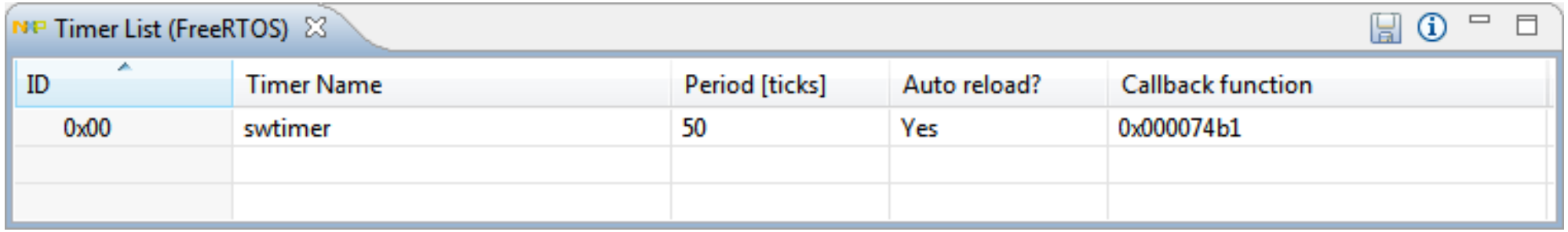
Queue List

- configQUEUE_REGISTRY_SIZE
- Queue Information
  - Address, Length, Item Size
  - Tx and Rx waiting
  - Head/Tail
  - Read (out) and Write (in)



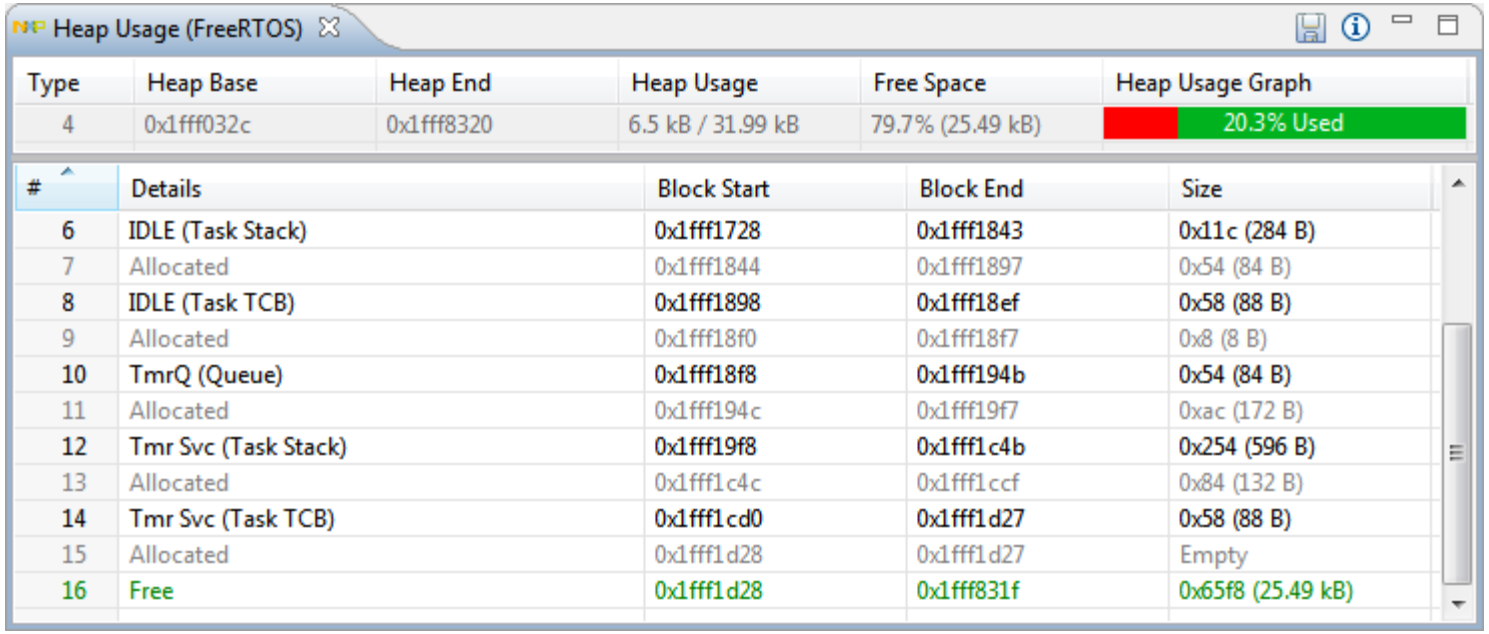
Timers

- View for FreeRTOS Software Timers
- Timer ID
- Timer name and period (ticks)
- Auto reload: timer gets restarted
- Address of timer callback function



Heap Usage

- Heap Type with address/size/usage information
- TCB (Task Control Block) and Task Stacks



Type	Heap Base	Heap End	Heap Usage	Free Space	Heap Usage Graph
4	0x1fff032c	0x1fff8320	6.5 kB / 31.99 kB	79.7% (25.49 kB)	20.3% Used

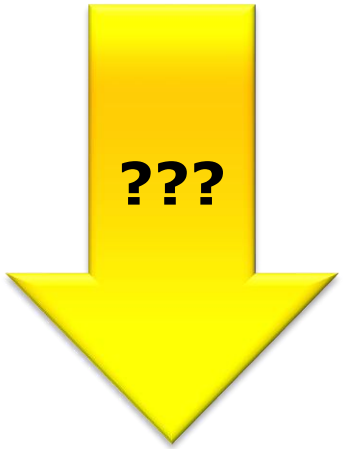
#	Details	Block Start	Block End	Size
6	IDLE (Task Stack)	0x1fff1728	0x1fff1843	0x11c (284 B)
7	Allocated	0x1fff1844	0x1fff1897	0x54 (84 B)
8	IDLE (Task TCB)	0x1fff1898	0x1fff18ef	0x58 (88 B)
9	Allocated	0x1fff18f0	0x1fff18f7	0x8 (8 B)
10	TmrQ (Queue)	0x1fff18f8	0x1fff194b	0x54 (84 B)
11	Allocated	0x1fff194c	0x1fff19f7	0xac (172 B)
12	Tmr Svc (Task Stack)	0x1fff19f8	0x1fff1c4b	0x254 (596 B)
13	Allocated	0x1fff1c4c	0x1fff1ccf	0x84 (132 B)
14	Tmr Svc (Task TCB)	0x1fff1cd0	0x1fff1d27	0x58 (88 B)
15	Allocated	0x1fff1d28	0x1fff1d27	Empty
16	Free	0x1fff1d28	0x1fff831f	0x65f8 (25.49 kB)

Lab: FreeRTOS Kernel Awareness

Knowing state of RTOS (Tasks, Timers, Queues, Stacks) with Eclipse

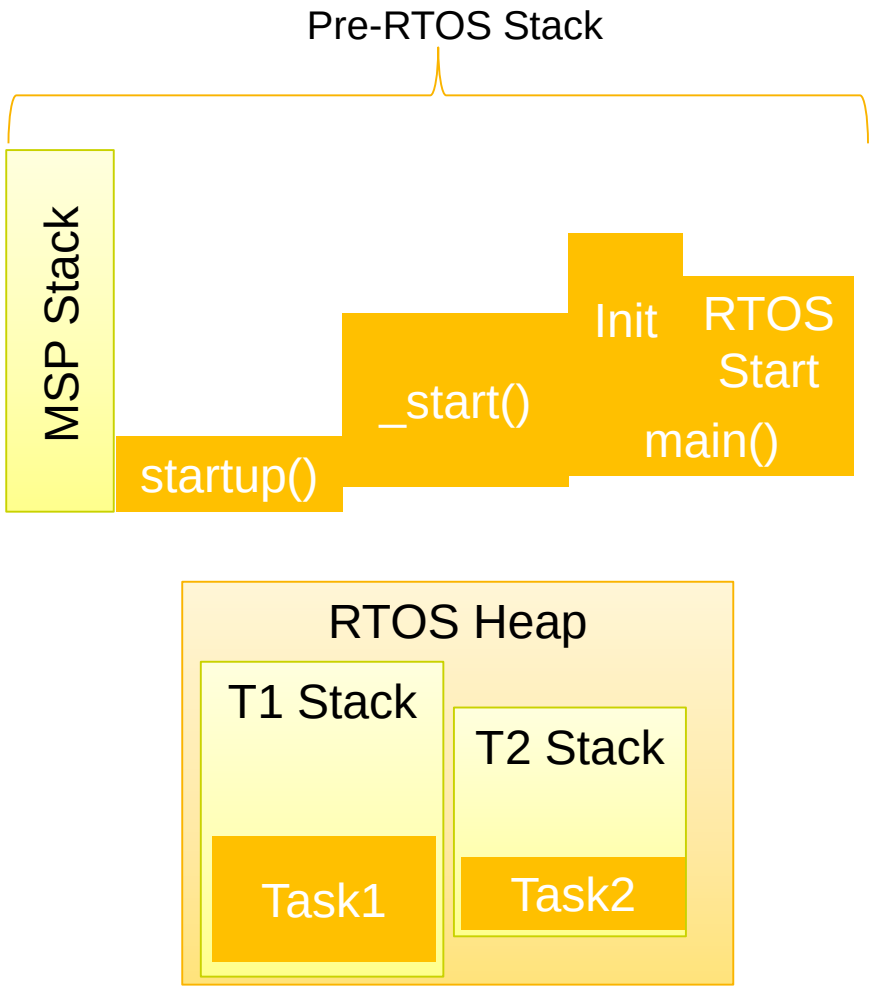
Outline: Stack Size

- **Problem**
  - Too much RAM/Heap used
  - Check CPU load
- **Solution**
  - Reduce amount of stack needed by stack
  - Unblock CPU
- **Steps**
  - Inspect stack usage
  - Fix Stack Size
  - Free up CPU time



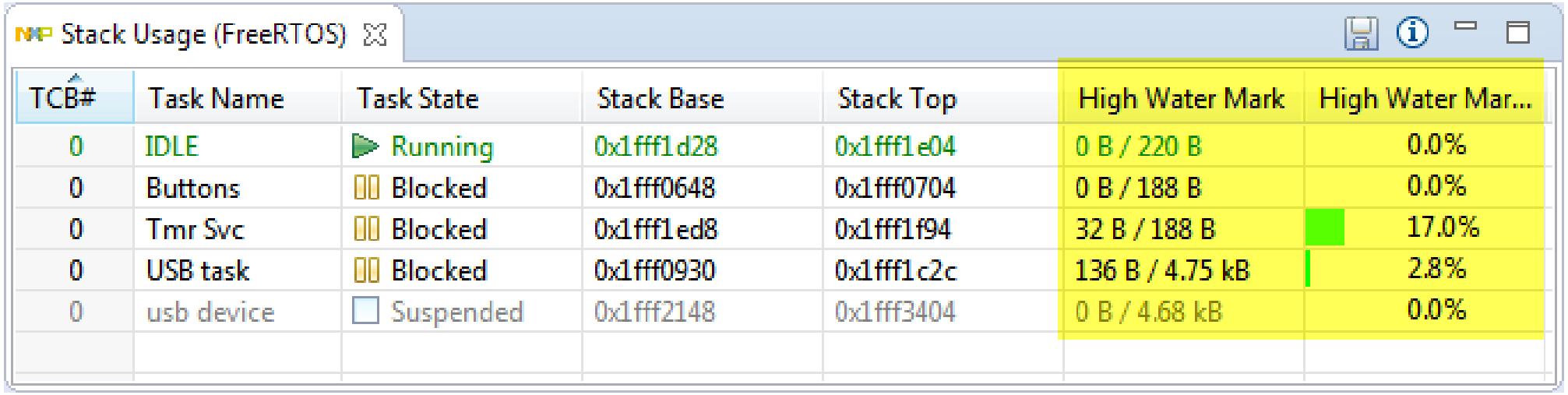
Heap/Stacks in FreeRTOS Application

- MSP (Mains Stack Pointer)
  - Startup code and scheduler start
  - Interrupts
- PSP (Process Stack Pointer)
  - configMINIMAL_STACK_SIZE for IDLE task
  - Number of 'addressable/aligned stack units' (Kinetis: 4 bytes!)



FreeRTOS Task Stack Usage

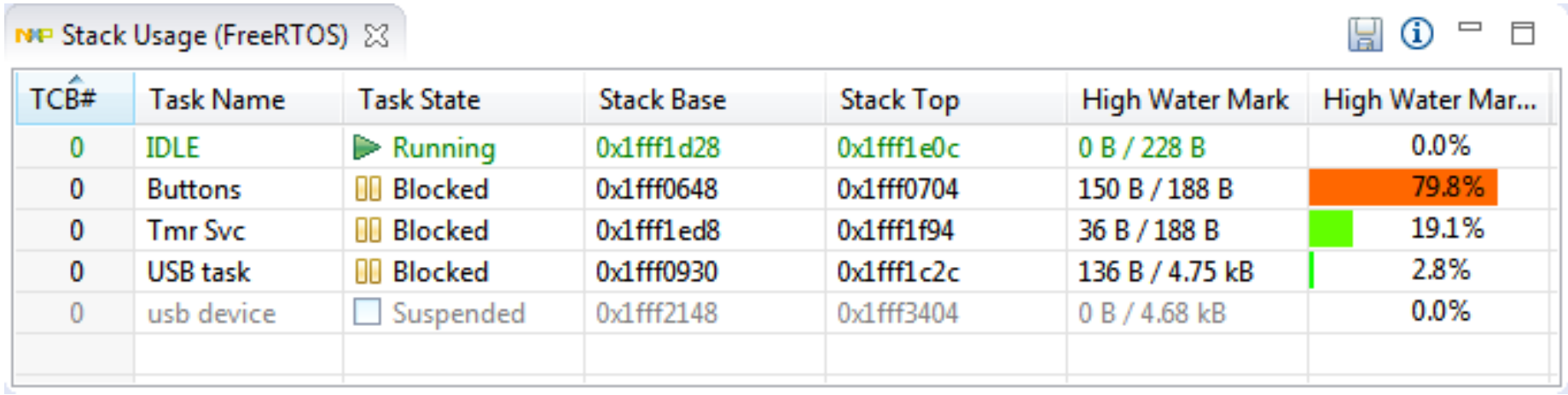
- High Water Mark for Stack
- Mark: set at context switch
- Everything looking good for you?



TCB#	Task Name	Task State	Stack Base	Stack Top	High Water Mark	High Water Mar...
0	IDLE	Running	0x1fff1d28	0x1fff1e04	0 B / 220 B	0.0%
0	Buttons	Blocked	0x1fff0648	0x1fff0704	0 B / 188 B	0.0%
0	Tmr Svc	Blocked	0x1fff1ed8	0x1fff1f94	32 B / 188 B	17.0%
0	USB task	Blocked	0x1fff0930	0x1fff1c2c	136 B / 4.75 kB	2.8%
0	usb device	Suspended	0x1fff2148	0x1fff3404	0 B / 4.68 kB	0.0%

Higher Stack Usage

- Press SW2 or SW3
- Stack usage increase and gets critical
- Increase Stack size in Application.c



TCB#	Task Name	Task State	Stack Base	Stack Top	High Water Mark	High Water Mar...
0	IDLE	Running	0x1fff1d28	0x1fff1e0c	0 B / 228 B	0.0%
0	Buttons	Blocked	0x1fff0648	0x1fff0704	150 B / 188 B	79.8%
0	Tmr Svc	Blocked	0x1fff1ed8	0x1fff1f94	36 B / 188 B	19.1%
0	USB task	Blocked	0x1fff0930	0x1fff1c2c	136 B / 4.75 kB	2.8%
0	usb device	Suspended	0x1fff2148	0x1fff3404	0 B / 4.68 kB	0.0%

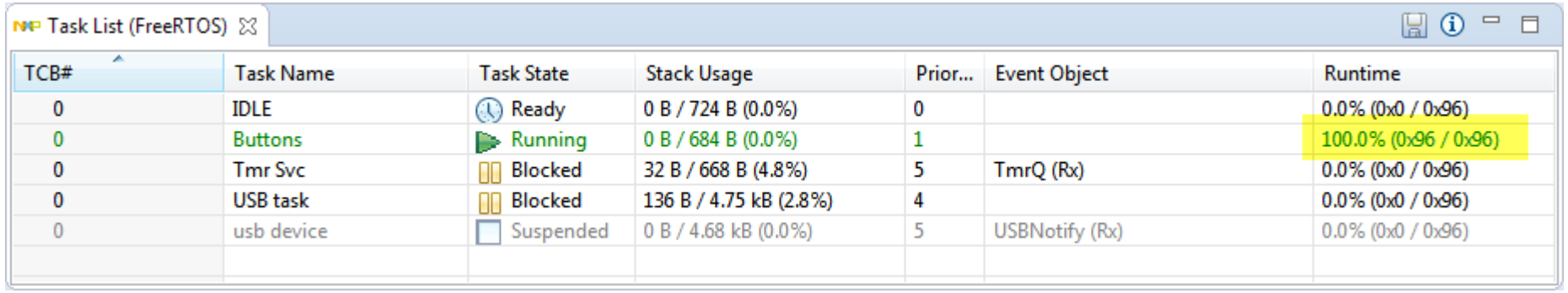
```
81    vQueueAddToRegistry(semSW3, "SW3_Sem");
82    if (xTaskCreate(ButtonTask, "Buttons", configMINIMAL_STACK_SIZE+50, NULL, tskIDLE_PRIORITY+1, NULL) != pdPASS) {
83      for(;;){} /* error */
84    }
85  }
```

Enabling Runtime Statistics

- Set to 1 in FreeRTOS_Config.h:
  - `configGENERATE_RUN_TIME_STATS` (line 125, uses SysTick)
  - `configUSE_TRACE_FACILITY` (line 164, additional structure members for execution visualization and tracing)
- Build
  - Adds about 100 bytes 'text' and 8 bytes 'bss'
- Debug
  - Inspect runtime

Runtime Problem

Problem: Buttons task is using 100% of the CPU



TCB#	Task Name	Task State	Stack Usage	Prior...	Event Object	Runtime
0	IDLE	Ready	0 B / 724 B (0.0%)	0		0.0% (0x0 / 0x96)
0	Buttons	Running	0 B / 684 B (0.0%)	1		100.0% (0x96 / 0x96)
0	Tmr Svc	Blocked	32 B / 668 B (4.8%)	5	TmrQ (Rx)	0.0% (0x0 / 0x96)
0	USB task	Blocked	136 B / 4.75 kB (2.8%)	4		0.0% (0x0 / 0x96)
0	usb device	Suspended	0 B / 4.68 kB (0.0%)	5	USBNotify (Rx)	0.0% (0x0 / 0x96)

Solution

- Add **delay** to ButtonTask() in Application.c
- `vTaskDelay(pdMS_TO_TICKS(10));`
- Save, Build and re-Run

Application.c | FreeRTOSConfig.h

```
33 static void ButtonTask(void *pvParameters) {
34   (void)pvParameters;
35
36   for(;;) {
37     if (SW2IsPressed()) { /* SW2 pressed */
38       vTaskDelay(pdMS_TO_TICKS(50)); /* debounce */
39       while(SW2IsPressed()) {
40         /* wait until released */
41       }
42       (void)xSemaphoreGive(semSW2); /* send message */
43     }
44     if (SW3IsPressed()) { /* SW3 pressed */
45       vTaskDelay(pdMS_TO_TICKS(50)); /* debounce */
46       while(SW3IsPressed()) {
47         /* wait until released */
48       }
49       (void)xSemaphoreGive(semSW3); /* send message */
50     }
51     vTaskDelay(pdMS_TO_TICKS(10));
52   }
53 }
```

Improved Runtime

System is now mostly IDLE which is expected

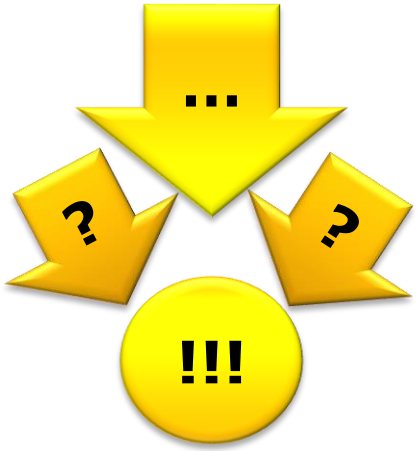
Task List (FreeRTOS) | Task Table (DSF)

TCB#	Task Name	Task State	Stack Usage	Prior...	Event Object	Runtime
0	IDLE	Running	0 B / 708 B (0.0%)	0		100.0% (0xd78 / 0xd78)
0	Buttons	Blocked	0 B / 676 B (0.0%)	1		0.0% (0x0 / 0xd78)
0	Tmr Svc	Blocked	32 B / 668 B (4.8%)	5	TmrQ (Rx)	0.0% (0x0 / 0xd78)
0	USB task	Blocked	136 B / 4.75 kB (2.8%)	4		0.0% (0x0 / 0xd78)
0	usb device	Suspended	0 B / 4.68 kB (0.0%)	5	USBNotify (Rx)	0.0% (0x0 / 0xd78)

Summary: FreeRTOS Kernel Awareness

- Eclipse Plug-in to show FreeRTOS information
  - Tasks
  - Queues
  - Timers
- Stack used
  - Startup, Tasks + Interrupts
- Default stack size
  - IDLE Task
  - Task Stacks

- Further Information:
  - http://www.freertos.org
  - http://mcuoneclipse.com/2013/08/04/diy-free-toolchain-for-kinetis-part-5-freertos-eclipse-kernel-awareness-with-gdb/
  - http://mcuoneclipse.com/2014/11/08/tutorial-freertos-with-the-kinetis-sdk-and-processor-expert/

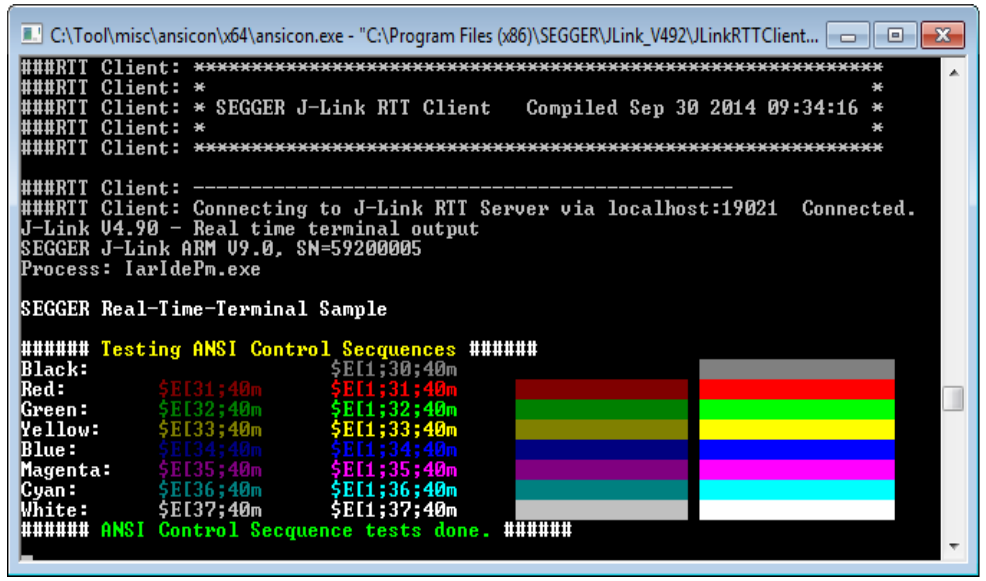


Lab: Segger SystemView

Inspecting runtime behavior of RTOS and Application

Segger Real Time Transfer

- Bi-directional data transfer through debug connection (Segger Real Time Transfer), multiple named up and down named channels
- Requires Segger J-Link debug probe or debug firmware (e.g. NXP OpenSDA)
- Small footprint: 500 Bytes Flash, 50 Bytes pro channel (plus buffer size, 64-1024 bytes).
- Special viewers by Segger, or standard Telnet (http://mcuoneclipse.com/2015/07/07/)

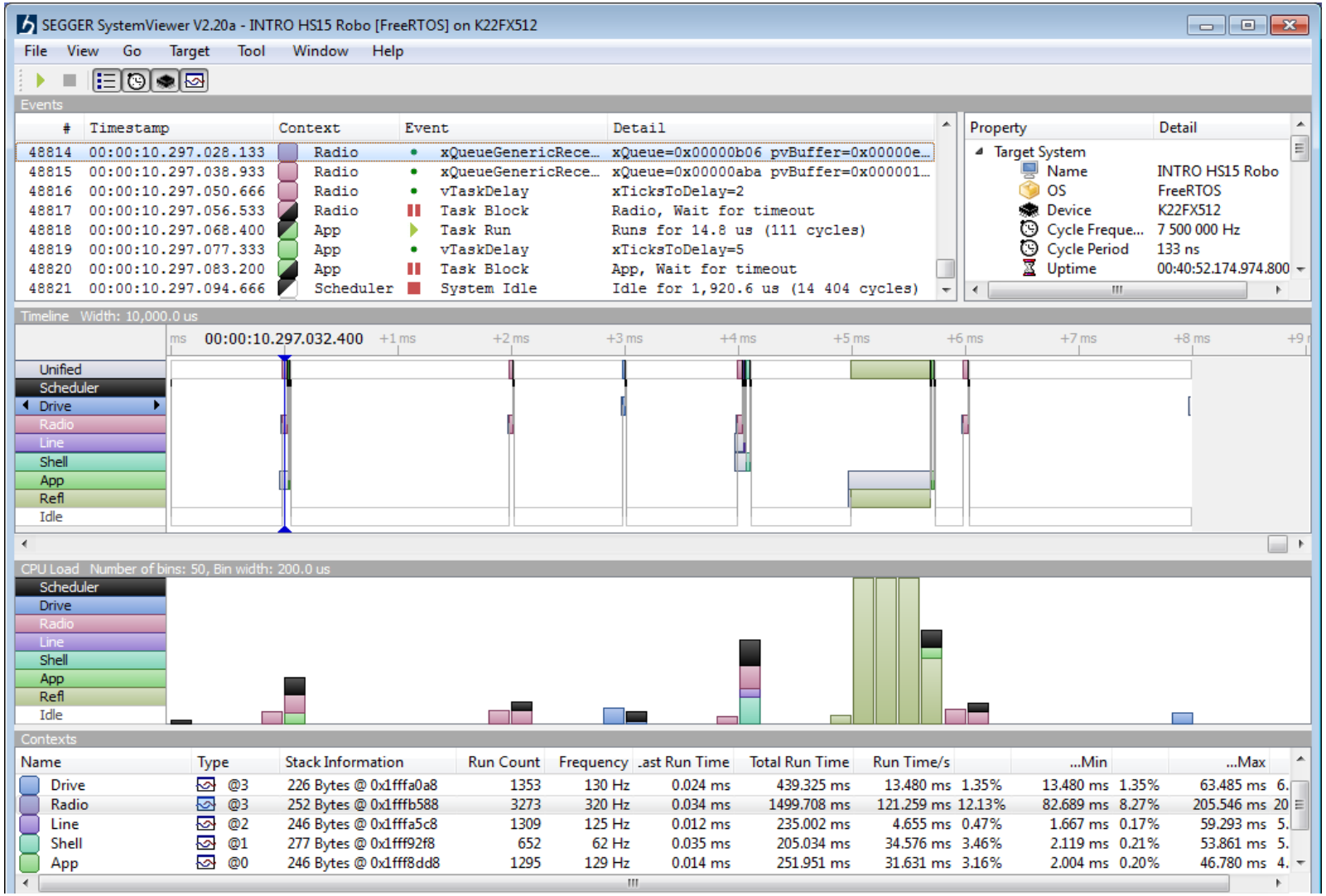


FreeRTOS Trace Hooks

- Trace Hooks in the Kernel (task creation, context switch, ...)
- Implemented with macros (instrumented), empty by default
- Can be ’filled’ with recording kernel activities
- configUSE_TRACE_HOOKS adds additional information to kernel objects
  - Custom recording and tracing
  - Percepio FreeRTOS+Trace
  - Segger SystemViewer

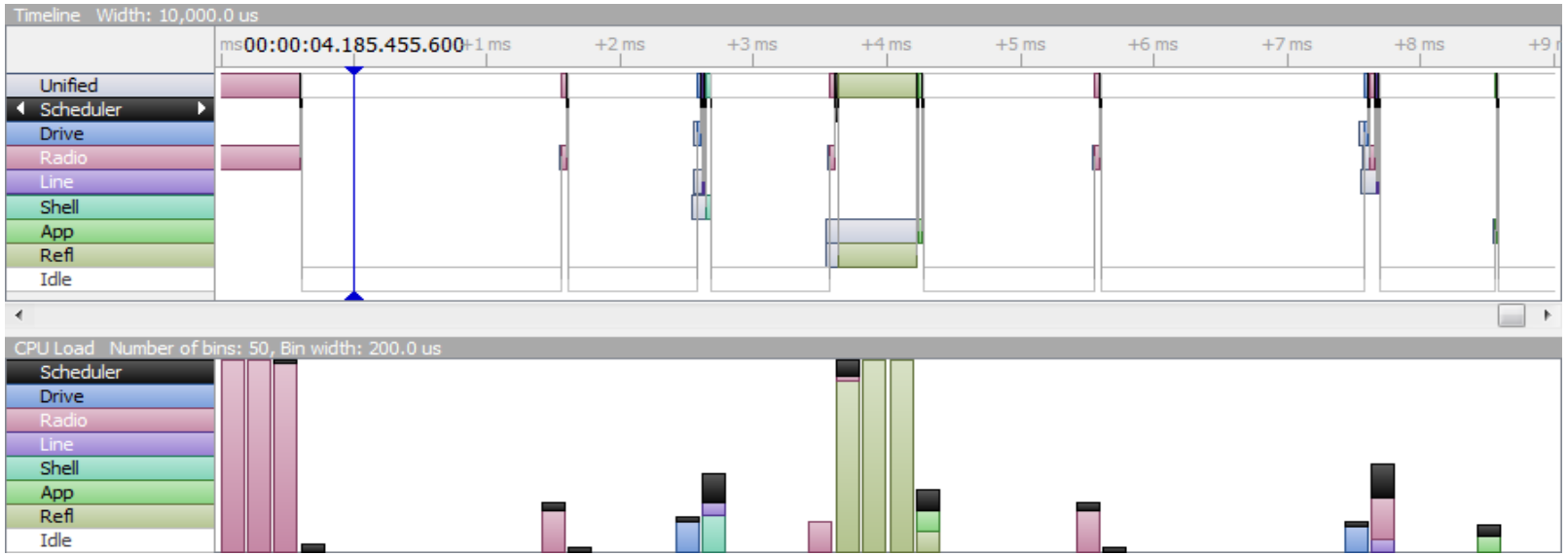
```
1 #ifndef traceTASK_SWITCHED_OUT
2   /* Called before a task has been selected to run.  pxCurrentTCB
        holds a pointer
3   to the task control block of the task being switched out. */
4   #define traceTASK_SWITCHED_OUT()
5 #endif
```

Segger SystemViewer



Segger SystemViewer

- Free-of-Charge, requires Segger debug interface
- Based on Segger RTT (Real Time Transfer)
- Realtime data recording and time measurement
- Uses Cortex M4 Cycle count register, SysTick on M0+
- http://mcuoneclipse.com/2015/11/16/segger-systemview



Segger SystemViewer - Timeline

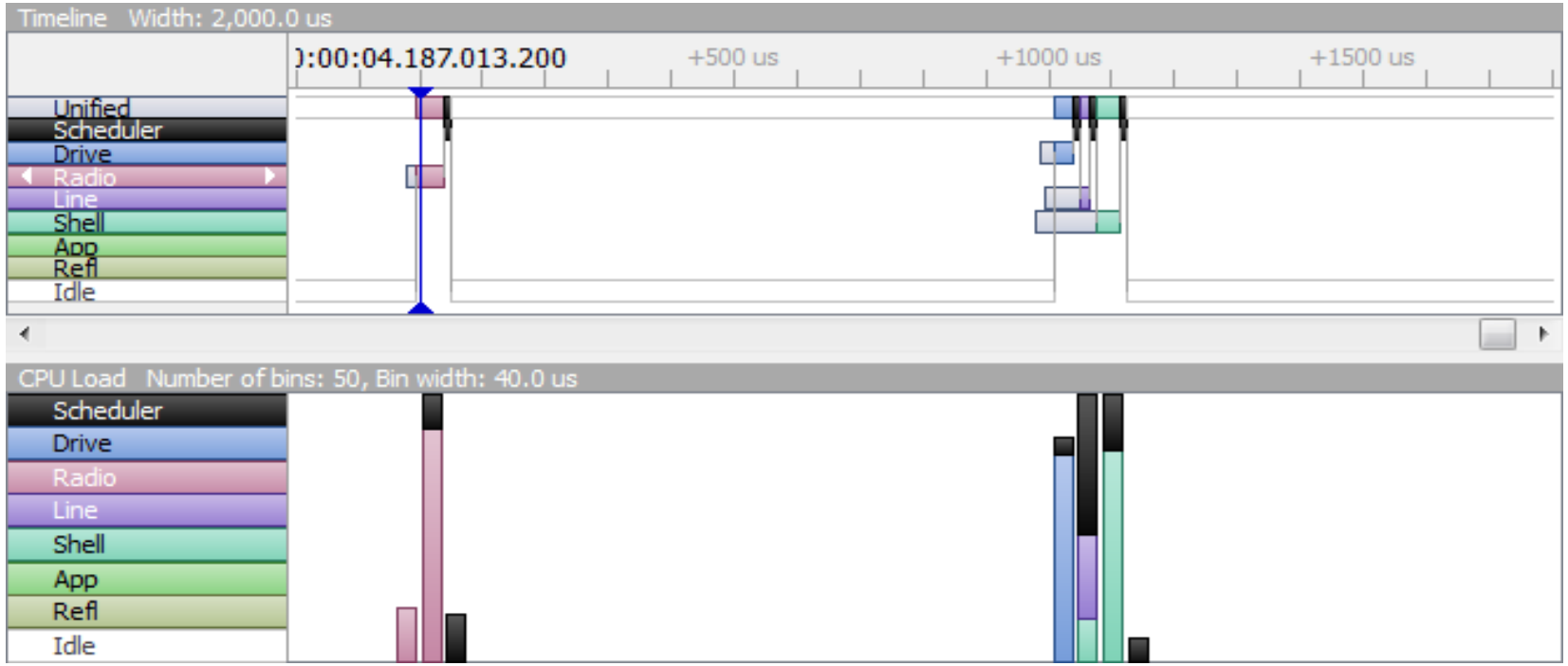
- Up to 1 Mio events
- Scheduler and Idle handled separately
- CPU load with ’bins’: how many items to stack/show in a bar

Events

#	Timestamp	Context	Event	Detail
19650	00:00:04.186.991.333	Idle	Task Ready	Radio, runs after 14.0 us (105 cycles)
19651	00:00:04.187.005.333	Radio	Task Run	Runs for 42.4 us (318 cycles)
19652	00:00:04.187.016.933	Radio	xQueueGeneric…	xQueue=0x00000b06 pvBuffer=0x00000e9f xTicksToWait=…
19653	00:00:04.187.028.933	Radio	xQueueGeneric…	xQueue=0x00000aba pvBuffer=0x000001c0 xTicksToWait=…
19654	00:00:04.187.036.400	Radio	vTaskDelay	xTicksToDelay=2
19655	00:00:04.187.047.733	Radio	Task Block	Radio, Wait for timeout
19656	00:00:04.187.060.133	Sched…	System Idle	Idle for 959.8 us (7 198 cycles)
19657	00:00:04.187.991.333	Idle	Task Ready	Shell, runs after 95.6 us (717 cycles)
19658	00:00:04.187.998.533	Idle	Task Ready	Drive, runs after 21.4 us (160 cycles)
19659	00:00:04.188.005.466	Idle	Task Ready	Line, runs after 56.8 us (426 cycles)
19660	00:00:04.188.019.866	Drive	Task Run	Runs for 30.6 us (230 cycles)
19661	00:00:04.188.034.933	Drive	xQueueGeneric…	xQueue=0x00000806 pvBuffer=0x00000948 xTicksToWait=…

Segger SystemViewer - Timeline

- Timeline: what is executed
- Scheduler and Idle handled separately
- CPU load with ’bins’: how many items to stack/show in a bar



Segger SystemViewer - Context

- List of tasks
- Priorities, stack information
- Runtime statistics, CPU load

Contexts

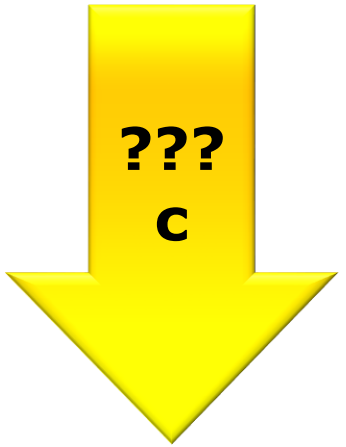
Name	Type	Stack Information	Count	Frequency	: Run Time	Total Run Time	Run Time/s		...Min		...Max	
Scheduler			3420	831 Hz	0.011 ms	285.398 ms	126.670 ms	12.67%	0.000 ms	0.00%	126.670 ms	12.67%
Drive	@3	226 Bytes @ 0x1fffa0a8	562	140 Hz	0.025 ms	100.098 ms	36.338 ms	3.63%	5.119 ms	0.51%	36.338 ms	3.63%
Radio	@3	252 Bytes @ 0x1fffb588	1345	328 Hz	0.042 ms	679.113 ms	96.286 ms	9.63%	96.286 ms	9.63%	204.636 ms	20.46%
Line	@2	246 Bytes @ 0x1fffa5c8	540	134 Hz	0.012 ms	105.481 ms	20.680 ms	2.07%	16.665 ms	1.67%	34.466 ms	3.45%
Shell	@1	274 Bytes @ 0x1fff92f8	268	64 Hz	0.037 ms	54.540 ms	13.941 ms	1.39%	3.635 ms	0.36%	27.940 ms	2.79%
App	@0	246 Bytes @ 0x1fff8dd8	513	122 Hz	0.015 ms	197.500 ms	66.941 ms	6.69%	22.612 ms	2.26%	66.941 ms	6.69%
Refl	@0	230 Bytes @ 0x1fff9a98	244	55 Hz	0.598 ms	194.751 ms	32.893 ms	3.29%	32.893 ms	3.29%	61.344 ms	6.13%
Idle			1828	447 Hz	1.945 ms	2578.060 ms	631.947 ms	63.19%	0.000 ms	0.00%	656.183 ms	65.62%

Lab: Percepio FreeRTOS+Trace

Inspecting runtime behavior of RTOS and Application with Percepio FreeRTOS+Trace

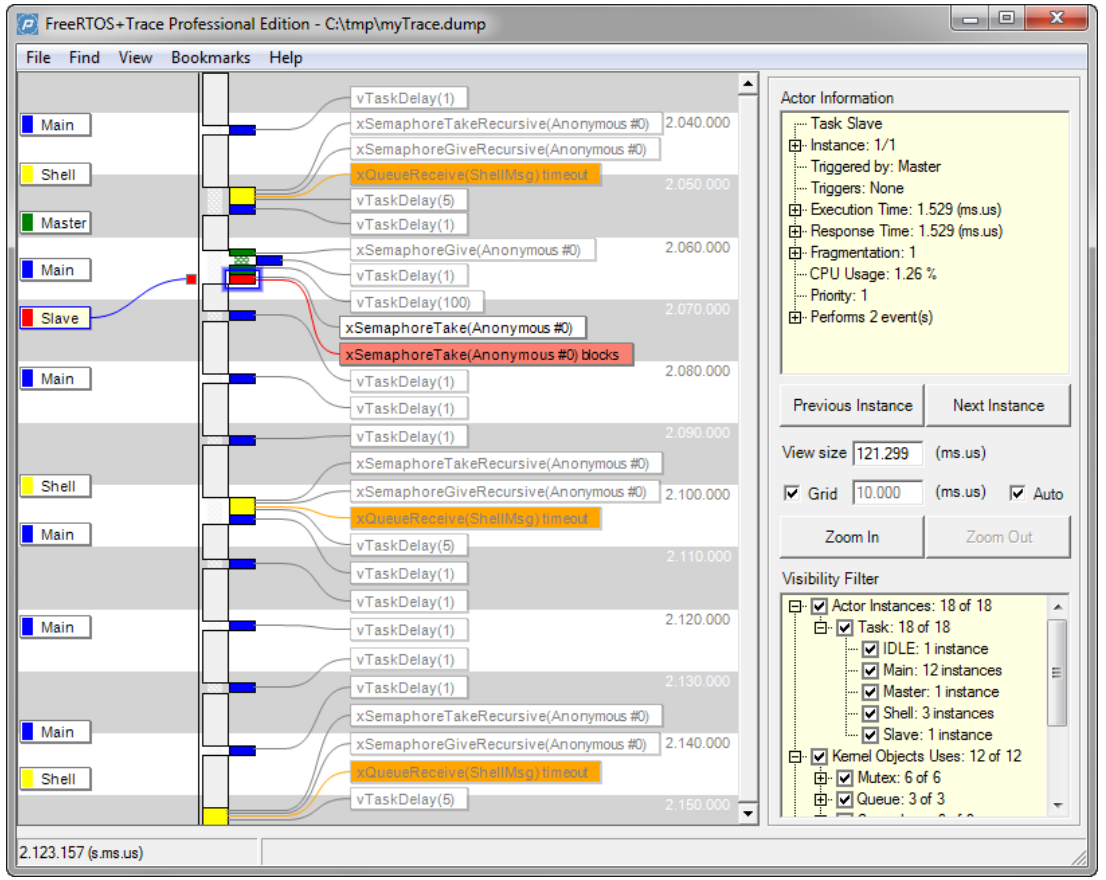
Outline: FreeRTOS+Trace

- **Problem**
  - Need insight into what is going on with application
  - Heap allocation
- **Solution**
  - Enable trace hooks in FreeRTOS
- **Steps**
  - Enable trace hooks
  - Dump trace data to host
  - Inspect data



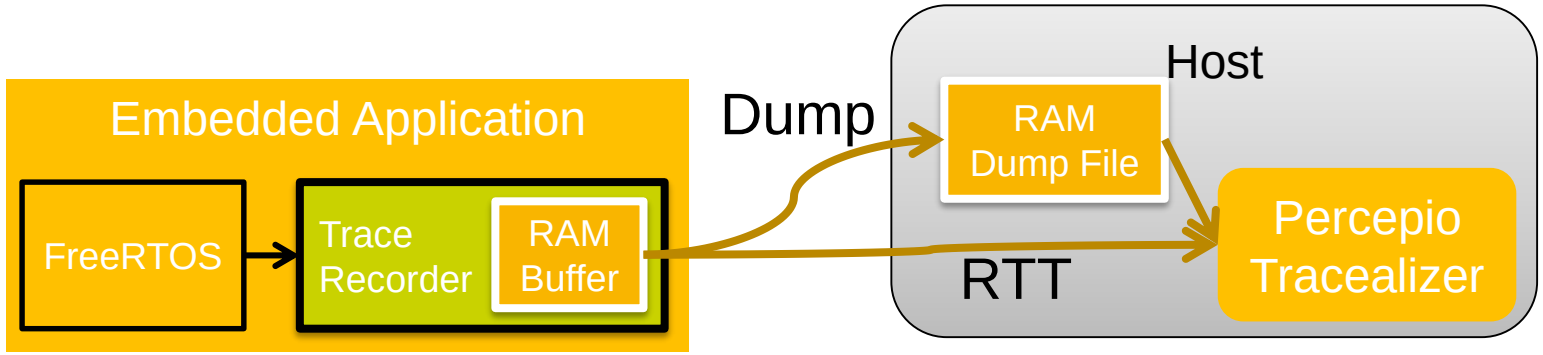
Goal: FreeRTOS+Trace

- From Percepio (http://www.percepio.com)
- Free and Professional edition
- Hosts: Windows, Linux
- Over 20 graphical views
- Tasks, System Calls and User Events
- CPU Load
- Timing Variations
- Communication Flow
- Kernel Object History
- User Events, Signal Plots
- …



How It Works…

- Trace Hooks in FreeRTOS
  - Macros which call recorder functions
- Recorder: task create, context switch, mutex ready, …
  - Recorder uses RAM/RTT buffer (circular, linear), 4 bytes/event, ~1-2% CPU load
- Dump/Export data: SD card, UART, debugger, semihosting, J-Link, …
- Direct streaming with SEGGER RTT



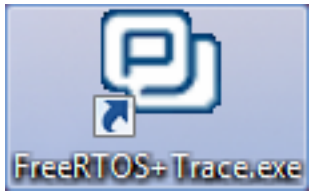
Enabling Percepio Trace

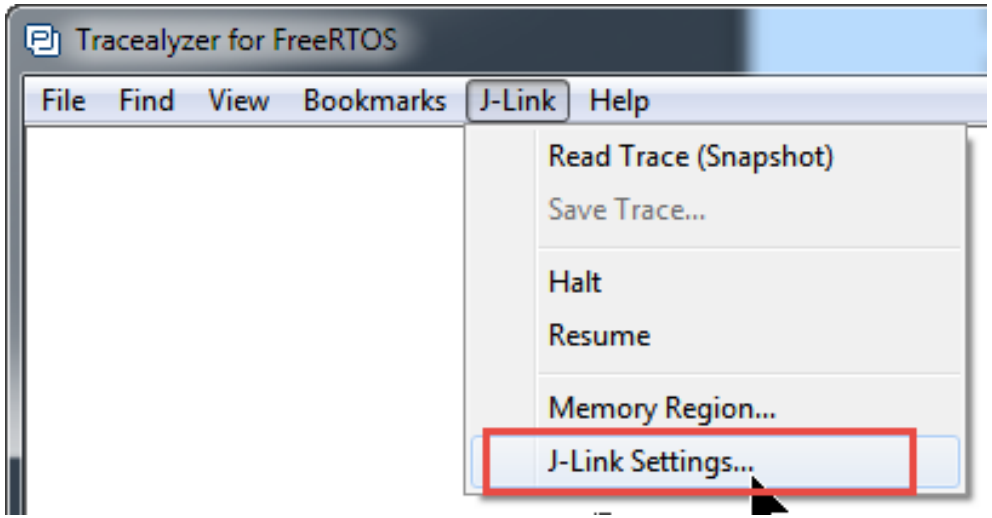
- Settings in source\FreeRTOS_Config.h
- Enable (around line #164)
  - configUSE_TRACE_FACILITY 1
  - configUSE_TRACE_HOOKS 1
- configUSE_SEGGER_SYSTEM_VIEWER_HOOKS has to be disabled!

```
#define configUSE_TRACE_FACILITY                1
#define configUSE_TRACE_HOOKS                   1
#define configUSE_SEGGER_SYSTEM_VIEWER_HOOKS    0
```

Percepio Debugger Selection

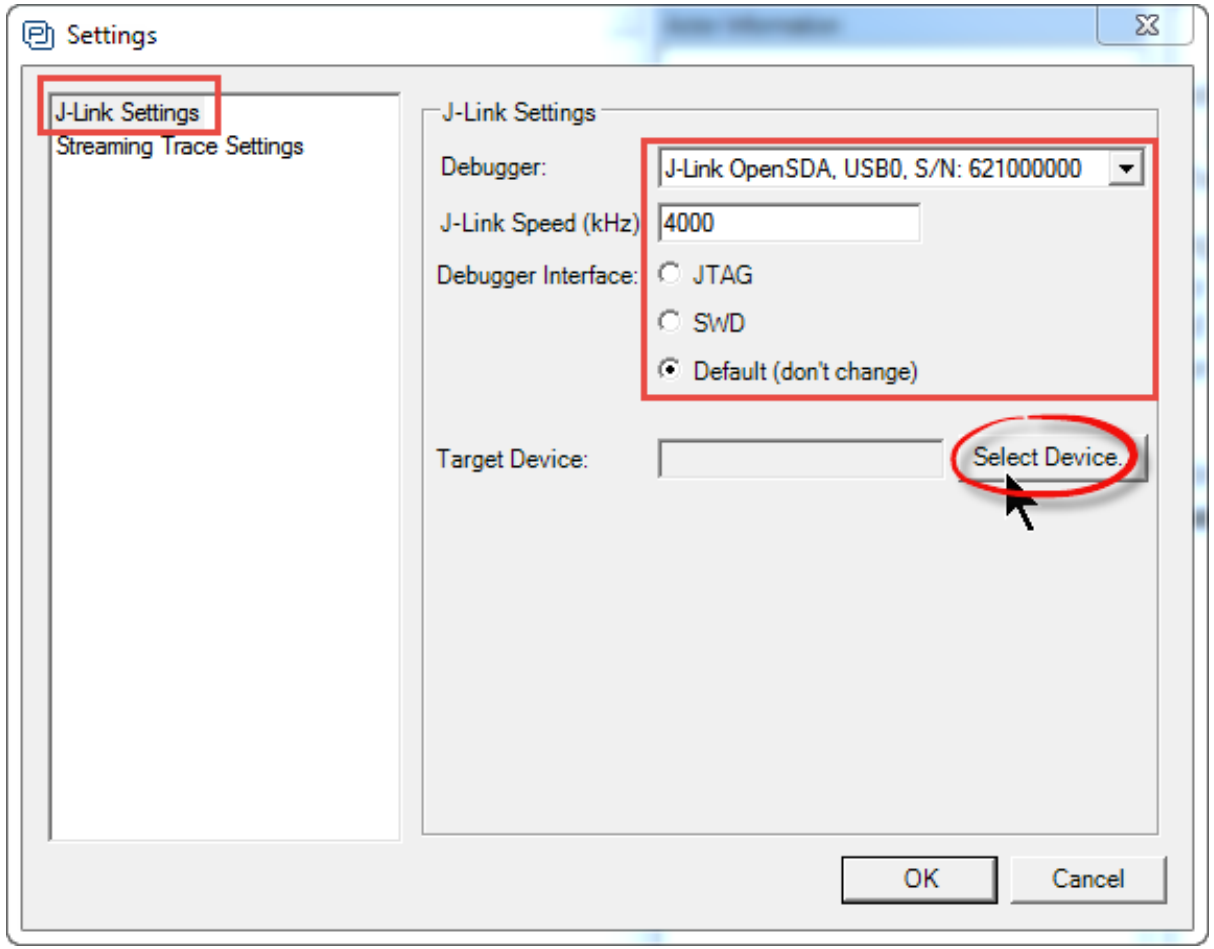
- **Launch** Percepio FreeRTOS+Trace
  - Shortcut on Desktop
- Menu ***J-Link > J-Link Settings…***





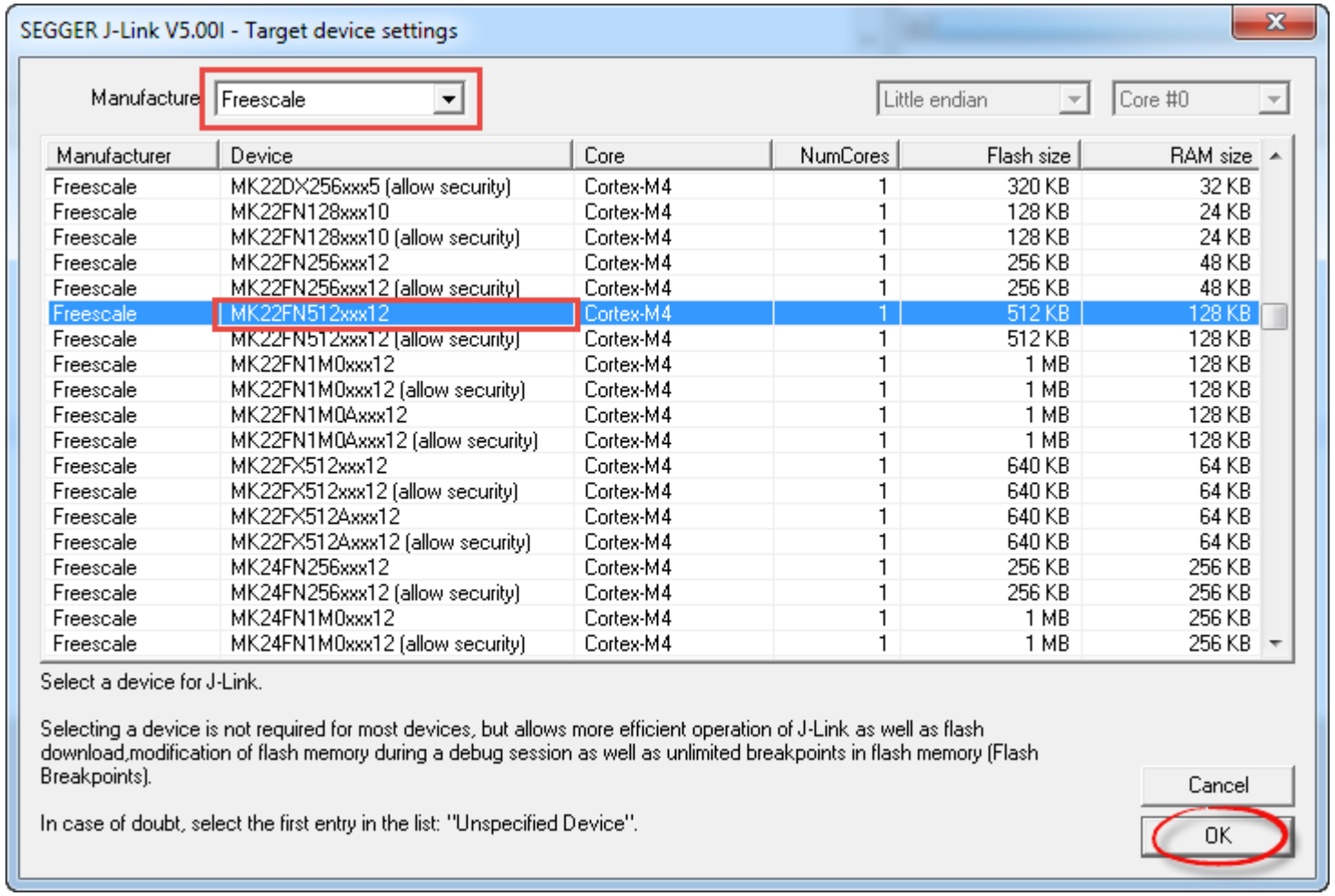
Connect to Target System

- J-Link Settings
  - Debugger (USB Port)
  - 4000 kHz
  - Default debugger interface
- Press Device Selection…



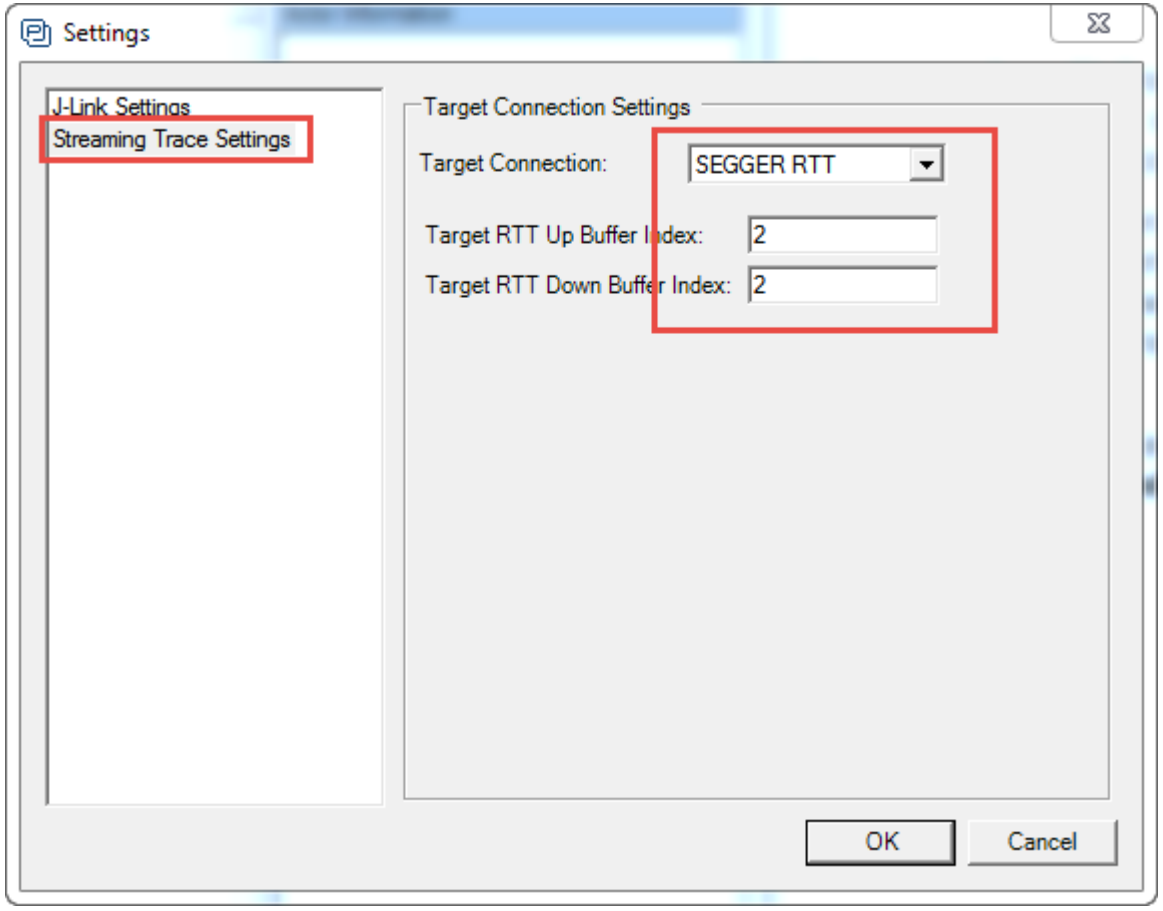
Device Selection

- Select device
  - **Freescale**
  - **MK22FN512xxx12**
- Press **OK**



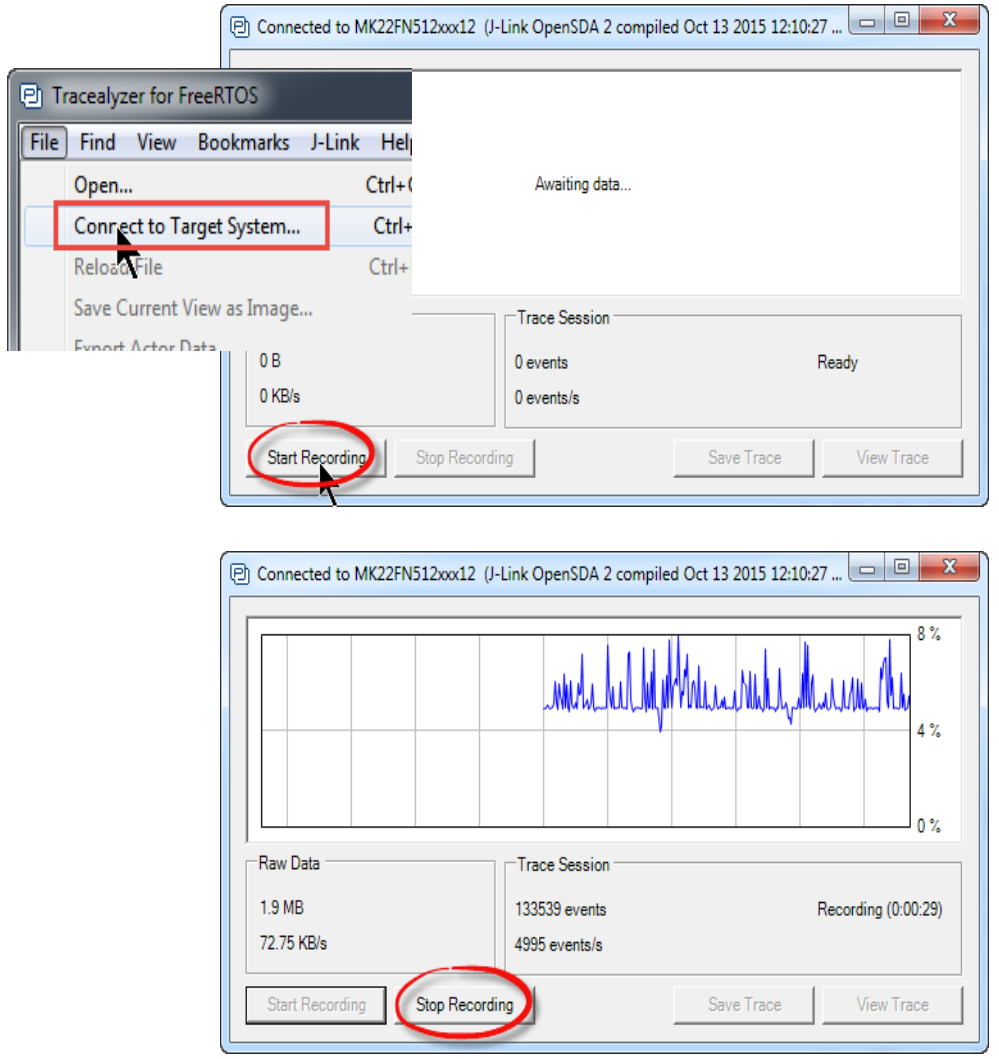
Streaming Trace Settings

- Select Streaming Trace Settings
  - SEGGER RTT
  - Up Buffer Index: 2
  - Down Buffer Index: 2
- Press OK



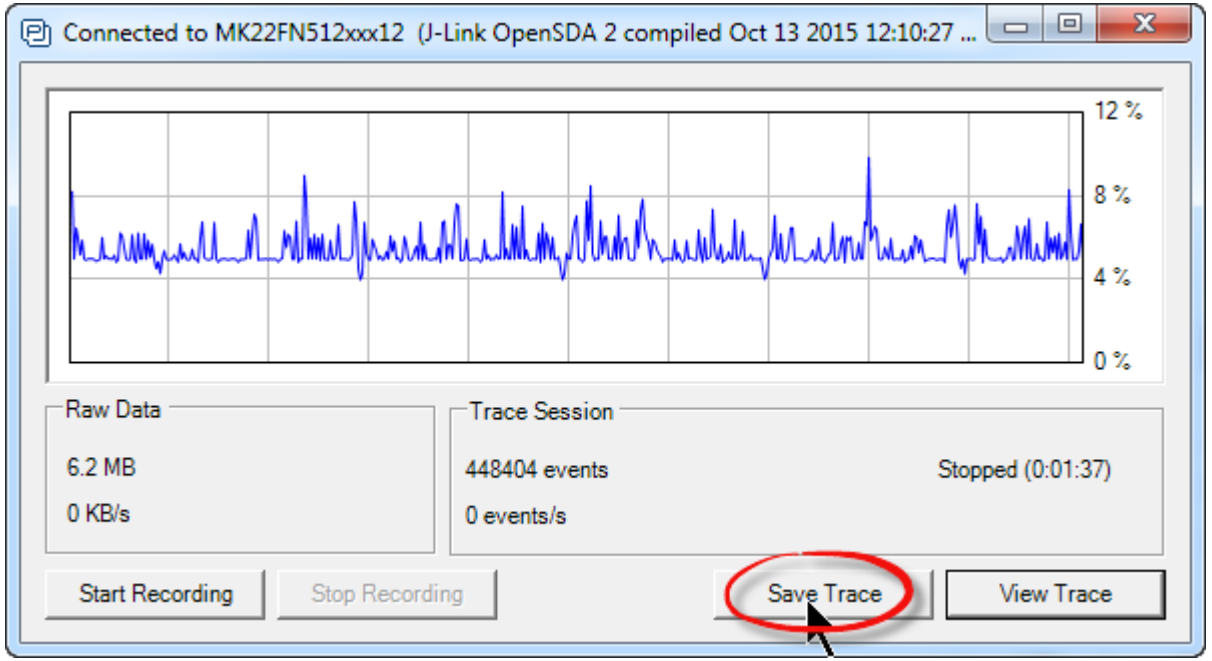
Collecting Trace

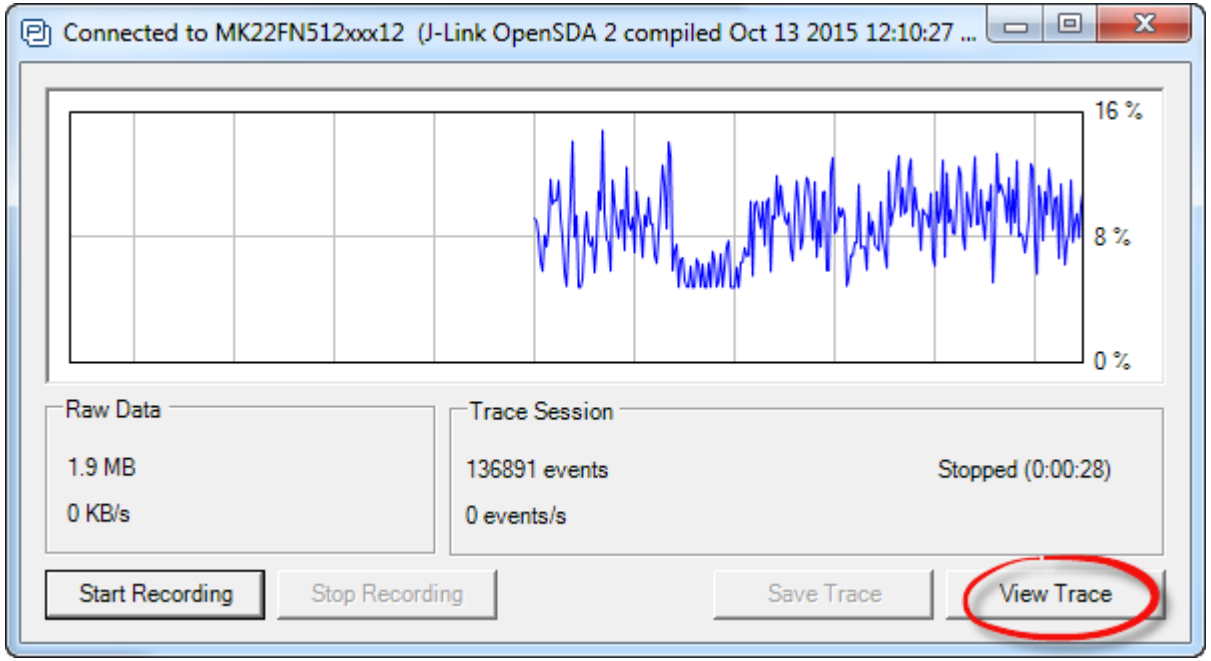
- Menu File > Connect to Target System…
- Press Start Recording
  - Percentage shows CPU load
  - Trace Session Information
    - Number of events
    - Number of events/second
    - Recording time
- Collect trace for a while
- Press Stop Recording



Saving and Viewing Trace

- Press Save Trace
  - Store it in the default location
- Press View Trace

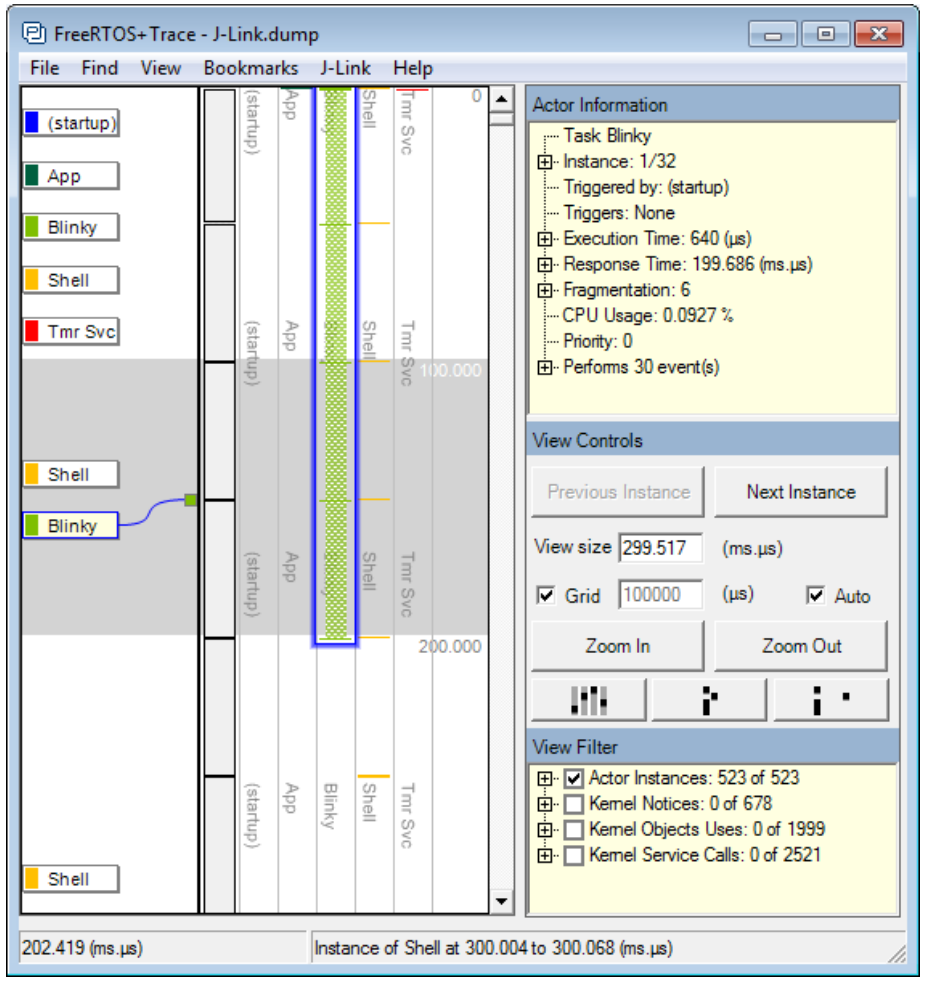




Blinky, What Are You Doing?

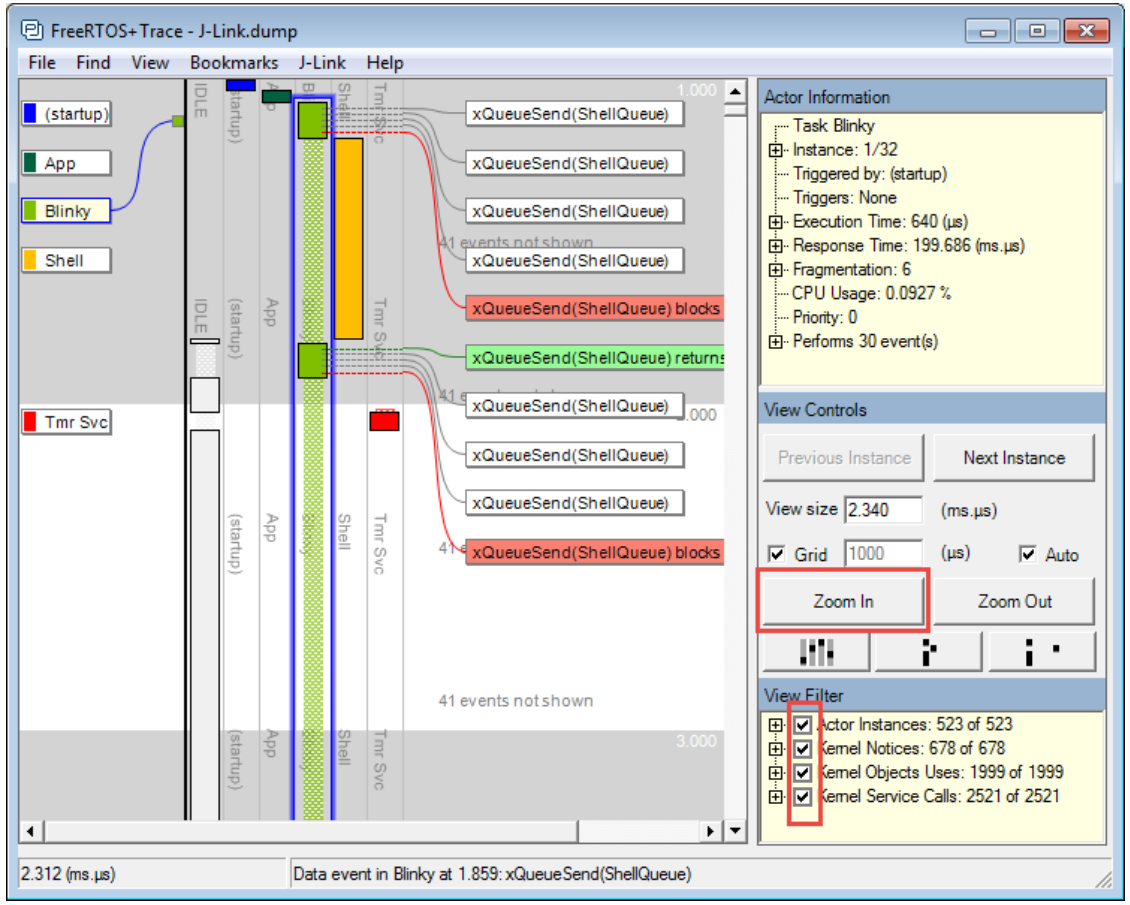
- Trace right after RTOS startup
- Blinky blinks the and writes to the UART
- Blinky Task execution is extended to 200 ms?

trc1.dump



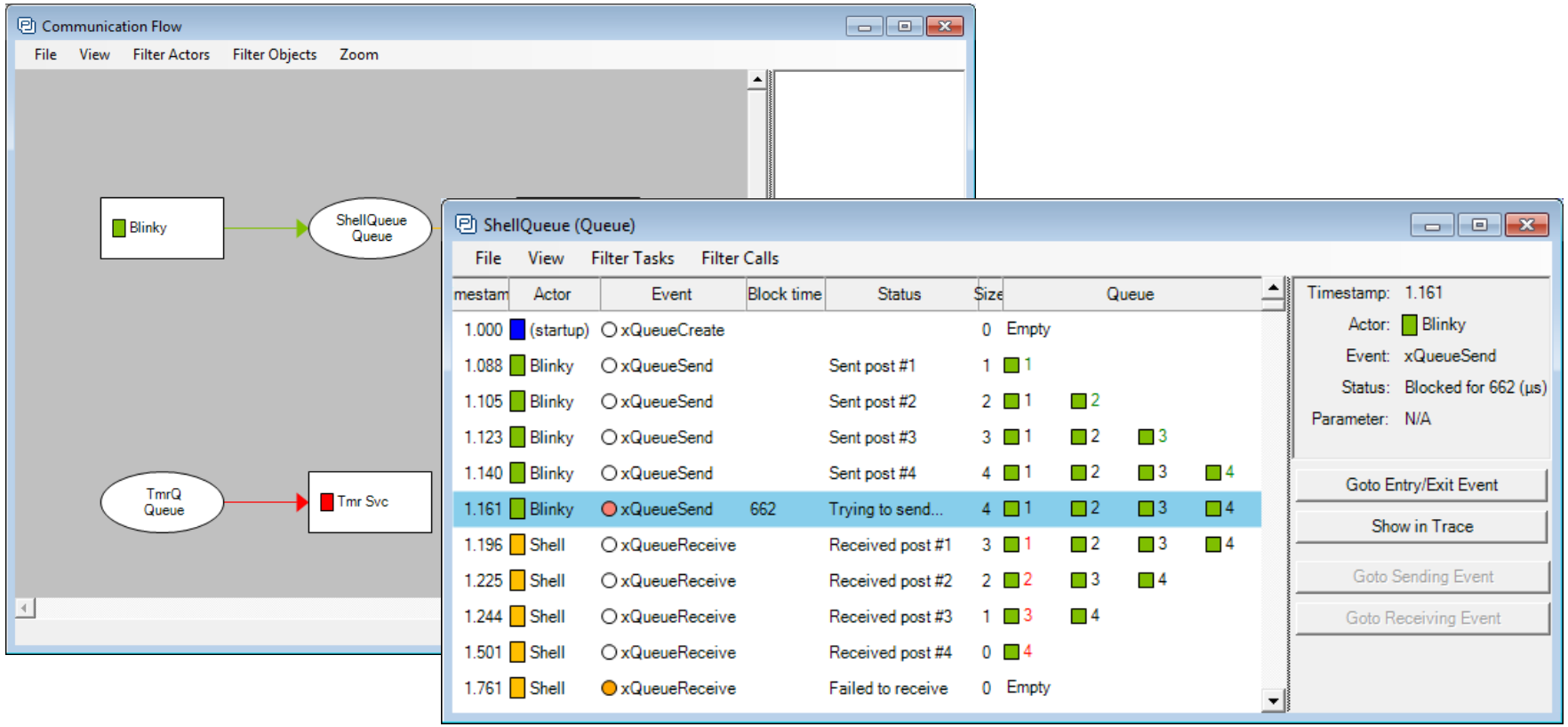
Blinky?

- Zoom into the very first milliseconds
- Enable all Kernel items
- Blinky sends for items to queue, is then blocked
- Shell receives four items, is then blocked



Communication Flow

- Menu View > Communication Flow
- Double Click on Queue to show Queue details



Blinky Task

- Queue Length is problem
- ShellQueue.c: Increase SQUEUE_LENGTH to 32

```c
static void blinky_task(void *param) {
  (void)param;
  for(;;) {
    switch(whichLED) {
    case RGB_LED_GREEN:
        SQUEUE_SendString("Blinking GREEN RGB LED\r\n");
        GPIO_DRV_TogglePinOutput(kGpioLED1);
        GPIO_DRV_SetPinOutput(kGpioLED2);
        GPIO_DRV_SetPinOutput(kGpioLED3);
        break;
    case RGB_LED_RED:
        SQUEUE_SendString("Blinking GREEN RED LED\r\n")
        GPIO_DRV_SetPinOutput(kGpioLED1);
        GPIO_DRV_TogglePinOutput(kGpioLED2);
        GPIO_DRV_SetPinOutput(kGpioLED3);
        break;
    case RGB_LED_BLUE:
        SQUEUE_SendString("Blinking GREEN BLUE LED\r\n"
        GPIO_DRV_SetPinOutput(kGpioLED1);
        GPIO_DRV_SetPinOutput(kGpioLED2);
        GPIO_DRV_TogglePinOutput(kGpioLED3);
        break;
    }
    vTaskDelay(pdMS_TO_TICKS(500)); /* wait for 500 ms */
  } /* for */
}
```

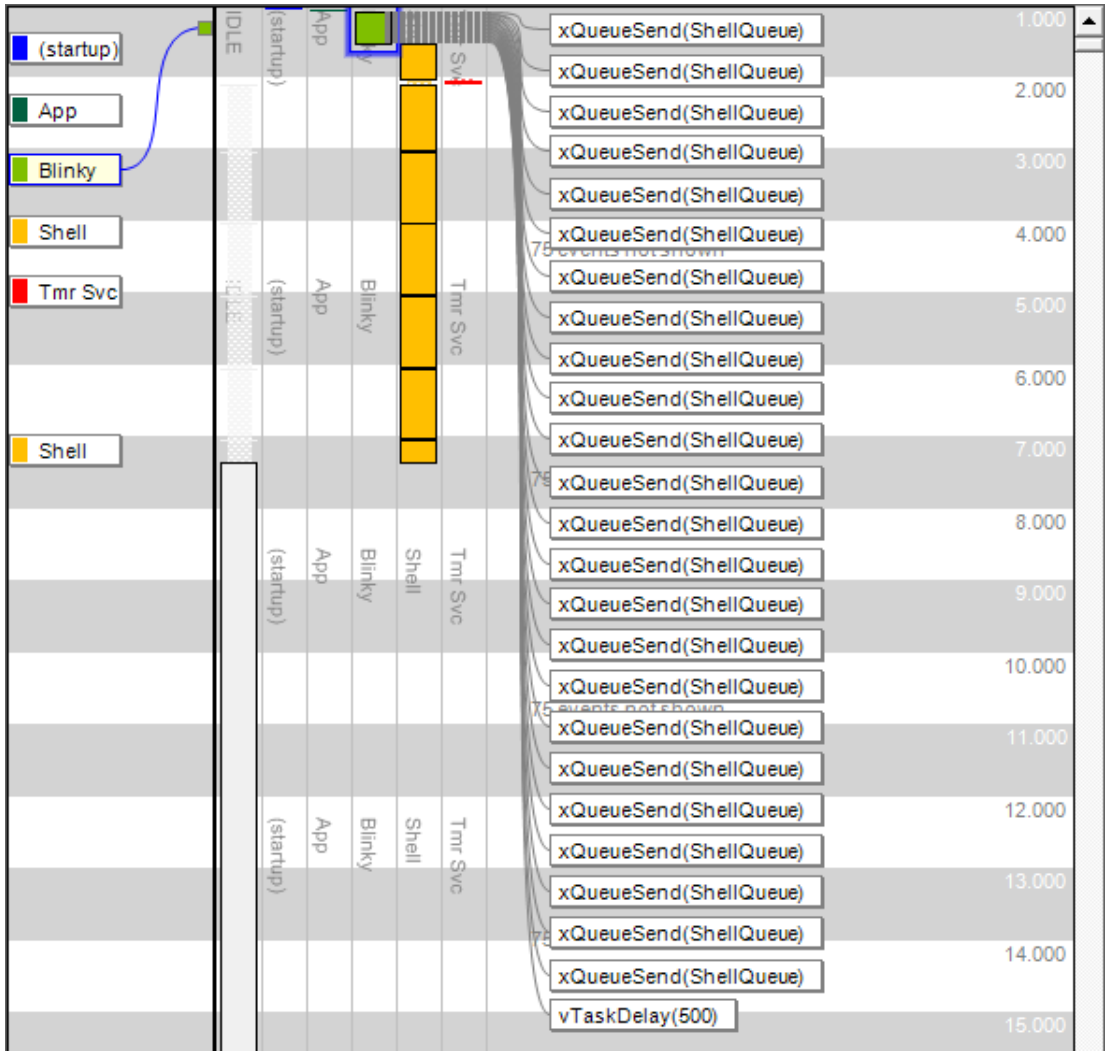
```c
#define SQUEUE_LENGTH      4 /* items in queue, that's my buffer size */
#define SQUEUE_ITEM_SIZE   1  /* each item is a single character */

void SQUEUE_SendString(const unsigned char *str) {
  while(*str!='\0') {
    if (xQueueSendToBack(SQUEUE_Queue, str, portMAX_DELAY)!=pdPASS) {
      for(;;){} /* ups? */
    }
    str++;
  }
}
```

Increased Queue Length

- Build, debug and trace
- Blinky task not blocked any more

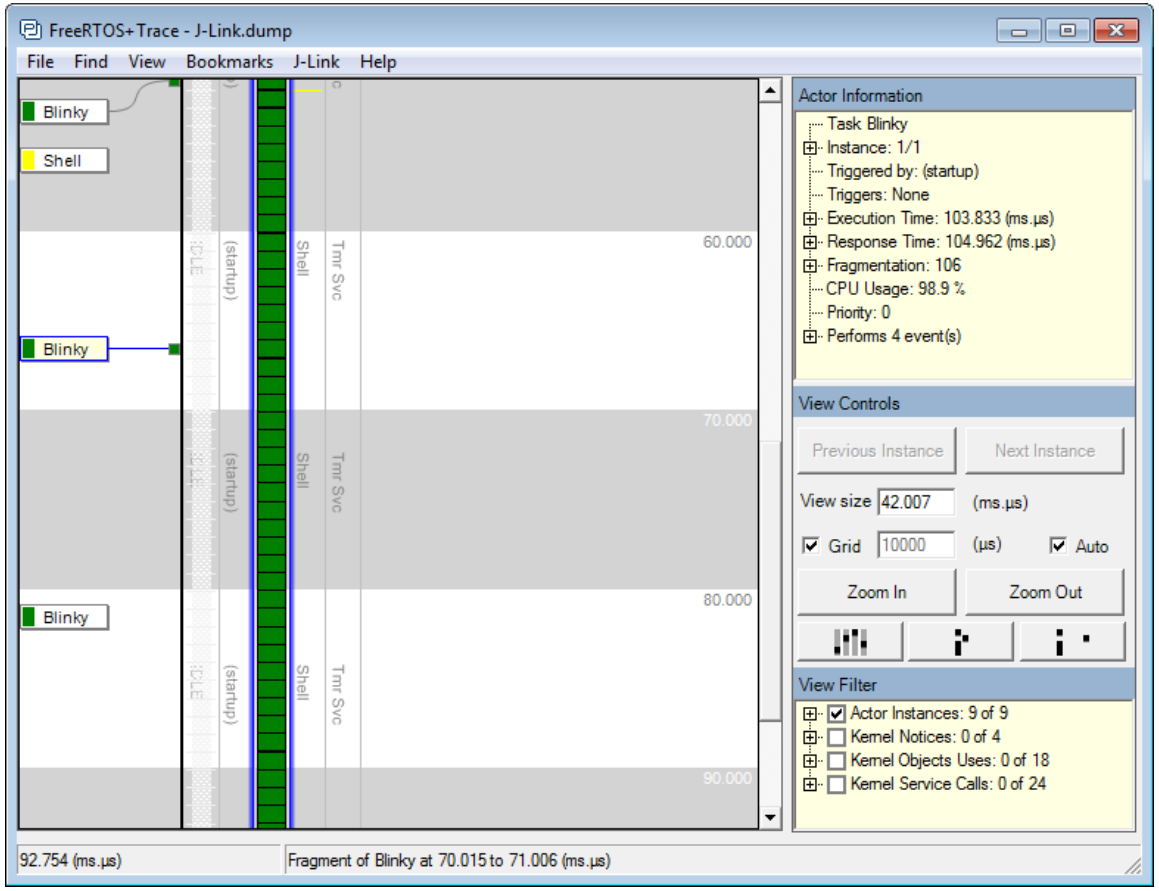
- 200 ms ➔ 7 ms ☺

trc2.dump



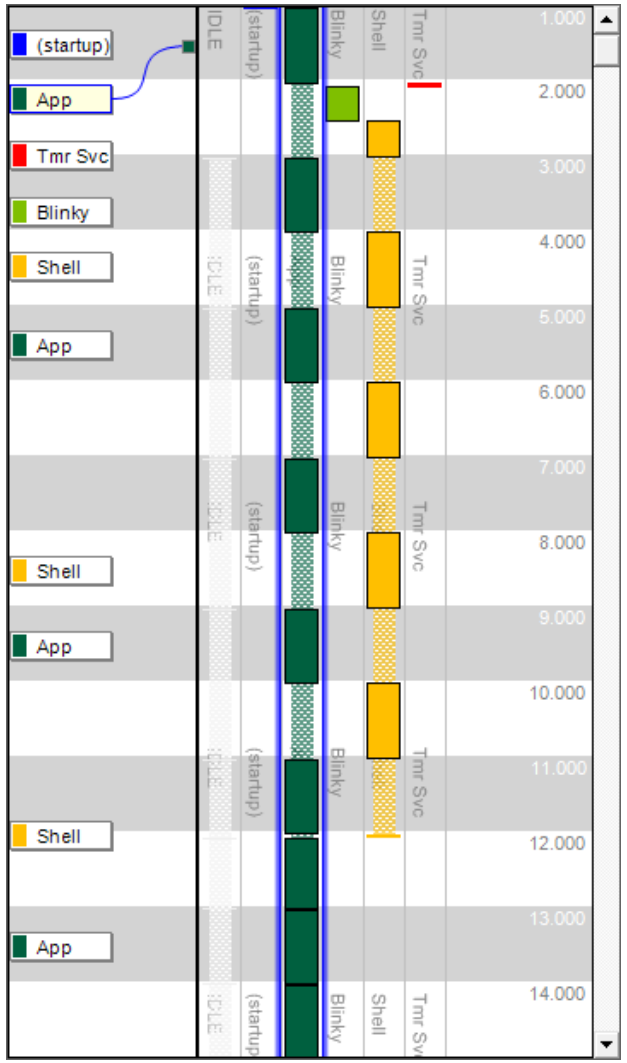
Blinky is Using a Lot of CPU…

Check what happens if you have the push buttons pressed



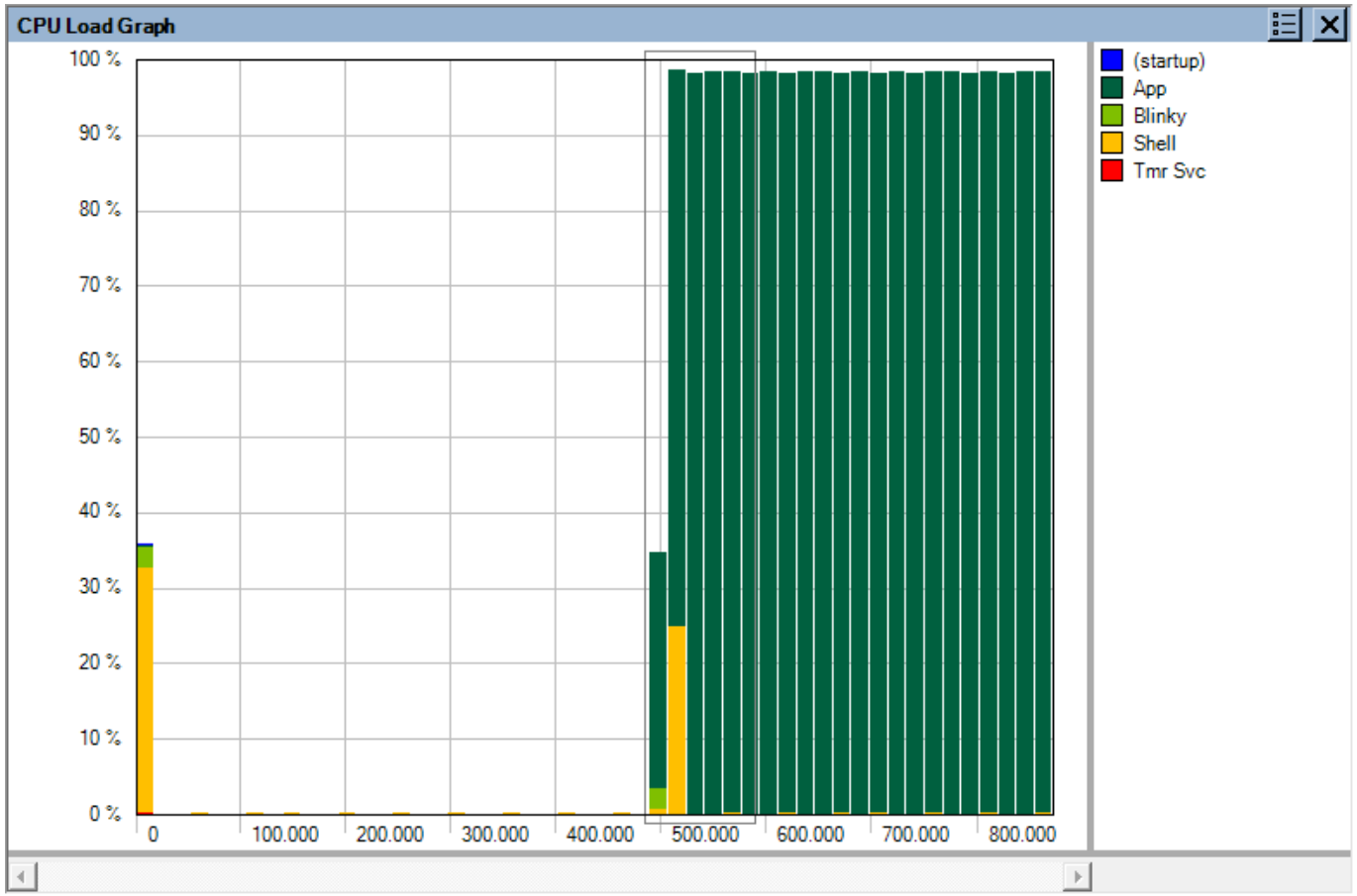
Problem with App Task

- Restart application with SW2
- Pressed
- App Task is blocking for a long time



CPU Load Graph

- Menu View > CPU Load Graph



No Busy Delay

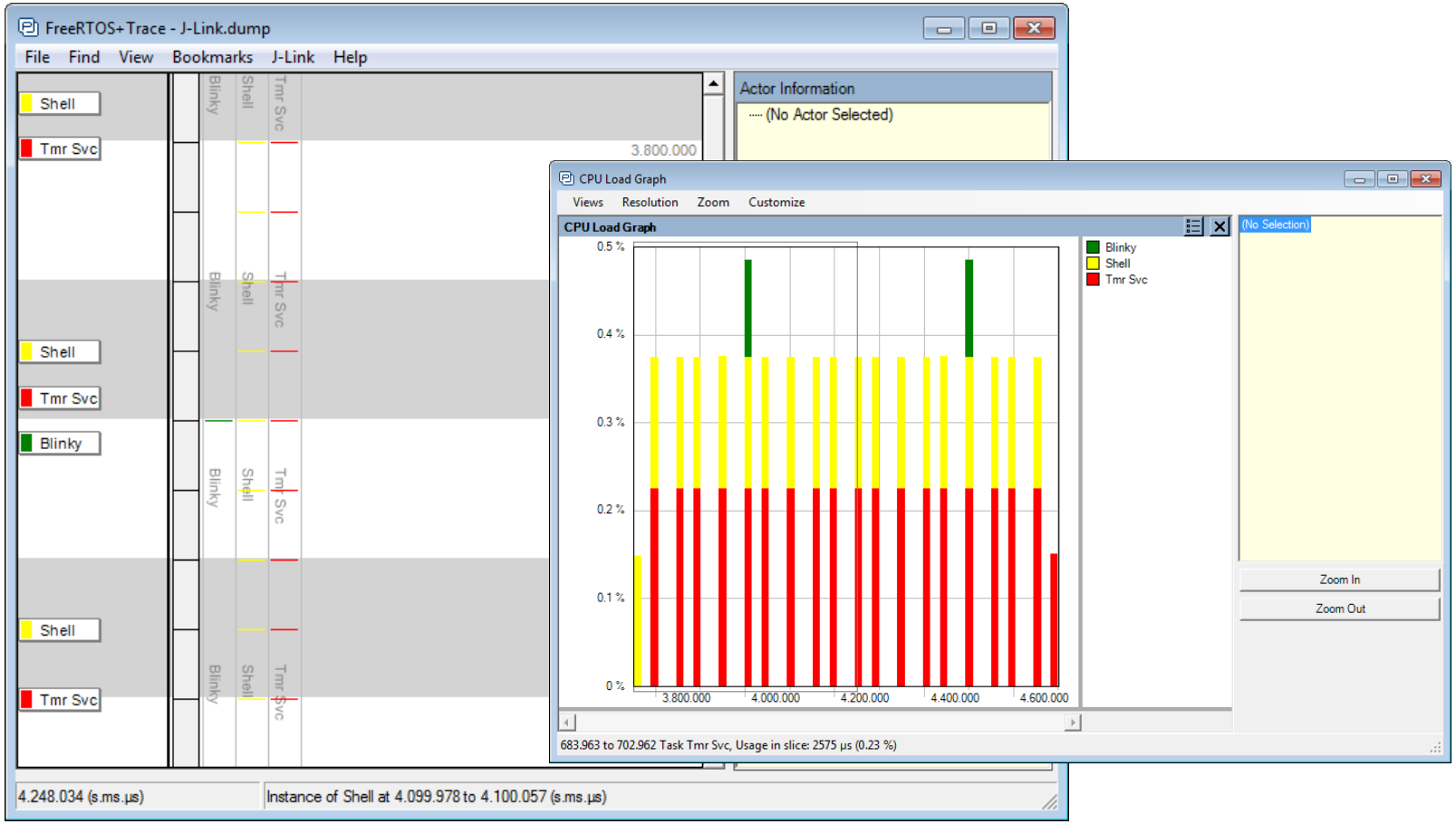
- vTaskDelay(pdMS_TO_TICKS(50));
- Build and debug/collect trace again

Application.c

```
75
76  static void app_task(void *param) {
77    (void)param;
78    for(;;) {
79      vTaskDelay(pdMS_TO_TICKS(500)); /* wait for 500 ms */
80      if (GPIO_DRV_ReadPinInput(kGpioSW2)==0) { /* pressed */
81        //busydelay(10000); /* debounce */
82        vTaskDelay(pdMS_TO_TICKS(50));
83        while (GPIO_DRV_ReadPinInput(kGpioSW2)==0) {
84          /* wait until released */
85        }
86        SQUEUE_SendString("SW2 has been pressed!\r\n");
87        whichLED <<= 1;
88        if (whichLED>RGB_LED_BLUE) {
89          whichLED = RGB_LED_RED;
90        }
91      }
92      if (GPIO_DRV_ReadPinInput(kGpioSW3)==0) { /* pressed */
93        //busydelay(10000); /* debounce */
94        vTaskDelay(pdMS_TO_TICKS(50));
95        while (GPIO_DRV_ReadPinInput(kGpioSW3)==0) {
96          /* wait until released */
97        }
98        SQUEUE_SendString("SW3 has been pressed!\r\n");
99        whichLED >>= 1;
100       if (whichLED<RGB_LED_RED) {
101         whichLED = RGB_LED_BLUE;
102       }
103     }
104   } /* for */
105 }
106
```

Improved Application Timing

RTOS wait instead of busy wait



Summary: FreeRTOS+Trace

- FreeRTOS Hooks to intercept RTOS or application calls
- Dump/stream/store/send trace data to host
- Percepio FreeRTOS+Trace viewer to analyze data

- **Further Information:**
  - http://percepio.com/
  - http://www.freertos.org/FreeRTOS-Plus/FreeRTOS_Plus_Trace/FreeRTOS_Plus_Trace.shtml
  - http://mcuoneclipse.com/2012/03/23/tracing-with-freertostrace-from-percepio/
  - http://mcuoneclipse.com/2015/01/05/updated-percepio-tracealyzer-and-trace-library-to-version-v2-7-0/
  - http://mcuoneclipse.com/2012/06/03/percepio-freertostrace-v2-2-2-released/

FreeRTOS Heap

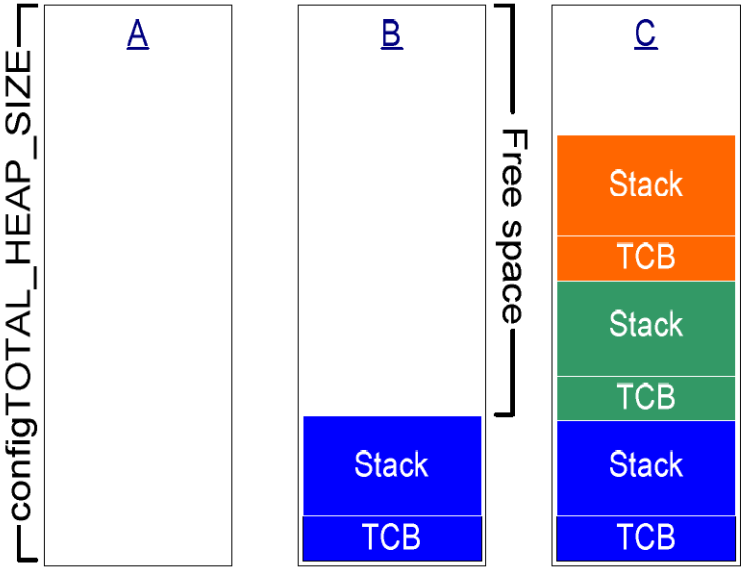
Reduce the amount of heap and RAM used…

Outline: FreeRTOS Heap

- **Problem**
  - Reducing RAM footprint of application
- **Solution**
  - Change allocation scheme
  - Reduce FreeRTOS Heap Size
- **Steps**
  - Inspect stack usage
  - Reduce default stack size
  - Reduce heap size

FreeRTOS Heap Size

- FreeRTOS uses dynamic heap memory for
  - Internal data structures (TCB, Task Control Block)
  - Queue, Semaphore, Mutex
  - Task Stack
- #define configTOTAL_HEAP_SIZE ((size_t)(32*1024))



Source: freeRTOS.org

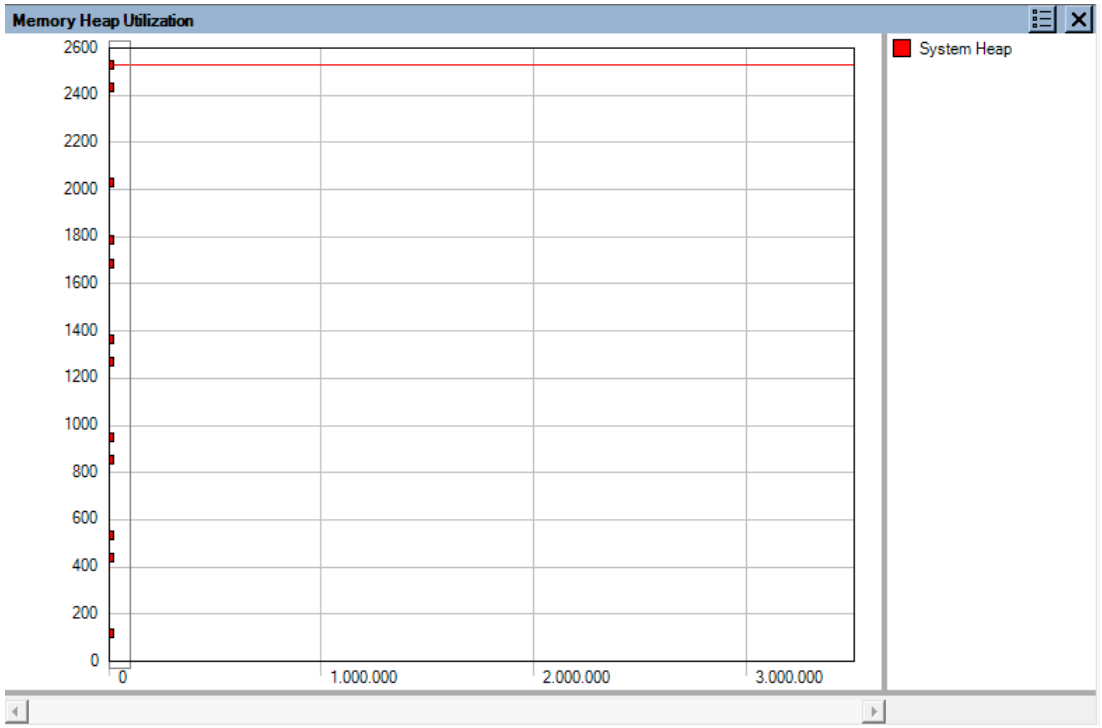
FreeRTOS Heap Schemes

- FreeRTOS Heap != ANSI/Runtime Heap
- Different schemes (allocate only, free with no merge, …)
- #define configFRTOS_MEMORY_SCHEME 4
  - 1 (only alloc) <<= Change to this
  - 2 (alloc/free)
  - 3 (malloc)
  - 4 (coalesc blocks)
  - 5 (multiple blocks)

```
137 /*-----------------------------------------------------------*/
138 /* Heap Memory */
139 #define configFRTOS_MEMORY_SCHEME                1 /* either 1 (only alloc), 2 (alloc/f
```

Heap Usage

- Menu View > Memory Heap Utilization
- Less than 3 Kbyte used now
- Line 140: #define configTOTAL_HEAP_SIZE ((size_t)(3*1024))



Lab: Heap

- Determine amount of Heap used
- Reduce heap size
- Determine that application is using allocation only
- Change heap scheme
- Rebuild application
  - Reduced RAM usage

Summary: Heap

- Heap used for FreeRTOS data structures
- Stack size allocated at task creation in heap
- Reduce heap size to the amount needed
- Use scheme1 (allocate only) if no task/object deletion

- Further Information:
  - http://www.freertos.org

Session Closing

What we have achieved…

Summary

- **Application**
  - Have enough headroom for diagnostics/trace
  - Architectural changes can have big impact
  - Use proper buffering

- **FreeRTOS and Kinetis SDK**
  - Configure what you need
  - Tune heap and stack size (but be careful)

- **Development Tools**
  - Use profiling/performance analysis
  - Use FreeRTOS+Trace with run control
  - Turn on optimizations in GNU Tools
  - Free tools can do a lot for you!

For Further Information

- Kinetis Design Studio IDE: www.nxp.com/kds
- Kinetis SDK: www.nxp.com/ksdk
- FreeRTOS: www.freertos.org
- Examples and Tutorials for Kinetis MCUs: www.mcuoneclipse.com

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- Erich Styger: erich.styger@nxp.com

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