Hands-On Workshop: Optimizing FreeRTOS

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SW and Tools Product Marketer

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SECURE CONNECTIONS FOR A SMARTER WORLD

Agenda

- MCUXpresso SW & Tools Overview
- Hands-on Lab
  - Basic Debugging
  - FreeRTOS Task Aware Debugging
  - FreeRTOS Optimization
  - FreeRTOS with SystemView
  - Compiler and Linker Optimization
- Summary

MCUXpresso SW & Tools Overview

MCUXpresso Software and Tools

for LPC & Kinetis MCUs and i.MX RT crossover processors

MCUXpresso IDE

Edit, compile, debug and optimize in an intuitive and powerful IDE

MCUXpresso SDK

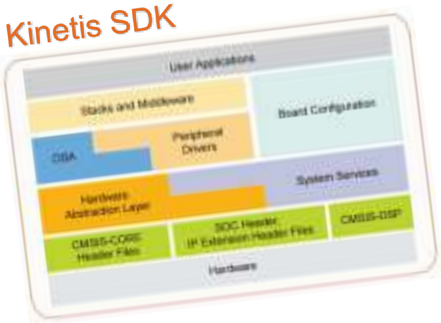
Runtime software including peripheral drivers, middleware, RTOS, demos and more

MCUXpresso Config Tools

Online and desktop tool suite for system configuration and optimization

NXP Microcontroller Enablement Consolidation

LPCOpen v2/3



2015 – 2016

MCUXpresso
Software and Tools

- IDE
- SDK
- Config Tools

For NXP Cortex-M controllers

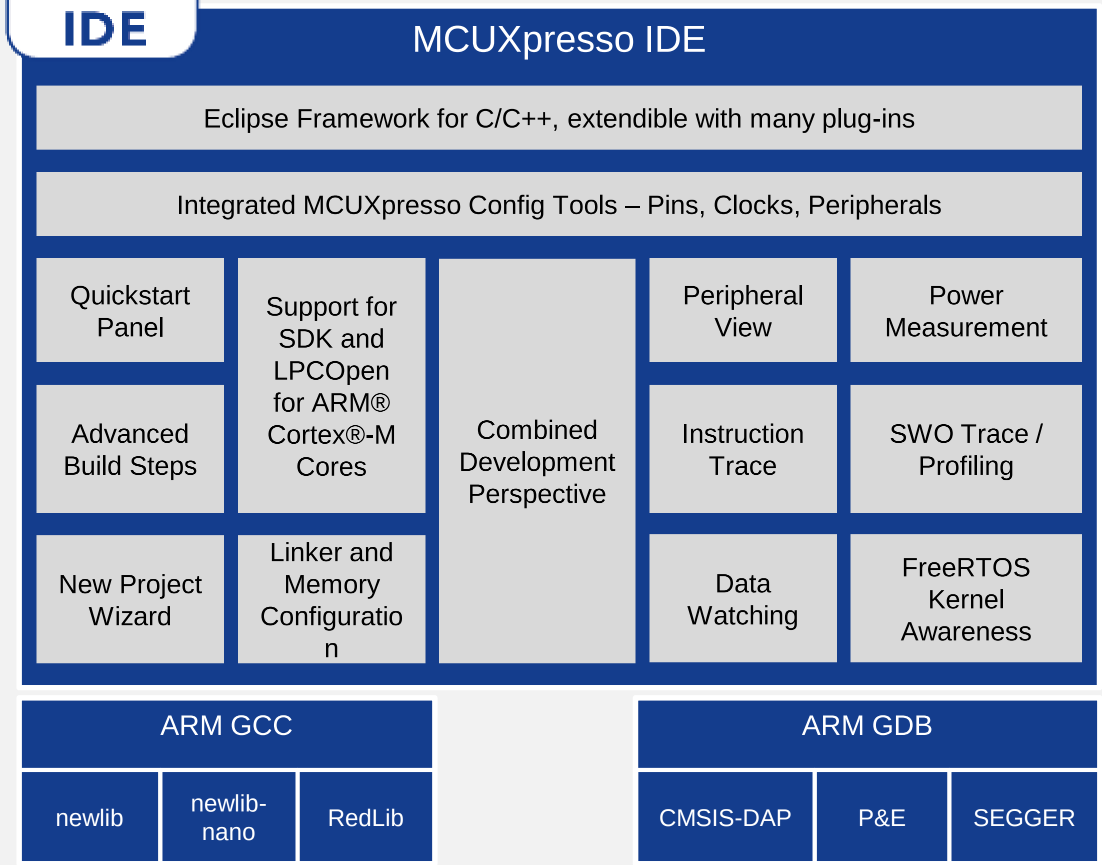
- Kinetis MCUs
- LPC Microcontrollers
- i.MX RT Crossover Processors

2017-2018

Learn more at: www.nxp.com/mcuxpresso/ide

MCUXpresso IDE

Free Eclipse / GCC-based development



MCUXpresso IDE

Eclipse Framework for C/C++, extendible with many plug-ins

Integrated MCUXpresso Config Tools – Pins, Clocks, Peripherals

Quickstart Panel

Advanced Build Steps

New Project Wizard

Support for SDK and LPCOpen for ARM® Cortex®-M Cores

Linker and Memory Configuratio n

Combined Development Perspective

Peripheral View

Instruction Trace

Data Watching

Power Measurement

SWO Trace / Profiling

FreeRTOS Kernel Awareness

ARM GCC

newlib

newlib-nano

RedLib

ARM GDB

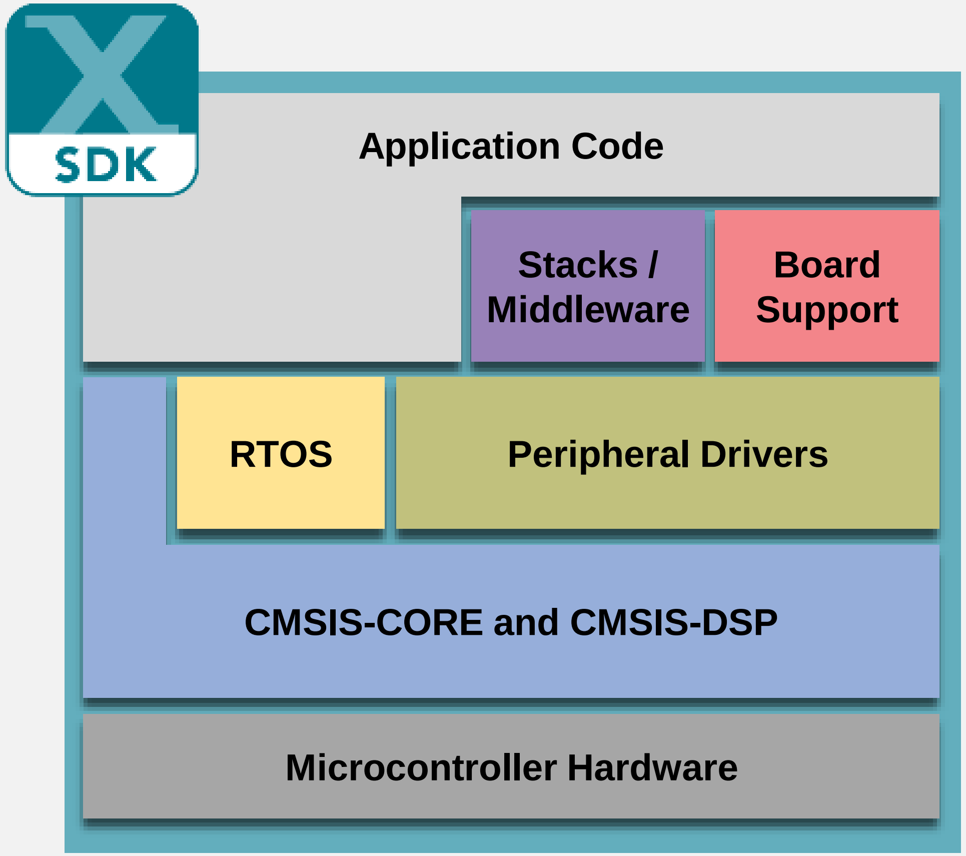
CMSIS-DAP

P&E

SEGGER

- **Feature-rich**, **unlimited code size**, optimized for ease-of-use, based on industry standard Eclipse framework for NXP’s **Kinetis** and **LPC** MCUs and **i.MX RT** crossover processors
- Application development with Eclipse and GCC-based IDE for advanced editing, compiling and debugging
- Supports custom development boards, Freedom, Tower and LPCXpresso boards with debug probes from NXP, P&E and Segger
- **Free:** Full Featured, unlimited Code Size, no special activation needed, community based support, advanced trace capabilities, MTB and ETB instruction trace
- Works in conjunction with **MCUXpresso Config Tools** and **MCUXpresso SDK** to provide complete development environment

Learn more at: www.nxp.com/mcuxpresso/sdk



SDK

Application Code

Stacks / Middleware

Board Support

RTOS

Peripheral Drivers

CMSIS-CORE and CMSIS-DSP

Microcontroller Hardware

MCUXpresso SDK

Software framework and drivers

Architecture:

- CMSIS-CORE compatible
- Single driver for each peripheral
- Transactional APIs w/ optional DMA support for communication peripherals

Integrated RTOS:

- Amazon FreeRTOS
- RTOS-native driver wrappers

Integrated Stacks and Middleware:

- USB Host, Device and OTG
- lwIP, FatFS, LittleFS
- Crypto acceleration plus wolfSSL & mbedTLS
- SD and eMMC card support

Reference Software:

- Peripheral driver usage examples
- Application demos
- FreeRTOS usage demos
- AWS WiFi and lwIP examples

License:

- Clear BSD 3-clause for startup, drivers, USB stack

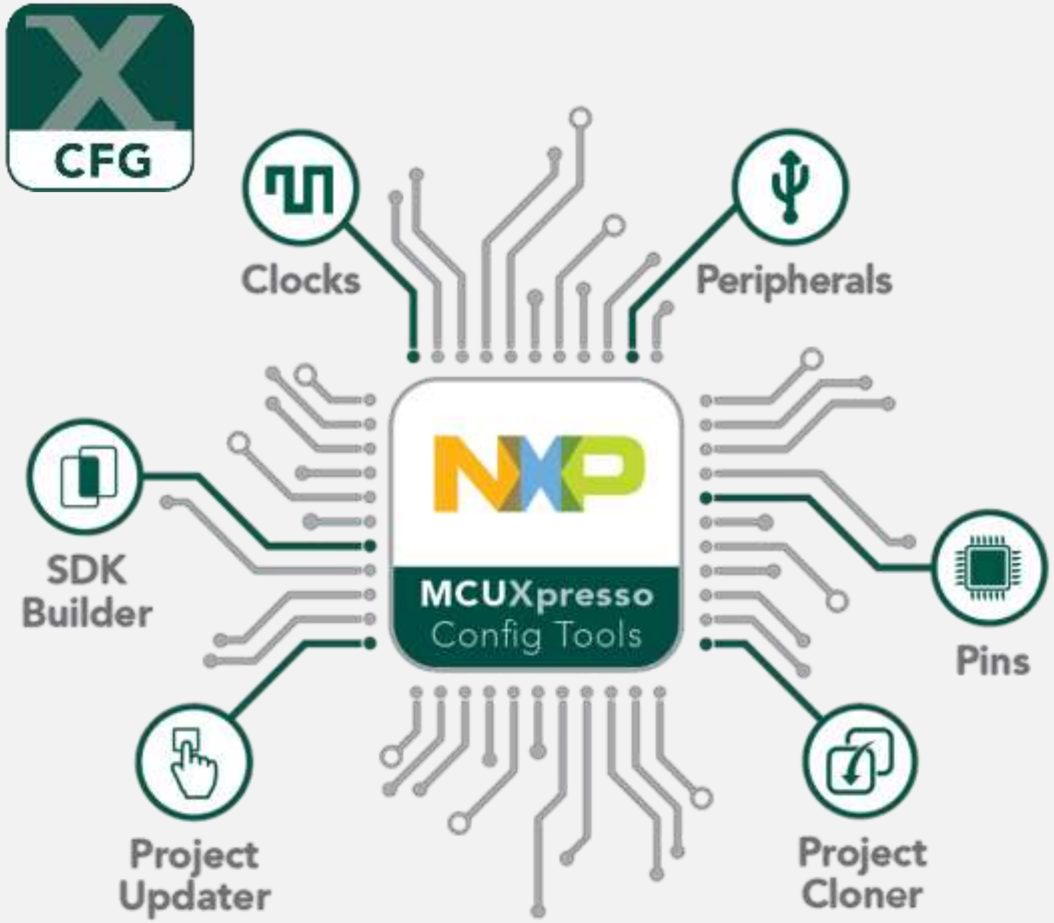
Toolchains:

- MCUXpresso IDE
- IAR®, ARM® Keil®, GCC w/ Cmake

Quality:

- Production-grade software
- MISRA 2004 compliance
- Checked with Coverity® static analysis tools

Learn more at: www.nxp.com/mcuxpresso/config



MCUXpresso Config Tools

Configuration and Code Generation

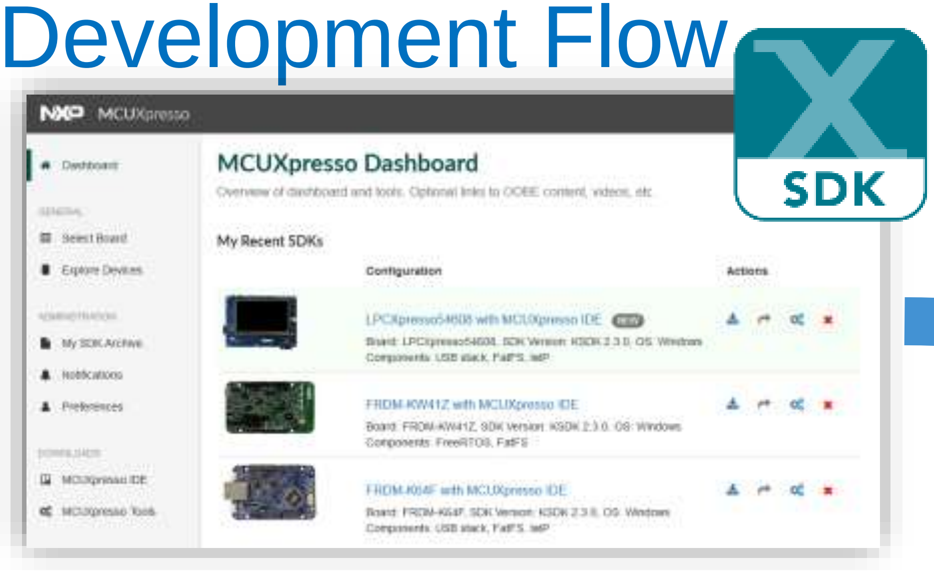
SDK Builder packages custom SDKs based on user selections of MCU, evaluation board, and optional software components.

Pins, **Clocks**, and **Peripheral** tools generate initialization C code for custom board support. Features validation of inputs and cross-tool conflict resolution.

Project Update works directly with existing SDK-based IDE projects with generated Pins, Clocks, and Peripheral source files.

Project Cloning creates a standalone SDK project based on a example application available within SDK release.

Development Flow



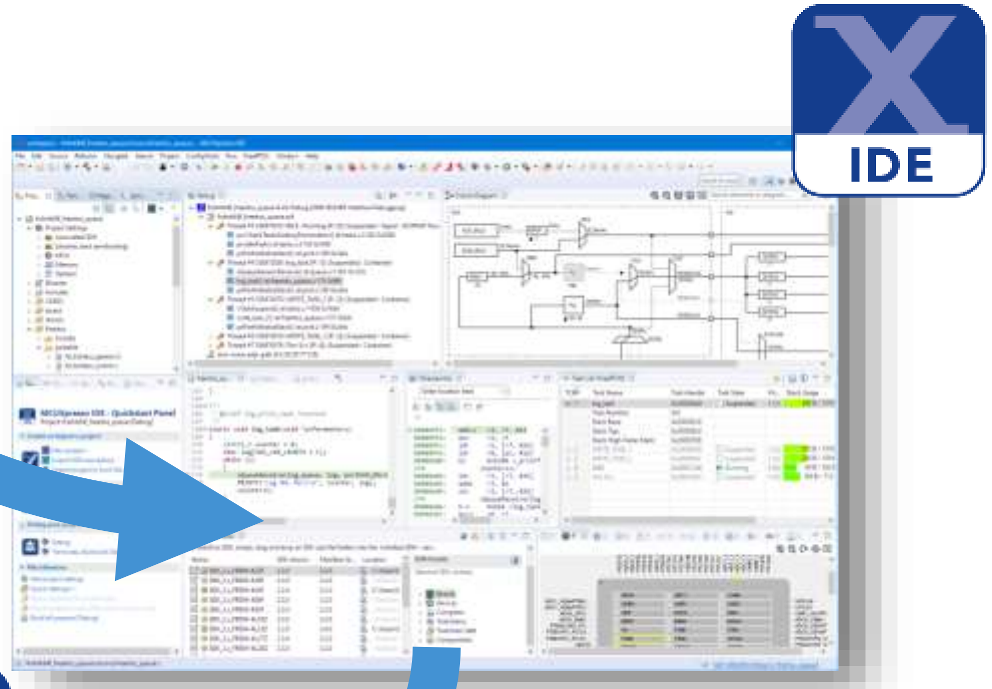
MCUXpresso

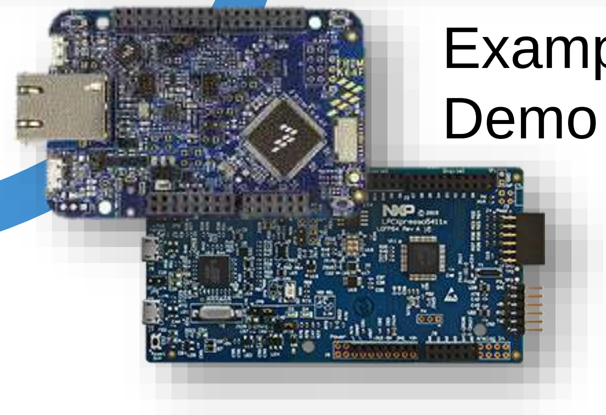
MCUXpresso Dashboard

Overview of dashboard and tools. Optional links to OOBE content, videos, etc

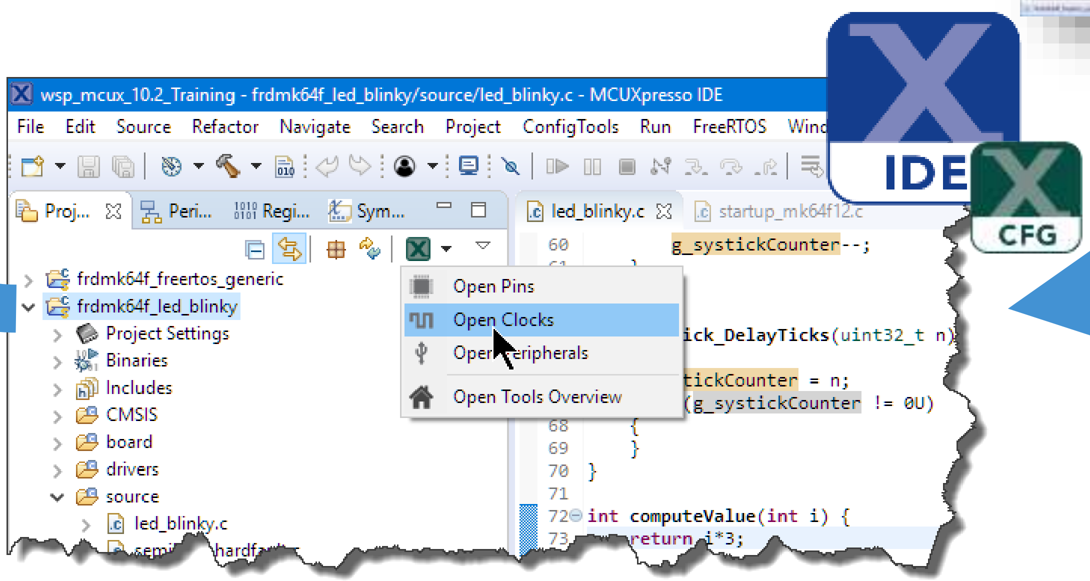
My Recent SDKs

Configuration	Actions
LPCXpresso54608 with MCUXpresso IDE NEW Board: LPCXpresso54608, SDK Version: KSDK 2.3.0, OS: Windows Components: USB stack, FatFS, lwIP	
FRDM-KW41Z with MCUXpresso IDE Board: FRDM-KW41Z, SDK Version: KSDK 2.3.0, OS: Windows Components: FreeRTOS, FatFS	
FRDM-K64F with MCUXpresso IDE Board: FRDM-K64F, SDK Version: KSDK 2.3.0, OS: Windows Components: USB stack, FatFS, lwIP	





Examples, Demo Apps



wsp_mcux_10.2_Training - frdmk64f_led_blinky/source/led_blinky.c - MCUXpresso IDE

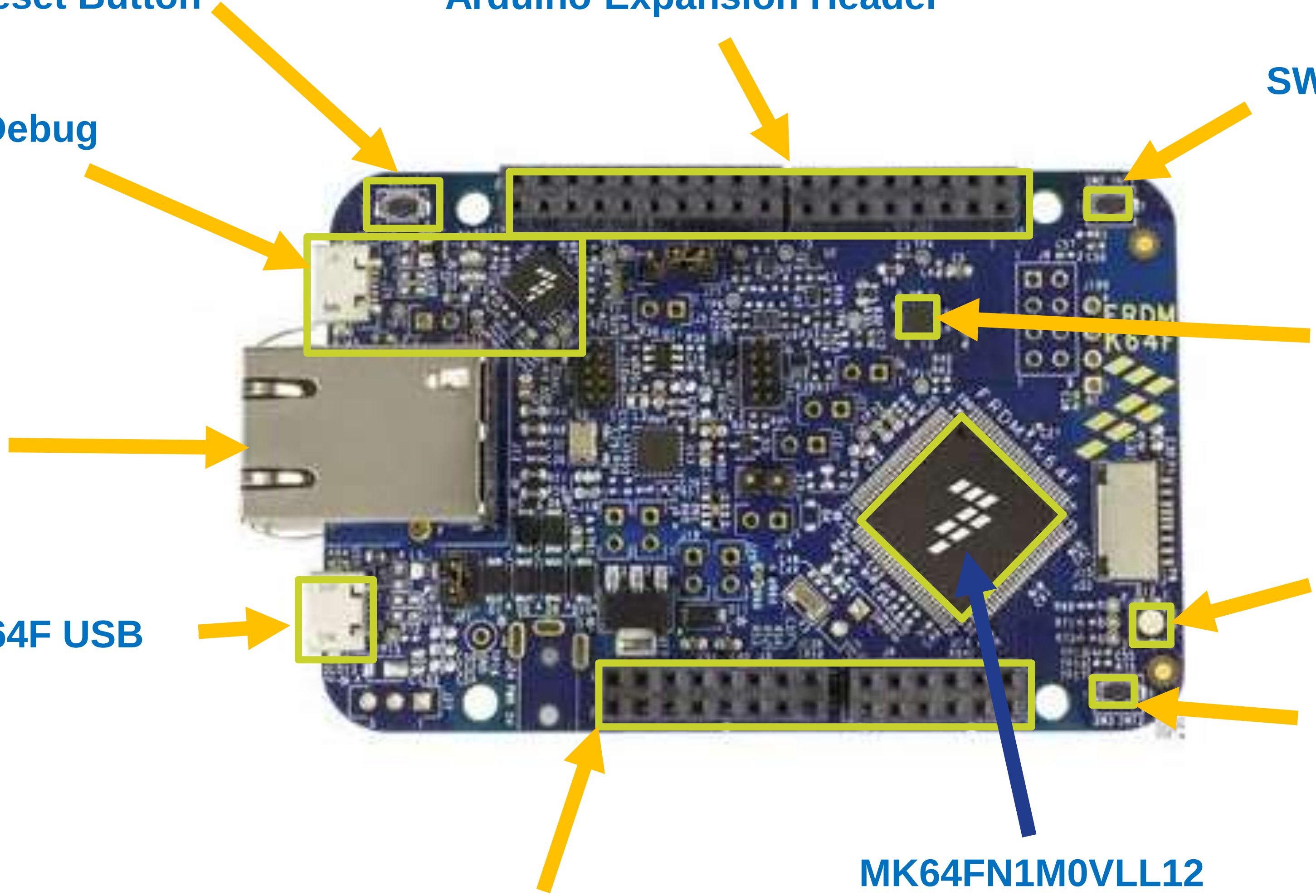
```
        g_systickCounter--;
    }
ick_DelayTicks(uint32_t n)

tickCounter = n;
(g_systickCounter != 0U)
    {
    }
}

int computeValue(int i) {
    return i*3;
```

Hands-On Lab

Lab Overview

1. Creating/Cloning MCUXpresso SDK Projects in the IDE
2. Building, Basic Debugging
3. Overview FreeRTOS TAD
   - FreeRTOS Configuration settings
   - Optimization Settings
   - Static code/data size impact
   - Segger SystemView
   - Dynamic system improvements

FRDM-K64F Hardware Overview



Reset Button

Arduino Expansion Header

SW2 Push Button

OpenSDAv2 Debug

FXOS8700CQ
Accel + Mag

Ethernet Port

Tri-Color LED

K64F USB

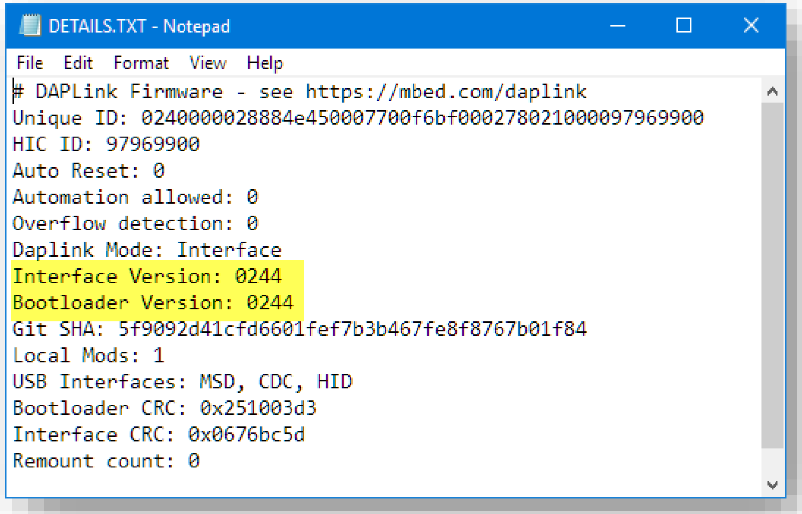
SW3 Push Button

Arduino Expansion Header

MK64FN1M0VLL12
120 MHz, Cortex-M4, 1MB Flash,
256K SRAM, USB, Ethernet, 16-bit ADC,
12-bit DAC, SDHC

Lab Setup/Prerequisites

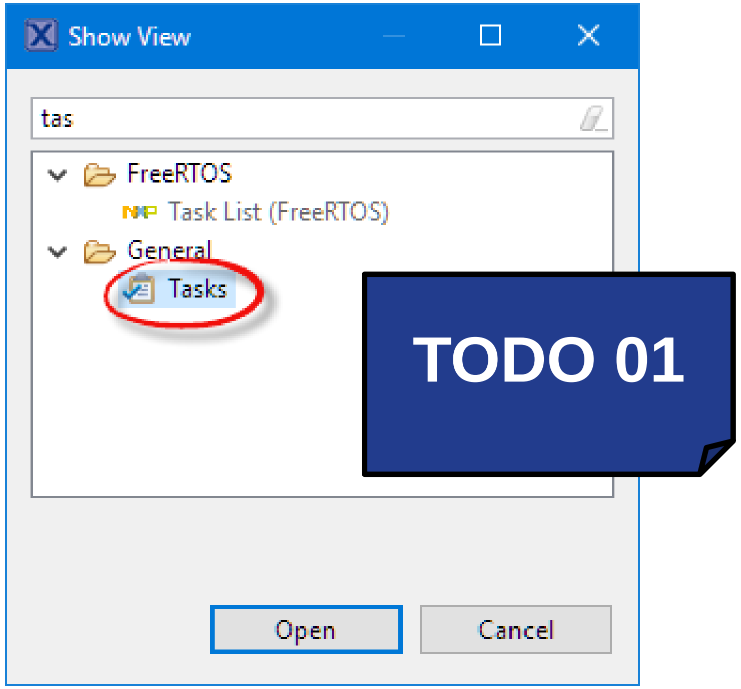
- MCUXpresso IDE 10.2.0 build 759
  - https://www.nxp.com/mcuxpresso/ide
- FRDM-K64 SDK V2.4.0
  - http://mcuxpresso.nxp.com/
- FRDM-K64F Board with micro-USB Cable
  - https://www.nxp.com/freedom
- FRDM-K64F Board with DAPlink/CMSIS-DAP Firmware
  - Bootloader rev0244 OpenSDA v2.2
  - DAPLink reve0244 Firmware
  - https://www.nxp.com/opensda



```
# DAPLink Firmware - see https://mbed.com/daplink
Unique ID: 0240000028884e450007700f6bf0002780210000097969900
HIC ID: 97969900
Auto Reset: 0
Automation allowed: 0
Overflow detection: 0
Daplink Mode: Interface
Interface Version: 0244
Bootloader Version: 0244
Git SHA: 5f9092d41cfd6601fef7b3b467fe8f8767b01f84
Local Mods: 1
USB Interfaces: MSD, CDC, HID
Bootloader CRC: 0x251003d3
Interface CRC: 0x0676bc5d
Remount count: 0
```

Lab Work Guidance

- Text in orange indicate actions/work to do
- TODO notes reference ‘Tasks/todo’ items
  - Markers in source files /* \todo .... */
  - Open Tasks View
  - Menu Window > Show View > General > Tasks
  - Double-Click on items to jump to source location



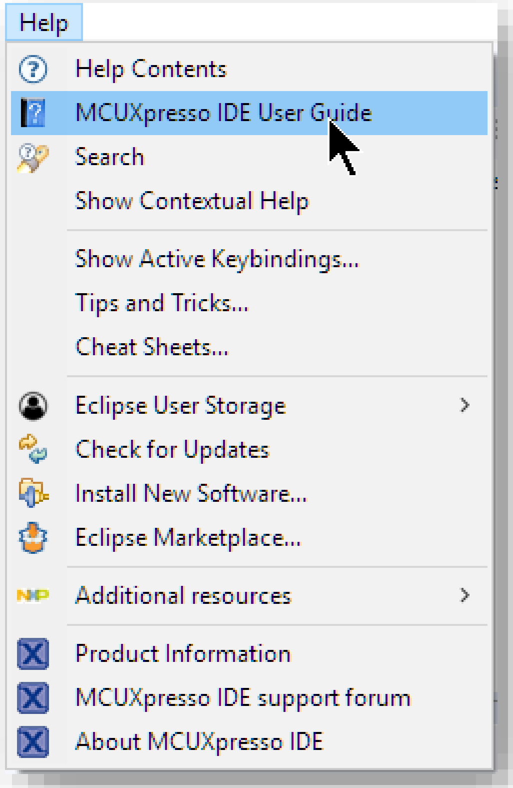
TODO 01

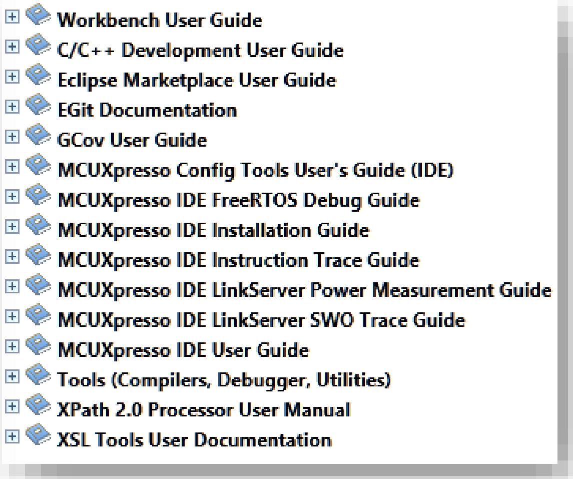
Overview: FreeRTOS and Tools

- http://www.freertos.org
  - Acquired by Amazon (29. Nov. 2017) ➔ MIT License
- Open Source, free-of-charge, royalty free
- >35 architectures, >154,000 downloads (2016)
- Portable, simple to learn and use
- Ecosystem
  - **OpenRTOS/SafeRTOS**: commercial supported versions
  - **Amazon FreeRTOS**: adds AWS and IoT use cases
  - **SEGGER SystemView**: System Visibility with Segger RTT
  - **PERCEPIO Tracealyzer**: Powerful Analysis Views
  - **NXP MCUXpresso SDK** with FreeRTOS v10
  - **NXP MCUXpresso IDE** with advanced FreeRTOS views

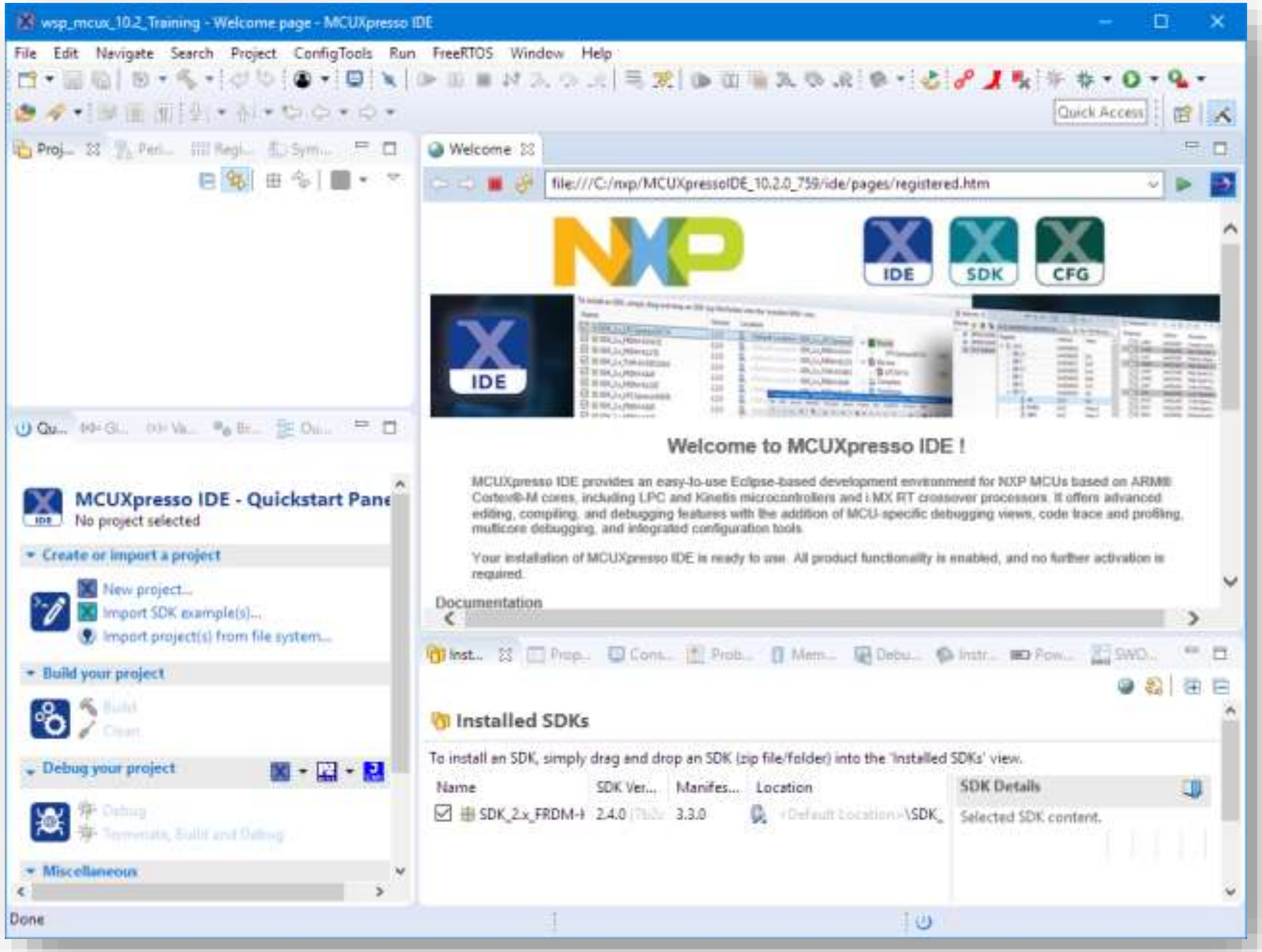
MCUXpresso IDE

- Start the IDE with Shortcut
- Select workspace
- Open MCUXpresso IDE User Guide





- Workbench User Guide
- C/C++ Development User Guide
- Eclipse Marketplace User Guide
- EGit Documentation
- GCov User Guide
- MCUXpresso Config Tools User's Guide (IDE)
- MCUXpresso IDE FreeRTOS Debug Guide
- MCUXpresso IDE Installation Guide
- MCUXpresso IDE Instruction Trace Guide
- MCUXpresso IDE LinkServer Power Measurement Guide
- MCUXpresso IDE LinkServer SWO Trace Guide
- MCUXpresso IDE User Guide
- Tools (Compilers, Debugger, Utilities)
- XPath 2.0 Processor User Manual
- XSL Tools User Documentation


wsp_mcux_10.2_Training - Welcome page - MCUXpresso IDE
File Edit Navigate Search Project ConfigTools Run FreeRTOS Window Help
Quick Access
Proj... Peri... Regi... Sym...
Welcome
file:///C:/nxp/MCUXpressoIDE_10.2.0_759/ide/pages/registered.htm
NXP
IDE
SDK
CFG
Qu... Gl... Va... Br... Ou...
MCUXpresso IDE - Quickstart Pane
No project selected
Create or import a project
New project...
Import SDK example(s)...
Import project(s) from file system...
Build your project
Build
Clean
Debug your project
Debug
Terminate, Build and Debug
Miscellaneous
Documentation
Inst... Prop... Cons... Prob... Mem... Debu... Instr... Pow... SWO...
Done

Welcome to MCUXpresso IDE !

MCUXpresso IDE provides an easy-to-use Eclipse-based development environment for NXP MCUs based on ARM® Cortex®-M cores, including LPC and Kinetis microcontrollers and i.MX RT crossover processors. It offers advanced editing, compiling, and debugging features with the addition of MCU-specific debugging views, code trace and profiling, multicore debugging, and integrated configuration tools.

Your installation of MCUXpresso IDE is ready to use. All product functionality is enabled, and no further activation is required.

Installed SDKs

To install an SDK, simply drag and drop an SDK (zip file/folder) into the 'Installed SDKs' view.

Name	SDK Ver...	Manifes...	Location
☑ SDK_2.x_FRDM-I	2.4.0	3.3.0	<Default Location>\SDK_

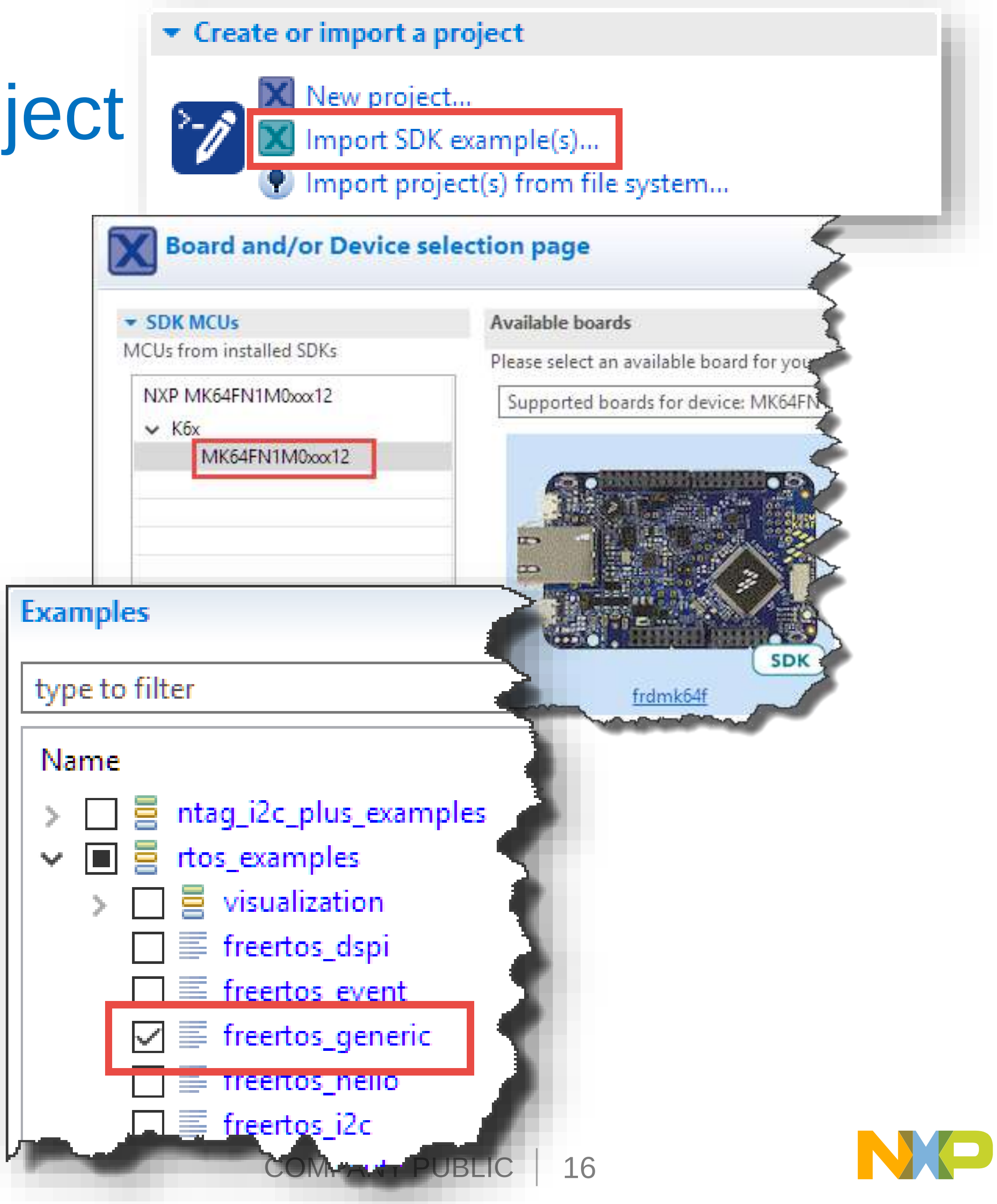
SDK Details

Selected SDK content.

Create FreeRTOS Example Project

- Prerequisite:
  - SDK_2.x_FRDM-K64F installed in IDE

- Use Quickstart Panel with “Import SDK example(s)…”
  - Select frdmk64f board image
  - Click “Next”
  - Select “rtos_examples > freertos_generic”
  - Click “Finish”

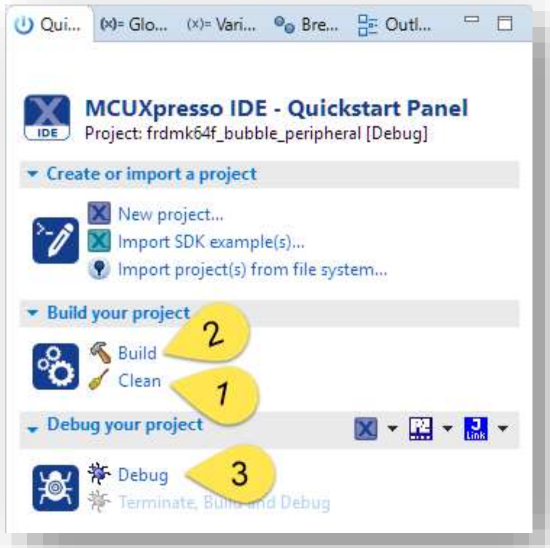


Create or import a project
New project...
Import SDK example(s)...
Import project(s) from file system...
Board and/or Device selection page
SDK MCUs
MCUs from installed SDKs
NXP MK64FN1M0xxx12
K6x
MK64FN1M0xxx12
Available boards
Please select an available board for you
Supported boards for device: MK64FN
SDK
frdmk64f
Examples
type to filter
Name

- › □ ntag_i2c_plus_examples
- ⌄ ■ rtos_examples
  - › □ visualization
  - □ freertos_dspi
  - □ freertos_event
  - ☑ freertos_generic
  - □ freertos_hello
  - □ freertos_i2c

Build and Debug

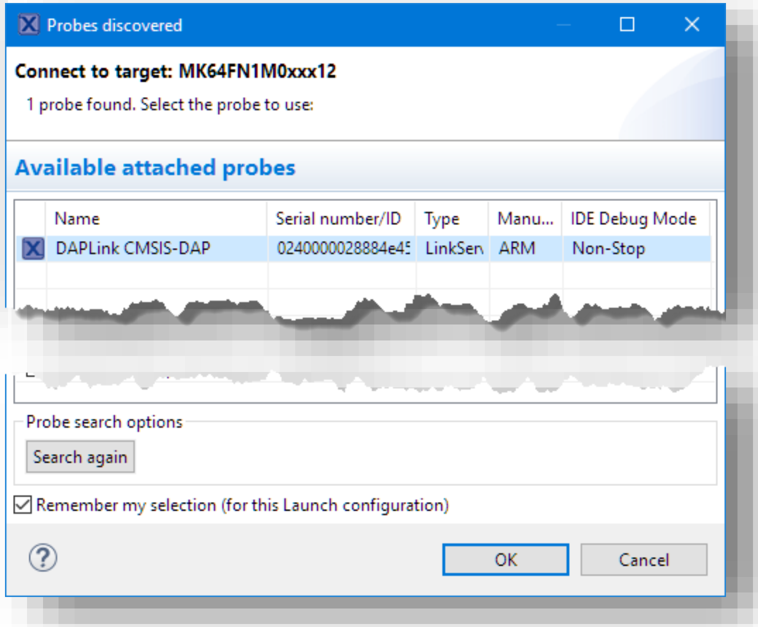
- Connect FRDM-K64F board (micro USB to OpenSDA)
  - Windows may need to enumerate USB connection
- Use IDE Quickstart Panel to:
  - Clean
  - Build
  - Debug
- Debugger discovers probe
  - Use SHIFT to force probe re-discovery



Qui... | Glo... | Vari... | Bre... | Outl...

MCUXpresso IDE - Quickstart Panel
Project: frdmk64f_bubble_peripheral [Debug]

- Create or import a project
  - New project...
  - Import SDK example(s)...
  - Import project(s) from file system...
- Build your project
  - Build (2)
  - Clean (1)
- Debug your project
  - Debug (3)
  - Terminate, Build and Debug



Probes discovered

Connect to target: MK64FN1M0xxx12

1 probe found. Select the probe to use:

Available attached probes

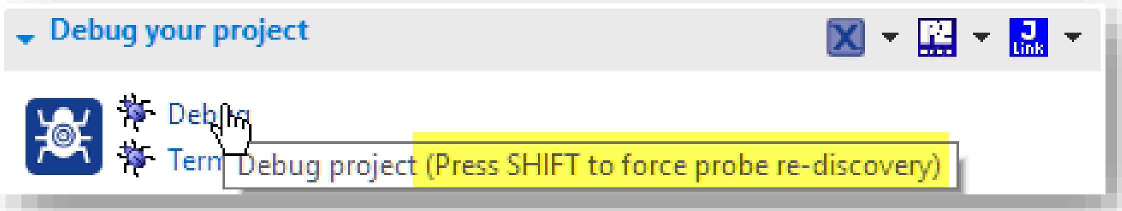
Name	Serial number/ID	Type	Manu...	IDE Debug Mode
DAPLink CMSIS-DAP	0240000028884e4	LinkSer	ARM	Non-Stop

Probe search options

Search again

☑ Remember my selection (for this Launch configuration)

OK | Cancel

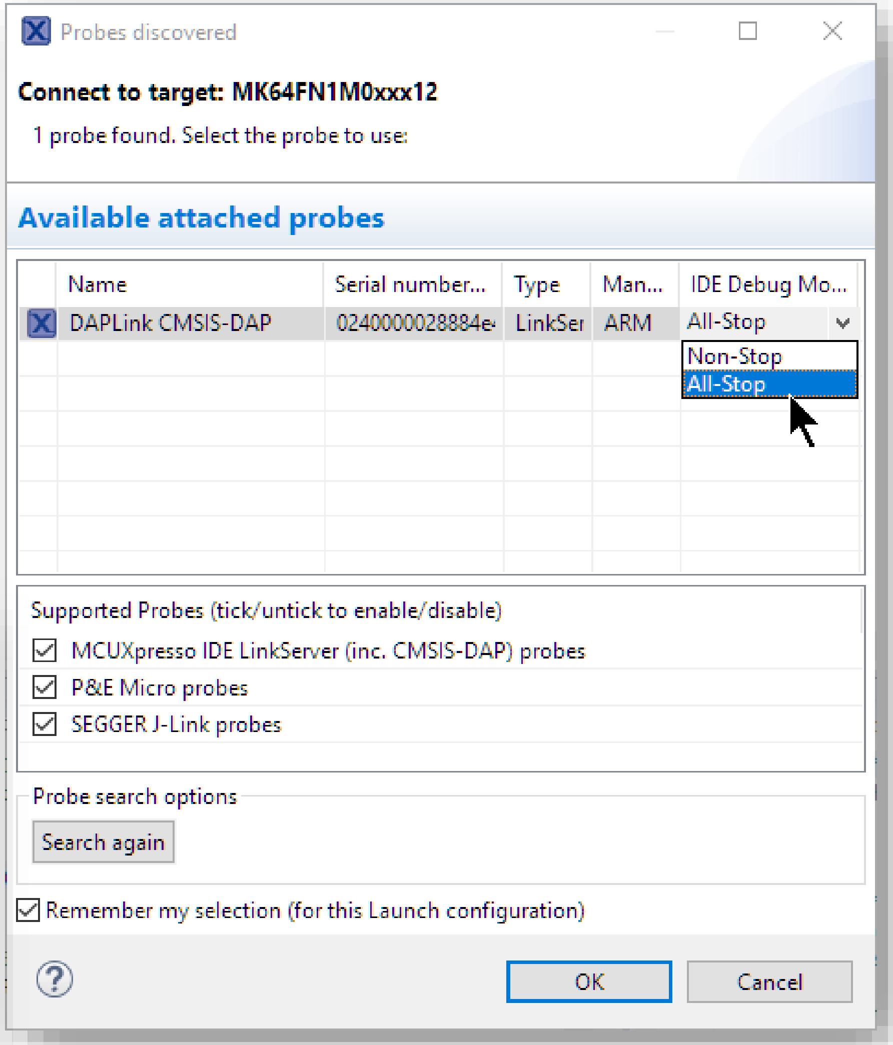


Debug your project

Debug
Term
Debug project (Press SHIFT to force probe re-discovery)

Debug Probe Connection

- Configure to use **All-Stop**
  - Allows thread aware debug view
  - Otherwise only current thread is shown
  - Note: ‘Live Variables’ not possible in All-Stop mode
- Resume, then Pause
- Application writes message counter to console



Probes discovered

Connect to target: MK64FN1M0xxx12

1 probe found. Select the probe to use:

Available attached probes

Name	Serial number...	Type	Man...	IDE Debug Mo...
DAPLink CMSIS-DAP	0240000028884e	LinkSer	ARM	All-Stop

Supported Probes (tick/untick to enable/disable)

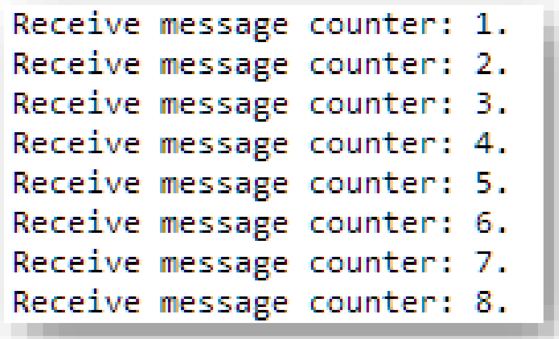
☑ MCUXpresso IDE LinkServer (inc. CMSIS-DAP) probes

☑ P&E Micro probes

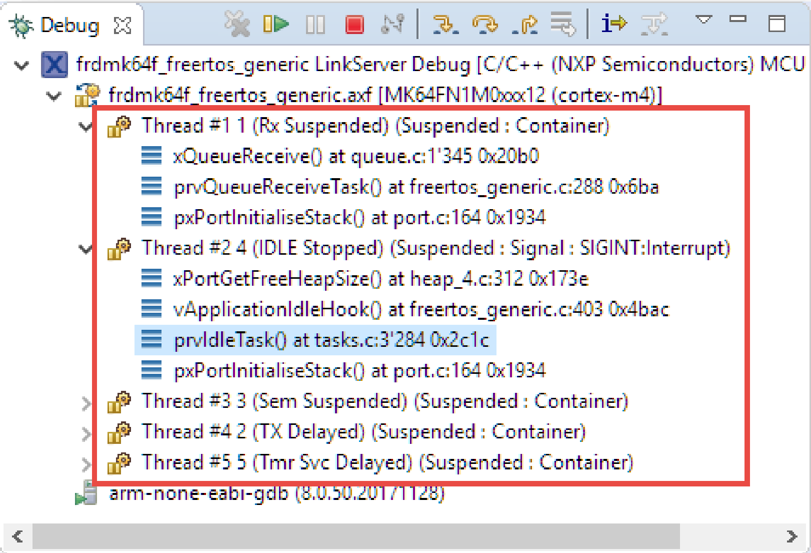
☑ SEGGER J-Link probes

Probe search options

☑ Remember my selection (for this Launch configuration)



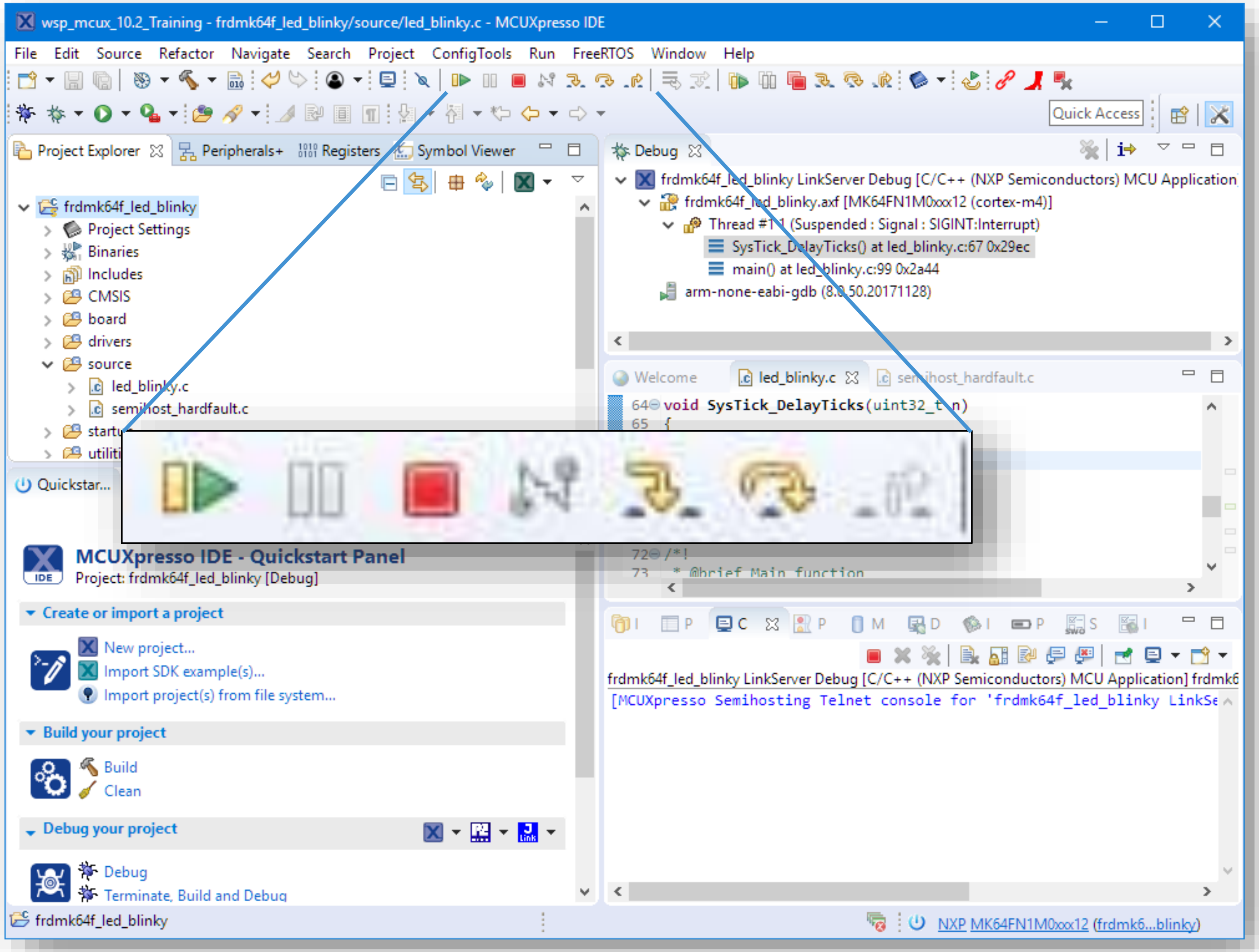
```
Receive message counter: 1.
Receive message counter: 2.
Receive message counter: 3.
Receive message counter: 4.
Receive message counter: 5.
Receive message counter: 6.
Receive message counter: 7.
Receive message counter: 8.
```



```
frdmk64f_freertos_generic LinkServer Debug [C/C++ (NXP Semiconductors) MCU
  frdmk64f_freertos_generic.axf [MK64FN1M0xxx12 (cortex-m4)]
    Thread #1 1 (Rx Suspended) (Suspended : Container)
      xQueueReceive() at queue.c:1'345 0x20b0
      prvQueueReceiveTask() at freertos_generic.c:288 0x6ba
      pxPortInitialiseStack() at port.c:164 0x1934
    Thread #2 4 (IDLE Stopped) (Suspended : Signal : SIGINT:Interrupt)
      xPortGetFreeHeapSize() at heap_4.c:312 0x173e
      vApplicationIdleHook() at freertos_generic.c:403 0x4bac
      prvIdleTask() at tasks.c:3'284 0x2c1c
      pxPortInitialiseStack() at port.c:164 0x1934
    Thread #3 3 (Sem Suspended) (Suspended : Container)
    Thread #4 2 (TX Delayed) (Suspended : Container)
    Thread #5 5 (Tmr Svc Delayed) (Suspended : Container)
  arm-none-eabi-gdb (8.0.50.20171128)
```

Debugger Run Control

- Resume/Run
- Suspend/Pause
- Terminate/Stop
- (Disconnect)
- Step Into
- Step Over
- Step Out
- Step trough the code



frdmk64f_led_blinky LinkServer Debug [C/C++ (NXP Semiconductors) MCU Application

frdmk64f_led_blinky.axf [MK64FN1M0xxx12 (cortex-m4)]

Thread #1 1 (Suspended : Signal : SIGINT:Interrupt)

SysTick_DelayTicks() at led_blinky.c:67 0x29ec

main() at led_blinky.c:99 0x2a44

arm-none-eabi-gdb (8.0.50.20171128)

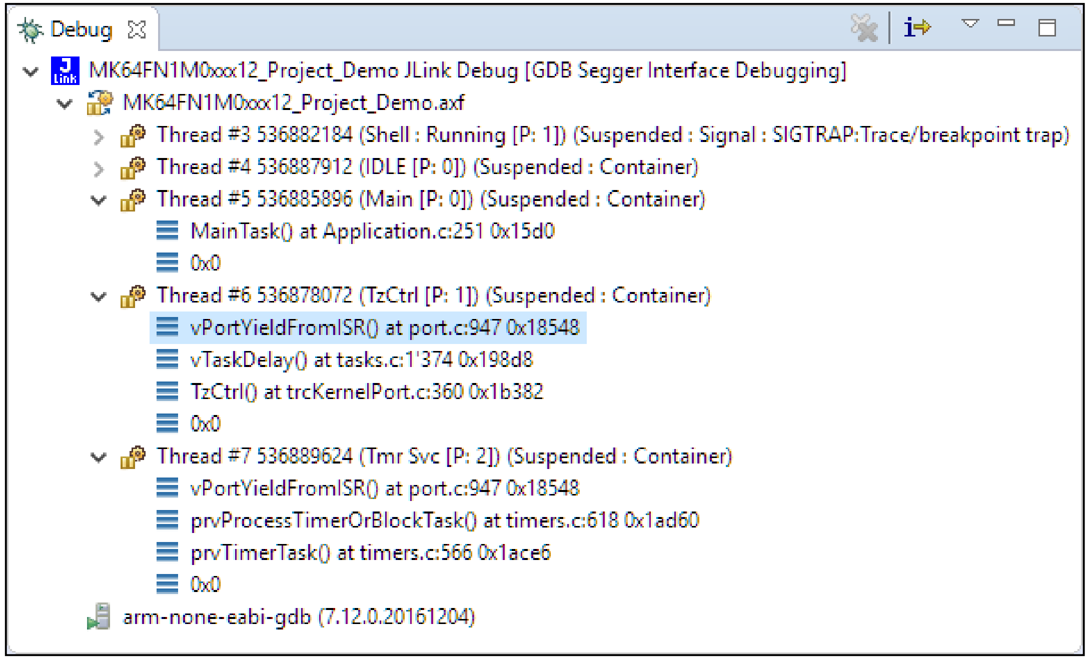
```
64⊖ void SysTick_DelayTicks(uint32_t n)
65  {
72⊖ /*!
73   * @brief Main function
```

frdmk64f_led_blinky LinkServer Debug [C/C++ (NXP Semiconductors) MCU Application] frdmk6

```
[MCUXpresso Semihosting Telnet console for 'frdmk64f_led_blinky LinkSe
```

FreeRTOS Thread Aware Debugging

- Part of MCUXpresso IDE
- Show and debug FreeRTOS Tasks/Threads
- **LinkServer** (LPC-Link, LPC-Link2, CMSIS-DAP)
  - Uses ‘freertos_tasks_c_additions.h’
  - Uses GDB ‘**all-stop mode**’
  - See ‘FreeRTOS_Thread_Aware_Setup.pdf’
- **P&E** (Multilink, OpenSDA)
  - automatically supported/enabled
- **Segger** (J-Link, OpenSDA)
  - Uses GDB server option:
    -rtos GDBServer/RTOSPlugin_FreeRTOS

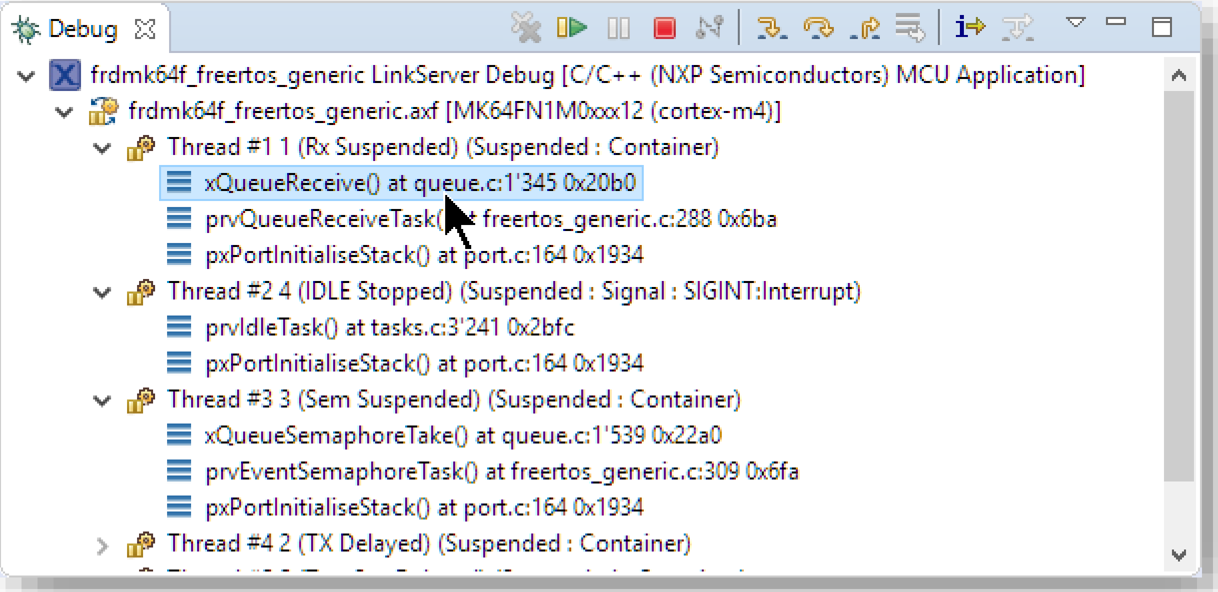


Debug

```
MK64FN1M0xxx12_Project_Demo JLink Debug [GDB Segger Interface Debugging]
  MK64FN1M0xxx12_Project_Demo.axf
    Thread #3 536882184 (Shell : Running [P: 1]) (Suspended : Signal : SIGTRAP:Trace/breakpoint trap)
    Thread #4 536887912 (IDLE [P: 0]) (Suspended : Container)
    Thread #5 536885896 (Main [P: 0]) (Suspended : Container)
      MainTask() at Application.c:251 0x15d0
      0x0
    Thread #6 536878072 (TzCtrl [P: 1]) (Suspended : Container)
      vPortYieldFromISR() at port.c:947 0x18548
      vTaskDelay() at tasks.c:1'374 0x198d8
      TzCtrl() at trcKernelPort.c:360 0x1b382
      0x0
    Thread #7 536889624 (Tmr Svc [P: 2]) (Suspended : Container)
      vPortYieldFromISR() at port.c:947 0x18548
      prvProcessTimerOrBlockTask() at timers.c:618 0x1ad60
      prvTimerTask() at timers.c:566 0x1ace6
      0x0
  arm-none-eabi-gdb (7.12.0.20161204)
```

Thread Aware Debug View

- Lists all FreeRTOS **tasks** with stacks
  - LinkServer: Requires ‘All-Stop’ mode!
  - Switch debug context to thread
  - Context, registers, stack
- Click on function (top) of a thread
- Debug it (step out, step over)
- Switch to another thread

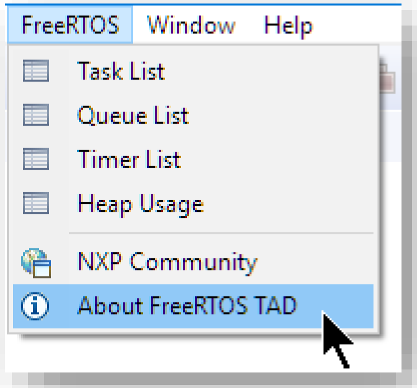


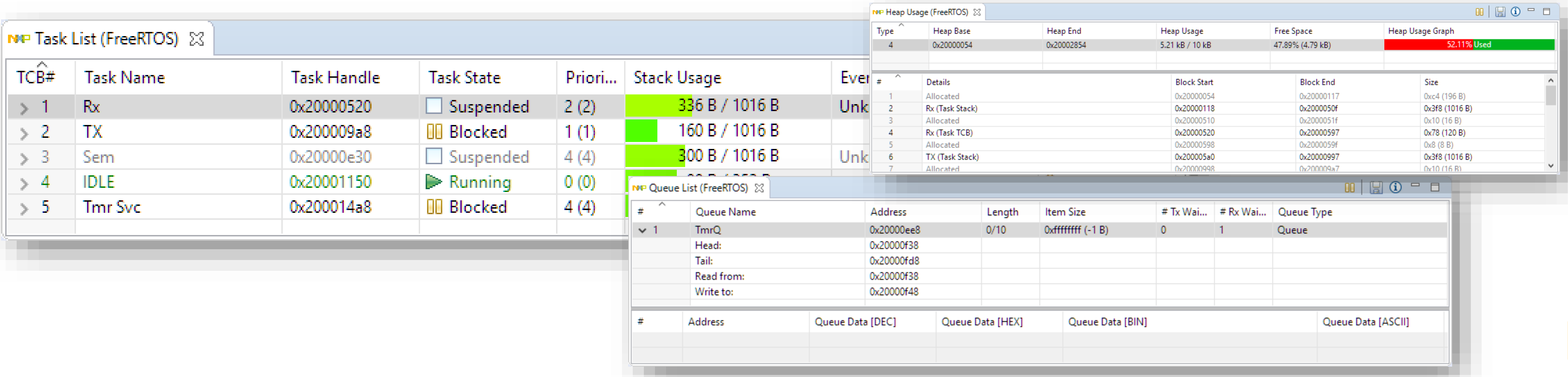
```
frdmk64f_freertos_generic LinkServer Debug [C/C++ (NXP Semiconductors) MCU Application]
  frdmk64f_freertos_generic.axf [MK64FN1M0xxx12 (cortex-m4)]
    Thread #1 1 (Rx Suspended) (Suspended : Container)
      xQueueReceive() at queue.c:1'345 0x20b0
      prvQueueReceiveTask() at freertos_generic.c:288 0x6ba
      pxPortInitialiseStack() at port.c:164 0x1934
    Thread #2 4 (IDLE Stopped) (Suspended : Signal : SIGINT:Interrupt)
      prvIdleTask() at tasks.c:3'241 0x2bfc
      pxPortInitialiseStack() at port.c:164 0x1934
    Thread #3 3 (Sem Suspended) (Suspended : Container)
      xQueueSemaphoreTake() at queue.c:1'539 0x22a0
      prvEventSemaphoreTask() at freertos_generic.c:309 0x6fa
      pxPortInitialiseStack() at port.c:164 0x1934
    Thread #4 2 (TX Delayed) (Suspended : Container)
```

FreeRTOS TAD

FreeRTOS TAD

- Thread Aware Debugging
  - Show and switch between threads in Debug View
  - Views to inspect status of the RTOS
- Views read RTOS data structures while target is haltet
- Debugger needs extra information: <IDE Installation Path>\MCUXpresso_IDE_FreeRTOS_Debug_Guide.pdf
  - SDK projects should be updated for this




Task List (FreeRTOS)

TCB#	Task Name	Task Handle	Task State	Priori...	Stack Usage	Ever
1	Rx	0x20000520	□ Suspended	2 (2)	336 B / 1016 B	Unk
2	TX	0x200009a8	Blocked	1 (1)	160 B / 1016 B	
3	Sem	0x20000e30	□ Suspended	4 (4)	300 B / 1016 B	Unk
4	IDLE	0x20001150	▶ Running	0 (0)		
5	Tmr Svc	0x200014a8	Blocked	4 (4)		

Heap Usage (FreeRTOS)

Type	Heap Base	Heap End	Heap Usage	Free Space	Heap Usage Graph
4	0x20000054	0x20002854	5.21 kB / 10 kB	47.89% (4.79 kB)	52.11% Used

#	Details	Block Start	Block End	Size
1	Allocated	0x20000054	0x20000117	0xc4 (196 B)
2	Rx (Task Stack)	0x20000118	0x2000050f	0x3f8 (1016 B)
3	Allocated	0x20000510	0x2000051f	0x10 (16 B)
4	Rx (Task TCB)	0x20000520	0x20000597	0x78 (120 B)
5	Allocated	0x20000598	0x2000059f	0x8 (8 B)
6	TX (Task Stack)	0x200005a0	0x20000997	0x3f8 (1016 B)
7	Allocated	0x20000998	0x200009a7	0x10 (16 B)

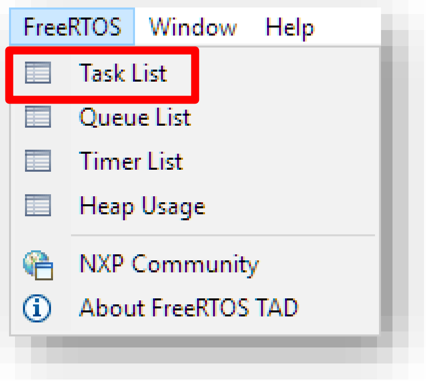
Queue List (FreeRTOS)

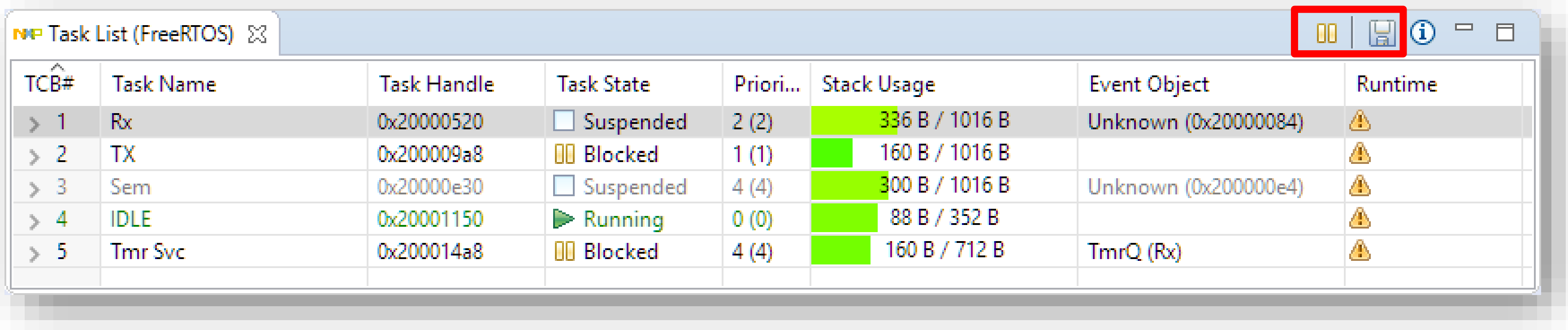
#	Queue Name	Address	Length	Item Size	# Tx Wai...	# Rx Wai...	Queue Type
1	TmrQ	0x20000ee8	0/10	0xffffffff (-1 B)	0	1	Queue
	Head:	0x20000f38					
	Tail:	0x20000fd8					
	Read from:	0x20000f38					
	Write to:	0x20000f48					

#	Address	Queue Data [DEC]	Queue Data [HEX]	Queue Data [BIN]	Queue Data [ASCII]

Task List

- Start debugging your FreeRTOS application
- Lists FreeRTOS Tasks in the System
- Menu FreeRTOS > Task List
- **Pause** Button: do not update data when target is stopped
- **Save** Button: Store information as .csv file

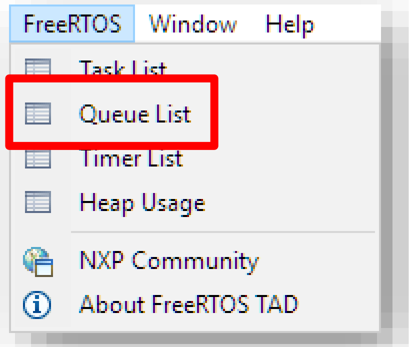


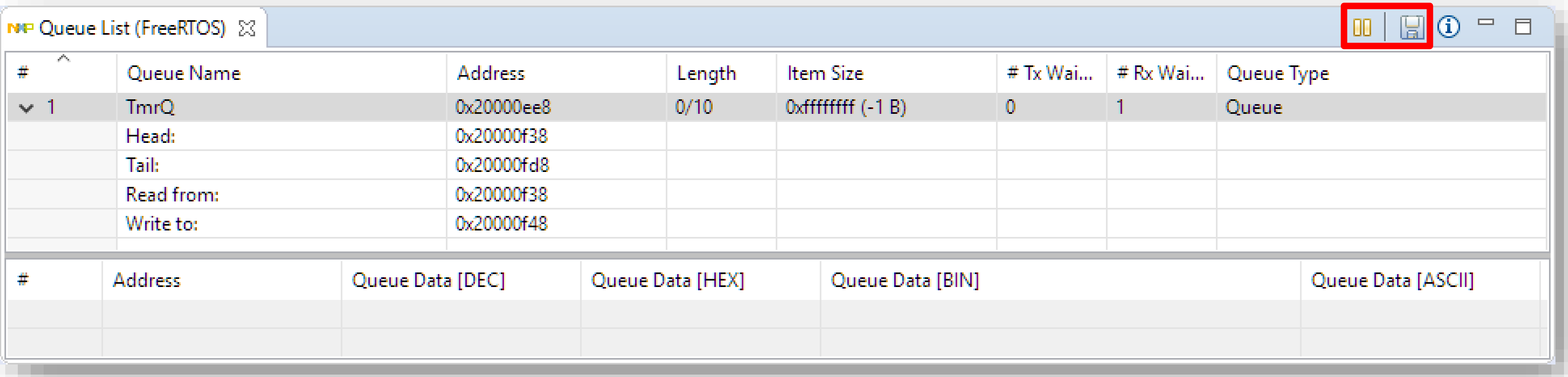


TCB#	Task Name	Task Handle	Task State	Priori...	Stack Usage	Event Object	Runtime
1	Rx	0x20000520	□ Suspended	2 (2)	336 B / 1016 B	Unknown (0x20000084)	⚠
2	TX	0x200009a8	Blocked	1 (1)	160 B / 1016 B		⚠
3	Sem	0x20000e30	□ Suspended	4 (4)	300 B / 1016 B	Unknown (0x200000e4)	⚠
4	IDLE	0x20001150	▶ Running	0 (0)	88 B / 352 B		⚠
5	Tmr Svc	0x200014a8	Blocked	4 (4)	160 B / 712 B	TmrQ (Rx)	⚠

Queue List

- Lists all FreeRTOS **Queues**
- Menu FreeRTOS > Queue List
- **Pause** Button: do not update data when target is stopped
- **Save** Button: Store information as .csv file



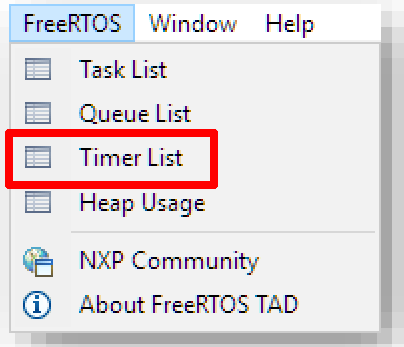


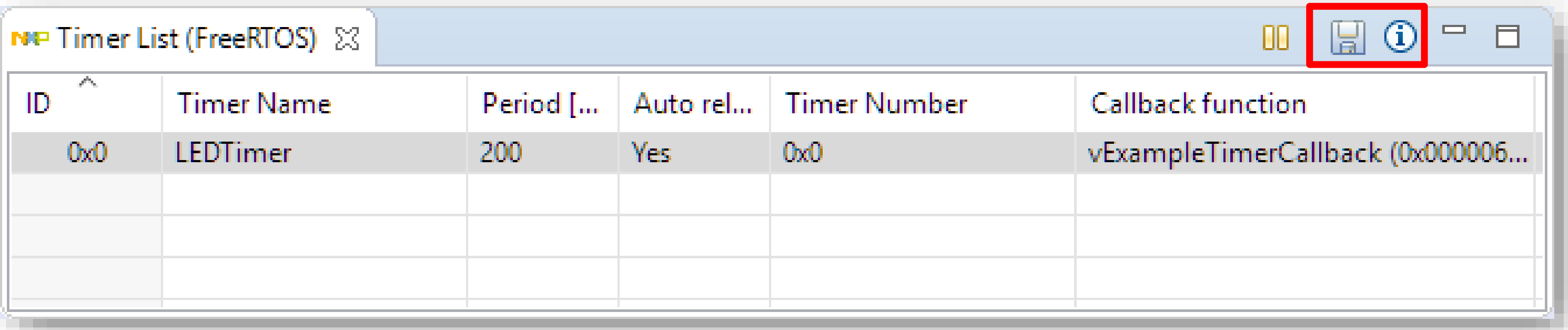
#	Queue Name	Address	Length	Item Size	# Tx Wai...	# Rx Wai...	Queue Type
1	TmrQ	0x20000ee8	0/10	0xffffffff (-1 B)	0	1	Queue
	Head:	0x20000f38					
	Tail:	0x20000fd8					
	Read from:	0x20000f38					
	Write to:	0x20000f48					

#	Address	Queue Data [DEC]	Queue Data [HEX]	Queue Data [BIN]	Queue Data [ASCII]

Queue Timer

- Lists all FreeRTOS **Software Timer**
- Menu FreeRTOS > Queue List
- **Pause** Button: do not update data when target is stopped
- **Save** Button: Store information as .csv file

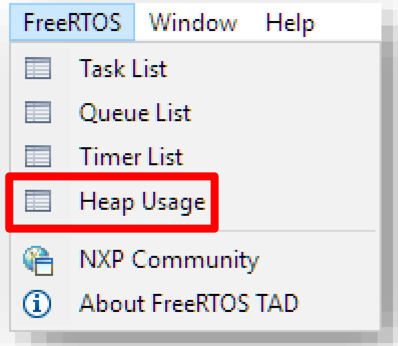


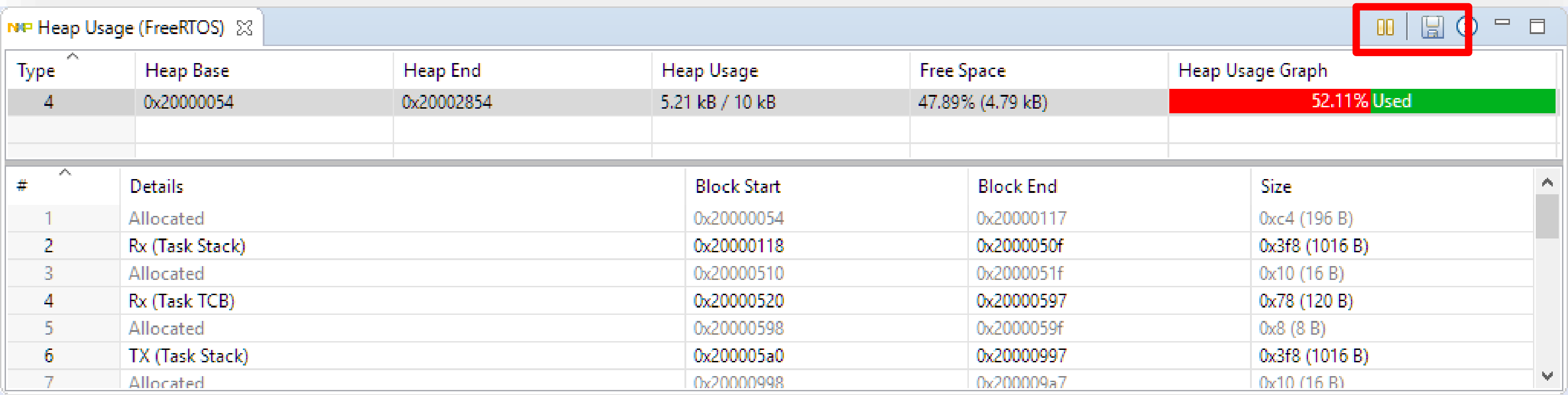


ID	Timer Name	Period [...	Auto rel...	Timer Number	Callback function
0x0	LEDTimer	200	Yes	0x0	vExampleTimerCallback (0x000006...

Heap Usage

- Status of FreeRTOS **Heap** and **Memory Allocation**
- Menu FreeRTOS > Heap Usage
- **Pause** Button: do not update data when target is stopped
- **Save** Button: Store information as .csv file





Type	Heap Base	Heap End	Heap Usage	Free Space	Heap Usage Graph
4	0x20000054	0x20002854	5.21 kB / 10 kB	47.89% (4.79 kB)	52.11% Used

#	Details	Block Start	Block End	Size
1	Allocated	0x20000054	0x20000117	0xc4 (196 B)
2	Rx (Task Stack)	0x20000118	0x2000050f	0x3f8 (1016 B)
3	Allocated	0x20000510	0x2000051f	0x10 (16 B)
4	Rx (Task TCB)	0x20000520	0x20000597	0x78 (120 B)
5	Allocated	0x20000598	0x2000059f	0x8 (8 B)
6	TX (Task Stack)	0x200005a0	0x20000997	0x3f8 (1016 B)
7	Allocated	0x20000998	0x200009a7	0x10 (16 B)

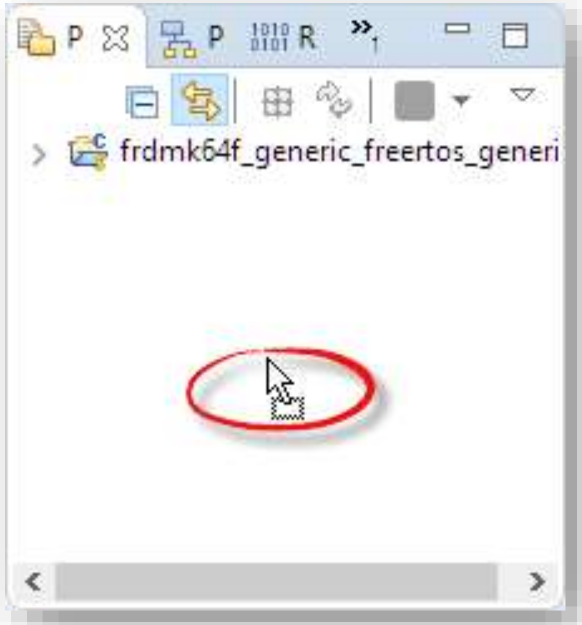
FreeRTOS Optimization

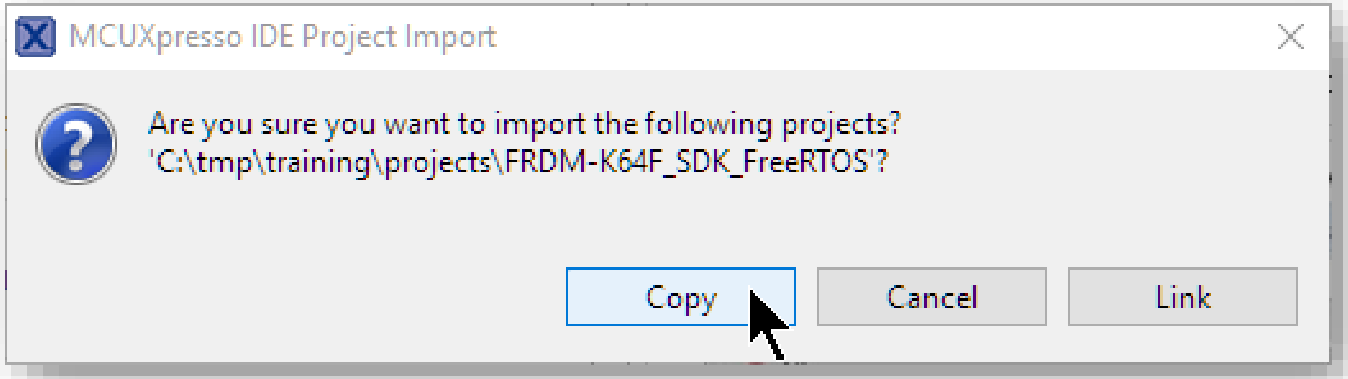
FreeRTOS Application Optimization Approach

- Static
  - FreeRTOS Configuration
    - Only enable what is necessary
  - Compiler/Linker
    - Enable higher level of optimizations (-O3, -flto)
    - Use optimized libraries (no semihosting/no-host, RedLib, newlib-nano)
- Dynamic
  - FreeRTOS Runtime Statistics
  - Segger SystemView
  - *Percepio Tracealyzer* ***(not covered in this lab, see backup slides)***

FRDM-K64F_SDK_FreeRTOS

- Import ‘**FRDM-K64F_SDK_FreeRTOS**’ project
  - Drag Folder into ‘Project Explorer’ view
  - Drage into ‘empty’ space on bottom of view
  - Use ‘Copy’
- Project uses FreeRTOS features with SEGGER RTT/SystemView

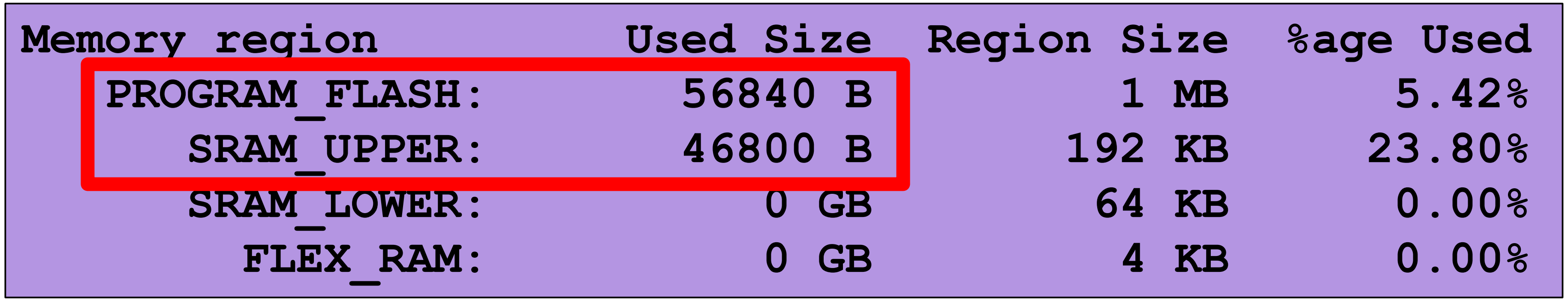



MCUXpresso IDE Project Import

Are you sure you want to import the following projects?
'C:\tmp\training\projects\FRDM-K64F_SDK_FreeRTOS'?

Base Code and Data Size

- Build Project
- Inspect Console view
- Note the initial code and data size needed

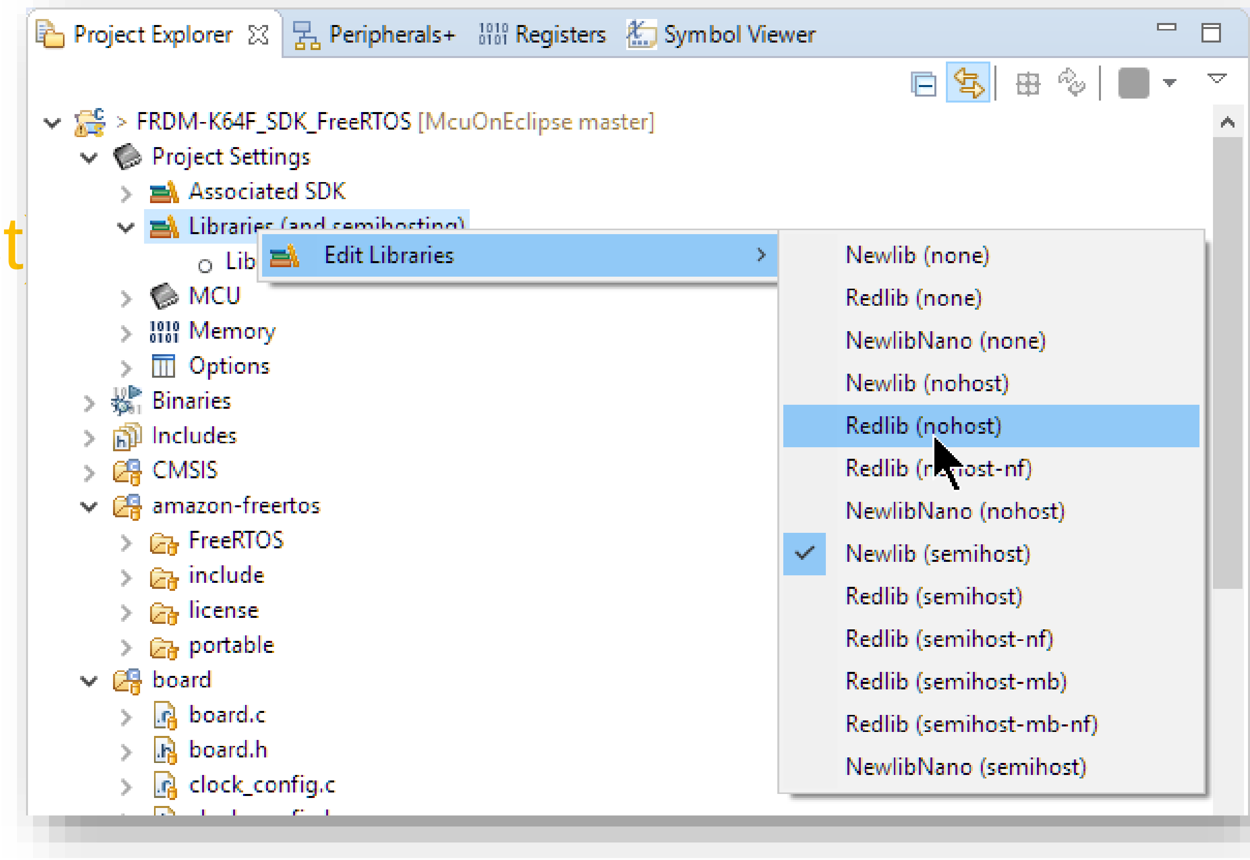


```
Memory region         Used Size  Region Size  %age Used
   PROGRAM_FLASH:        56840 B         1 MB      5.42%
      SRAM_UPPER:        46800 B       192 KB     23.80%
      SRAM_LOWER:           0 GB        64 KB      0.00%
        FLEX_RAM:           0 GB         4 KB      0.00%
```

Note your sizes

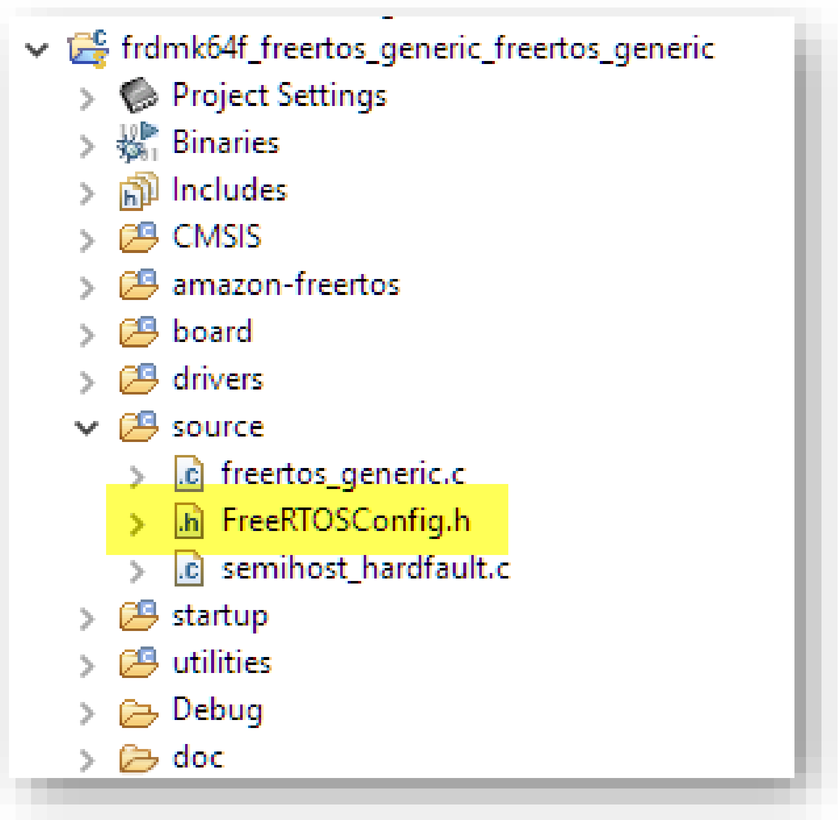
Libraries and Printf()/semihosting

- Avoid semihosting/printf (➔ nohost)
- Use smaller library ➔ newlib-nano ➔ RedLib (nohost
  - ‘nohost’ maps printf to empty functions
- Rebuild
- Check code size impact



FreeRTOS Configuration File

- **FreeRTOSConfig.h**
- Header file configuring the RTOS
  - Features
  - API functionality
  - Diagnostics
  - Performance analysis
  - Hardware configuration and interrupts



- *Recommendation*
  - *Only enable what is needed!*
  - *Requires knowledge of application and RTOS functionality (will cover in next sections)*

Assertions

```
#define configASSERT(x) if((x) == 0) \
        {taskDISABLE_INTERRUPTS(); for (;;);}
```

TODO 01

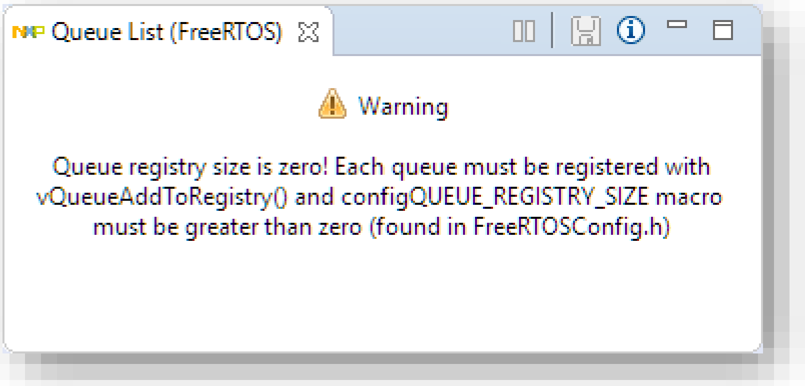
- *Recommendation*
  - *Turn on during development*
  - *Disable for ‘release’ version (define as ‘empty’)*
  - *Impact: reduced code size*
- Rebuild
- Check code size impact

Queue Registry

```
#define configQUEUE_REGISTRY_SIZE                   0
```

- Registry to store names for queues, semaphore and mutex
- *Recommendation*
  - *As small as possible, or 0 to disable*
  - *Impact: reduced RAM size, reduced code size, no names for queues/semaphore/mutex*
- Set queue registry size to 2 (better 3) and verify in the debugger

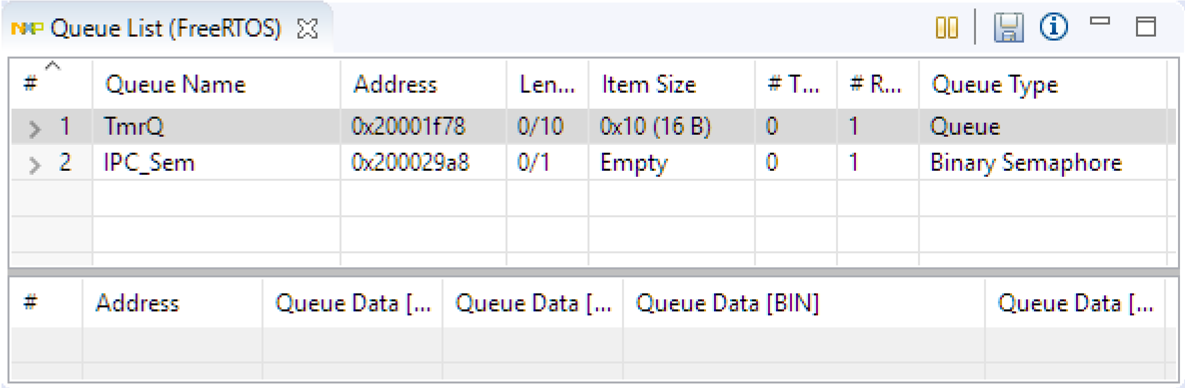
TODO 02



Queue List (FreeRTOS)

⚠ Warning

Queue registry size is zero! Each queue must be registered with vQueueAddToRegistry() and configQUEUE_REGISTRY_SIZE macro must be greater than zero (found in FreeRTOSConfig.h)



Queue List (FreeRTOS)

#	Queue Name	Address	Len...	Item Size	# T...	# R...	Queue Type
1	TmrQ	0x20001f78	0/10	0x10 (16 B)	0	1	Queue
2	IPC_Sem	0x200029a8	0/1	Empty	0	1	Binary Semaphore

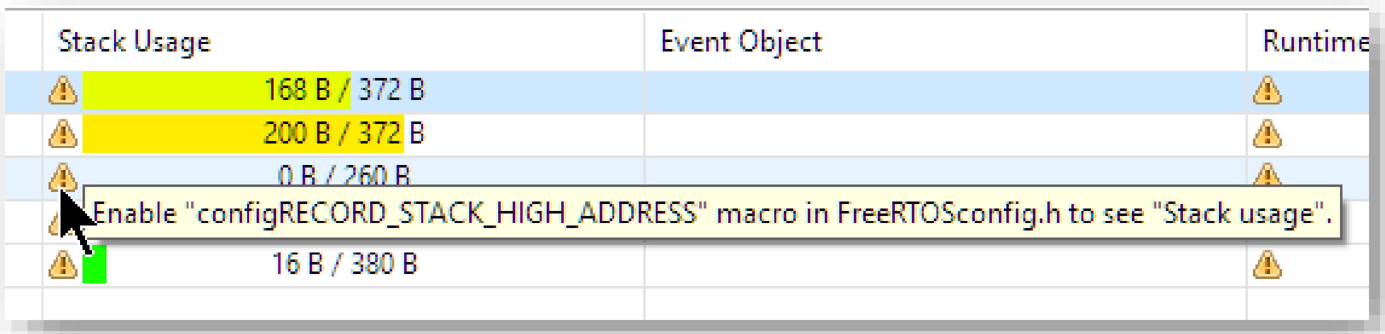
#	Address	Queue Data [...	Queue Data [...	Queue Data [BIN]	Queue Data [...

Stack High Address

```
#define configRECORD_STACK_HIGH_ADDRESS      0
```

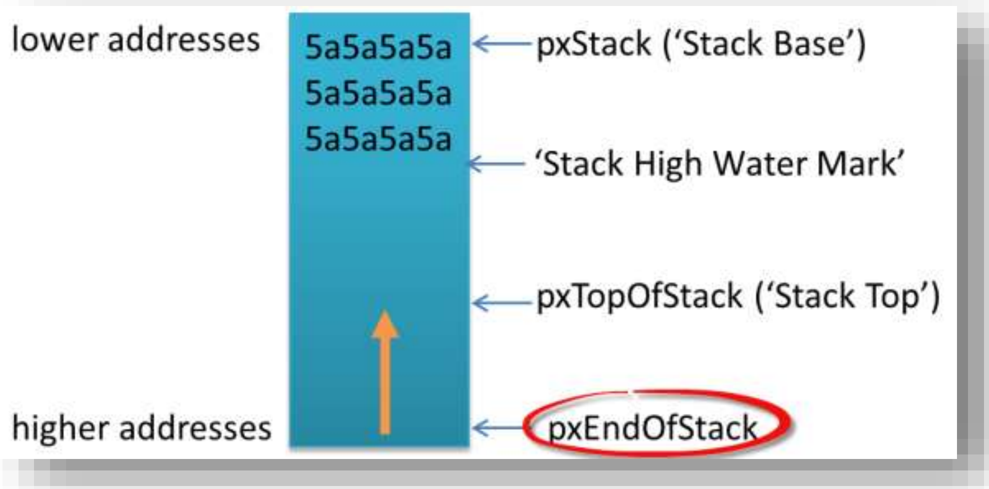
- Stores stack end address in task control block (TCB)
- *Recommendation*
  - *Enable for debugging, disable for release*
  - *Impact: better stack size debugging, less RAM usage*
  - Details see [this article]()
- Enable recording of stack end address

TODO 03



Stack Usage	Event Object	Runtime
⚠ 168 B / 372 B		⚠
⚠ 200 B / 372 B		⚠
⚠ 0 B / 260 B		⚠
⚠		
⚠ 16 B / 380 B		⚠

Enable "configRECORD_STACK_HIGH_ADDRESS" macro in FreeRTOSconfig.h to see "Stack usage".

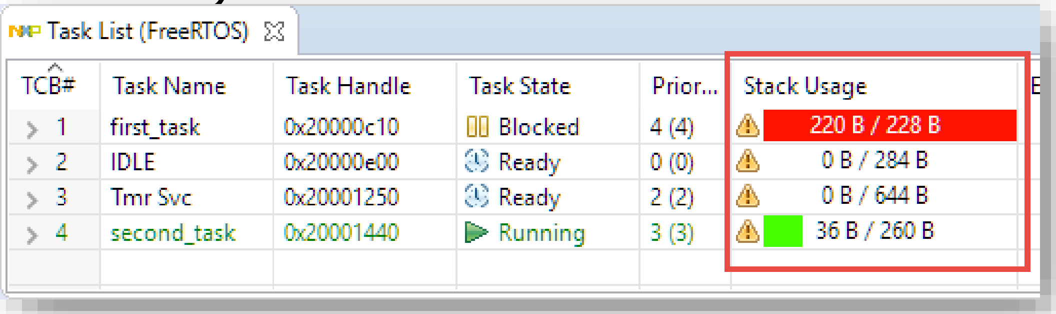


Task Stack Size

```
#define configMINIMAL_STACK_SIZE        ((unsigned short)200)
```

- Stack units on ARM: 32bits!
  - Used by IDLE task, dedicated macro for timer task
  - Often used for task stacks

- *Recommendation*
  - *Use* ***`configMINIMAL_STACK_SIZE`*** *for IDLE task only*
  - *Timer Task: use dedicated size*
  - *Value as small as possible (use Stack Usage)*
  - *Impact: reduced RAM and Heap*

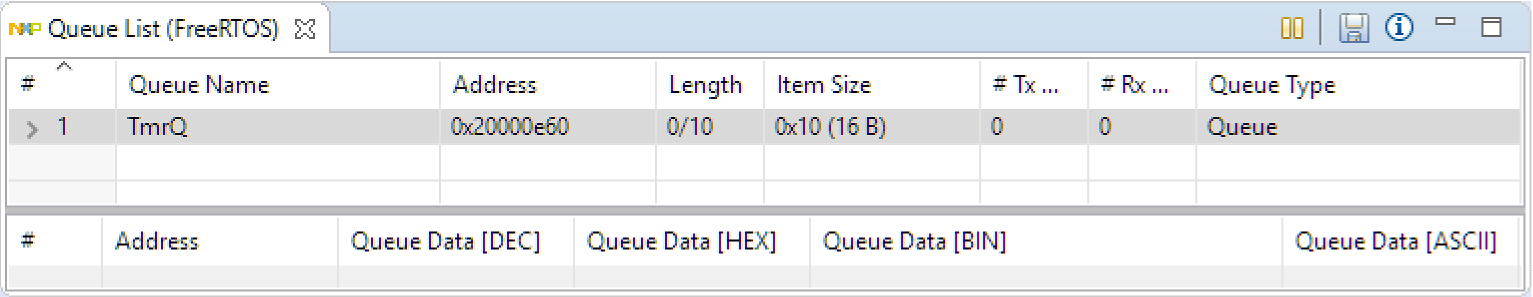


TCB#	Task Name	Task Handle	Task State	Prior...	Stack Usage
1	first_task	0x20000c10	Blocked	4 (4)	⚠ 220 B / 228 B
2	IDLE	0x20000e00	Ready	0 (0)	⚠ 0 B / 284 B
3	Tmr Svc	0x20001250	Ready	2 (2)	⚠ 0 B / 644 B
4	second_task	0x20001440	Running	3 (3)	⚠ 🟩 36 B / 260 B

RTOS Timers

```
#define configUSE_TIMERS                1
#define configTIMER_TASK_PRIORITY       2
#define configTIMER_QUEUE_LENGTH       10
#define configTIMER_TASK_STACK_DEPTH  (configMINIMAL_STACK_SIZE * 2)
```

- Software timer, implemented with Daemon task and message queue
- *Recommendation*
  - *Disable if not used, or use values as small as possible*
  - *Use FreeRTOS timers for low power applications instead of HW timers*
  - *Use reduced command queue length*
  - *Impact: reduced RAM size, reduced code size*



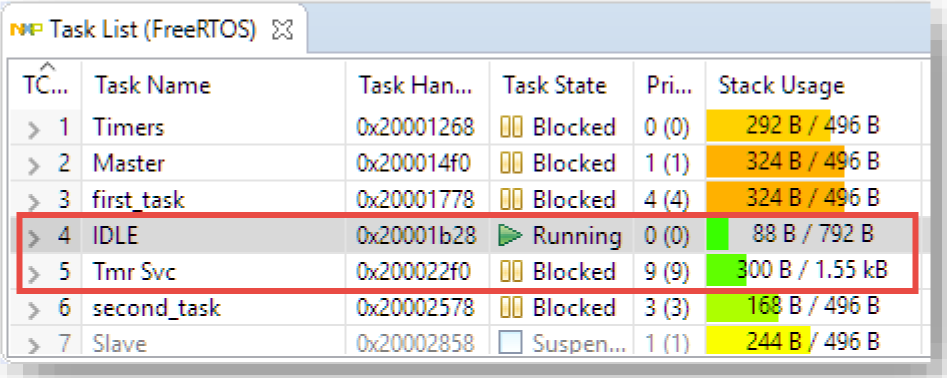
#	Queue Name	Address	Length	Item Size	# Tx ...	# Rx ...	Queue Type
1	TmrQ	0x20000e60	0/10	0x10 (16 B)	0	0	Queue

#	Address	Queue Data [DEC]	Queue Data [HEX]	Queue Data [BIN]	Queue Data [ASCII]

Timer and IDLE Stack Size

TODO 04
TODO 05
TODO 06

- Check current stack usage
- Reduce stack size needed for IDLE task
  - Hint: Number is for 32bit entities
- Reduce stack size needed for TmrSvc task
  - Hint: Should be more than for IDLE task
  - Hint: queue operations
- Reduce Timer Queue Length
  - Hint: number of timer commands (3 should be ok)



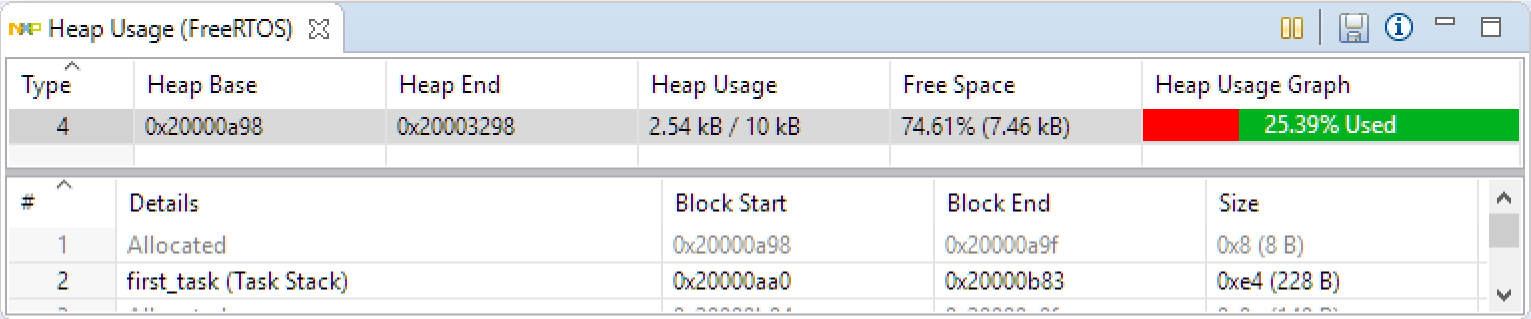
Task List (FreeRTOS)

TC...	Task Name	Task Han...	Task State	Pri...	Stack Usage
1	Timers	0x20001268	Blocked	0 (0)	292 B / 496 B
2	Master	0x200014f0	Blocked	1 (1)	324 B / 496 B
3	first_task	0x20001778	Blocked	4 (4)	324 B / 496 B
4	IDLE	0x20001b28	Running	0 (0)	88 B / 792 B
5	Tmr Svc	0x200022f0	Blocked	9 (9)	300 B / 1.55 kB
6	second_task	0x20002578	Blocked	3 (3)	168 B / 496 B
7	Slave	0x20002858	Suspen...	1 (1)	244 B / 496 B

Heap Scheme

```
#define configFRTOS_MEMORY_SCHEME                        4
```

- 1: allocate only, 2: no block merge, 3: malloc()/free(), 4: merges blocks, 5: multiple memory areas
- *Recommendation*
  - *Use scheme 1, 3 if middleware uses malloc()/free(), otherwise 4*
  - *Use static allocation* (configSUPPORT_STATIC_ALLOCATIO 1) *with no dynamic allocation* (configSUPPORT_DYNAMIC_ALLOCATION 0)
  - *Impact: reduced RAM size, reduced code size*



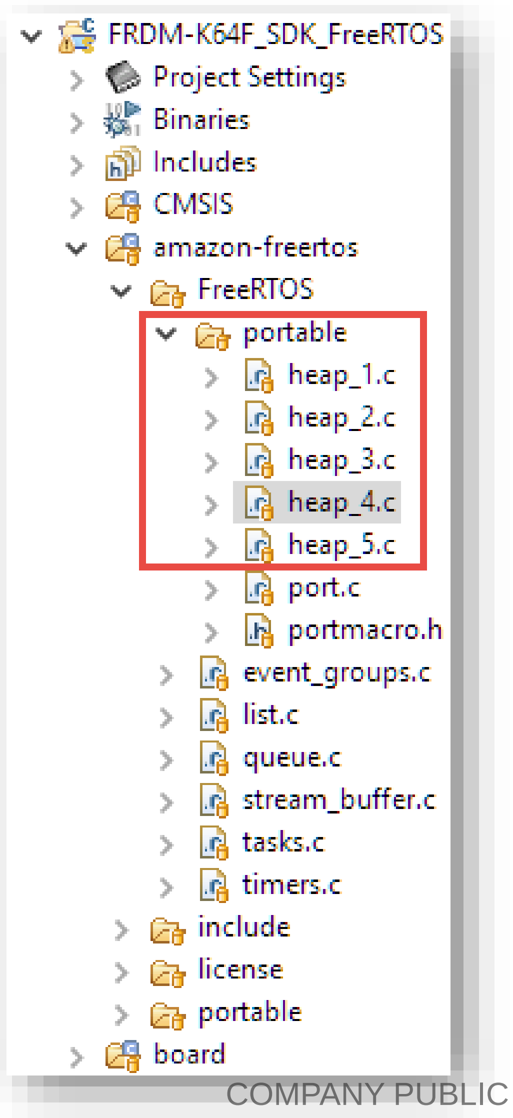
Type	Heap Base	Heap End	Heap Usage	Free Space	Heap Usage Graph
4	0x20000a98	0x20003298	2.54 kB / 10 kB	74.61% (7.46 kB)	25.39% Used

#	Details	Block Start	Block End	Size
1	Allocated	0x20000a98	0x20000a9f	0x8 (8 B)
2	first_task (Task Stack)	0x20000aa0	0x20000b83	0xe4 (228 B)

Heap Scheme

TODO 07

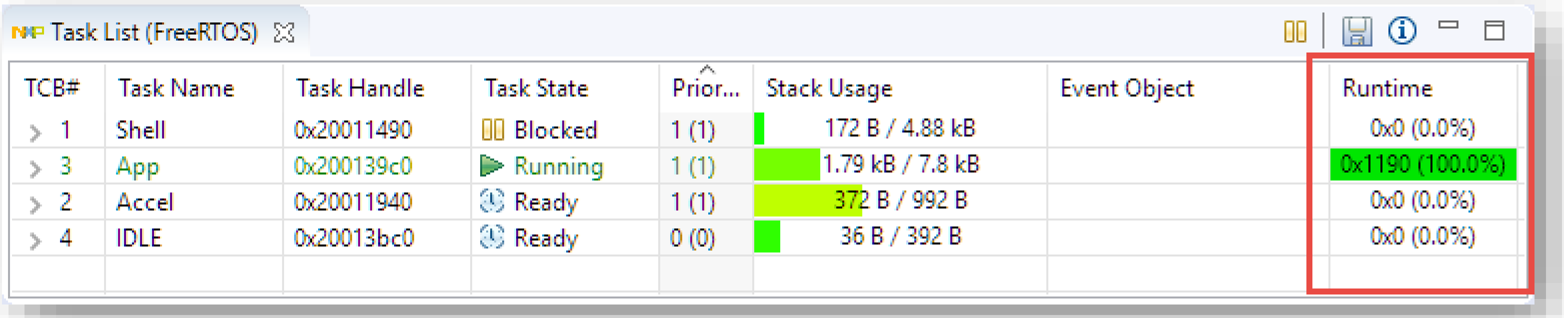
- Change **`configFRTOS_MEMORY_SCHEME`** to 1 (alloc only)
- Build
- Observe code/data size change
- Note
  - macro selects which heap file is used (heap_1.c, ... heap_5.c)



Runtime Statistics

```
#define configGENERATE_RUN_TIME_STATS          0
#define configUSE_TRACE_FACILITY               1
#define configUSE_STATS_FORMATTING_FUNCTIONS   0
```

- Collects runtime statistics
- *Recommendation*
  - *Turn off for release*
  - *Impact: reduced RAM size, reduced code size, improved performance, no statistics*



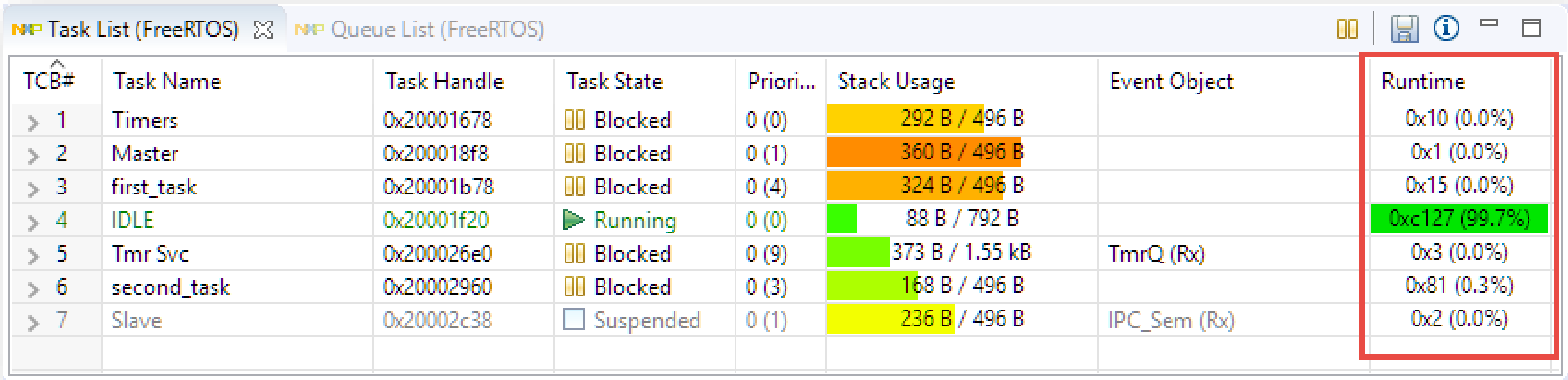
Task List (FreeRTOS)

TCB#	Task Name	Task Handle	Task State	Prior...	Stack Usage	Event Object	Runtime
1	Shell	0x20011490	Blocked	1 (1)	172 B / 4.88 kB		0x0 (0.0%)
3	App	0x200139c0	Running	1 (1)	1.79 kB / 7.8 kB		0x1190 (100.0%)
2	Accel	0x20011940	Ready	1 (1)	372 B / 992 B		0x0 (0.0%)
4	IDLE	0x20013bc0	Ready	0 (0)	36 B / 392 B		0x0 (0.0%)

Task Runtime

TODO 08

- Enable configGENERATE_RUN_TIME_STATS
  - Application has setup a 0.1 ms timer to measure task execution time
- Build and Debug
- Can you spot (and fix) a performance problem in your application?
  - Hint: Press SW3 and keep it pressed



TCB#	Task Name	Task Handle	Task State	Priori...	Stack Usage	Event Object	Runtime
1	Timers	0x20001678	Blocked	0 (0)	292 B / 496 B		0x10 (0.0%)
2	Master	0x200018f8	Blocked	0 (1)	360 B / 496 B		0x1 (0.0%)
3	first_task	0x20001b78	Blocked	0 (4)	324 B / 496 B		0x15 (0.0%)
4	IDLE	0x20001f20	Running	0 (0)	88 B / 792 B		0xc127 (99.7%)
5	Tmr Svc	0x200026e0	Blocked	0 (9)	373 B / 1.55 kB	TmrQ (Rx)	0x3 (0.0%)
6	second_task	0x20002960	Blocked	0 (3)	168 B / 496 B		0x81 (0.3%)
7	Slave	0x20002c38	Suspended	0 (1)	236 B / 496 B	IPC_Sem (Rx)	0x2 (0.0%)

FreeRTOS with SystemView

FreeRTOS Trace Hooks

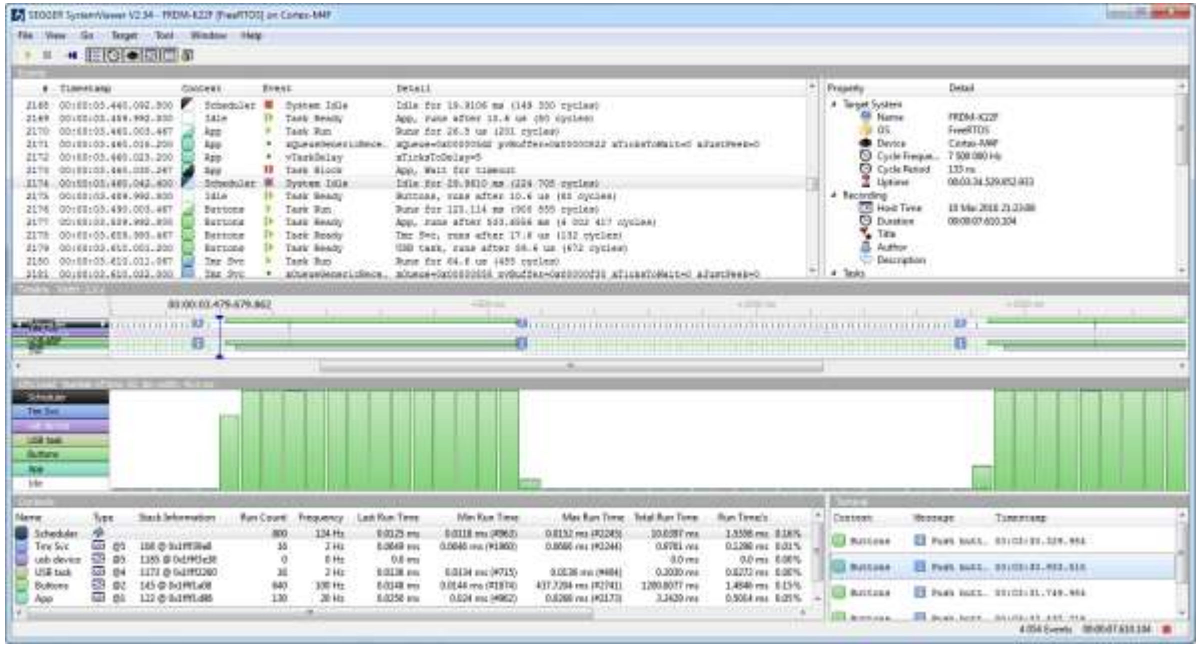
```
#ifndef traceTASK_SWITCHED_OUT
  /* Called before a task has been selected to run.  pxCurrentTCB holds a pointer
  to the task control block of the task being switched out. */
  #define traceTASK_SWITCHED_OUT()
#endif
```

- Instruments Kernel with additional trace hooks
- Macros provided by user or trace library
  - Percepio Tracalyzer
  - Segger SystemView

- *Recommendation*
  - *Disable for release version, use for application tuning and debugging*
  - *Impact: improved application performance*

Segger SystemView

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


SEGGER SystemViewer V2.34 - FRDM-K22F (FreeRTOS) on Cortex-M4F
File View Go Target Tool Window Help
00:00:03.479.479.862
Scheduler
Tmr Svc
usb device
USB task
Buttons
App
Idle

#	Timestamp	Context	Event	Detail
2168	00:00:03.440.092.300	Scheduler	System Idle	Idle for 19.9106 ms (149 330 cycles)
2169	00:00:03.459.992.300	Idle	Task Ready	App, runs after 10.6 us (80 cycles)
2170	00:00:03.460.003.467	App	Task Run	Runs for 26.5 us (201 cycles)
2171	00:00:03.460.016.200	App	xQueueGenericRece...	xQueue=0x[illegible] pvBuffer=0x[illegible] xTicksToWait=0 xJustPeek=0
2172	00:00:03.460.023.200	App	vTaskDelay	xTicksToDelay=5
2173	00:00:03.460.030.267	App	Task Block	App, Wait for timeout
2174	00:00:03.460.042.400	Scheduler	System Idle	Idle for 29.9610 ms (224 708 cycles)
2175	00:00:03.489.990.300	Idle	Task Ready	Buttons, runs after 10.6 us (80 cycles)
2176	00:00:03.490.003.467	Buttons	Task Run	Runs for 121.114 ms (908 855 cycles)
2177	00:00:03.[illegible]	Buttons	Task Ready	App, runs after 533.4666 ms (4 002 417 cycles)
2178	00:00:03.[illegible]	Buttons	Task Ready	Tmr Svc, runs after 17.6 us (132 cycles)
2179	00:00:03.[illegible]	Buttons	Task Ready	USB task, runs after 89.6 us (672 cycles)
2180	00:00:03.[illegible]	Tmr Svc	Task Run	Runs for 64.6 us (485 cycles)
2181	00:00:03.[illegible]	Tmr Svc	xQueueGenericRece...	xQueue=0x[illegible] pvBuffer=0x[illegible] xTicksToWait=0 xJustPeek=0

Property	Detail
Target System	
Name	FRDM-K22F
OS	FreeRTOS
Device	Cortex-M4F
Cycle Freque...	7 500 000 Hz
Cycle Period	133 ns
Uptime	00:03:34.529.852.933
Recording	
Host Time	18 Mar 2016 21:23:08
Duration	00:00:07.610.204
Title	
Author	
Description	
Tasks	

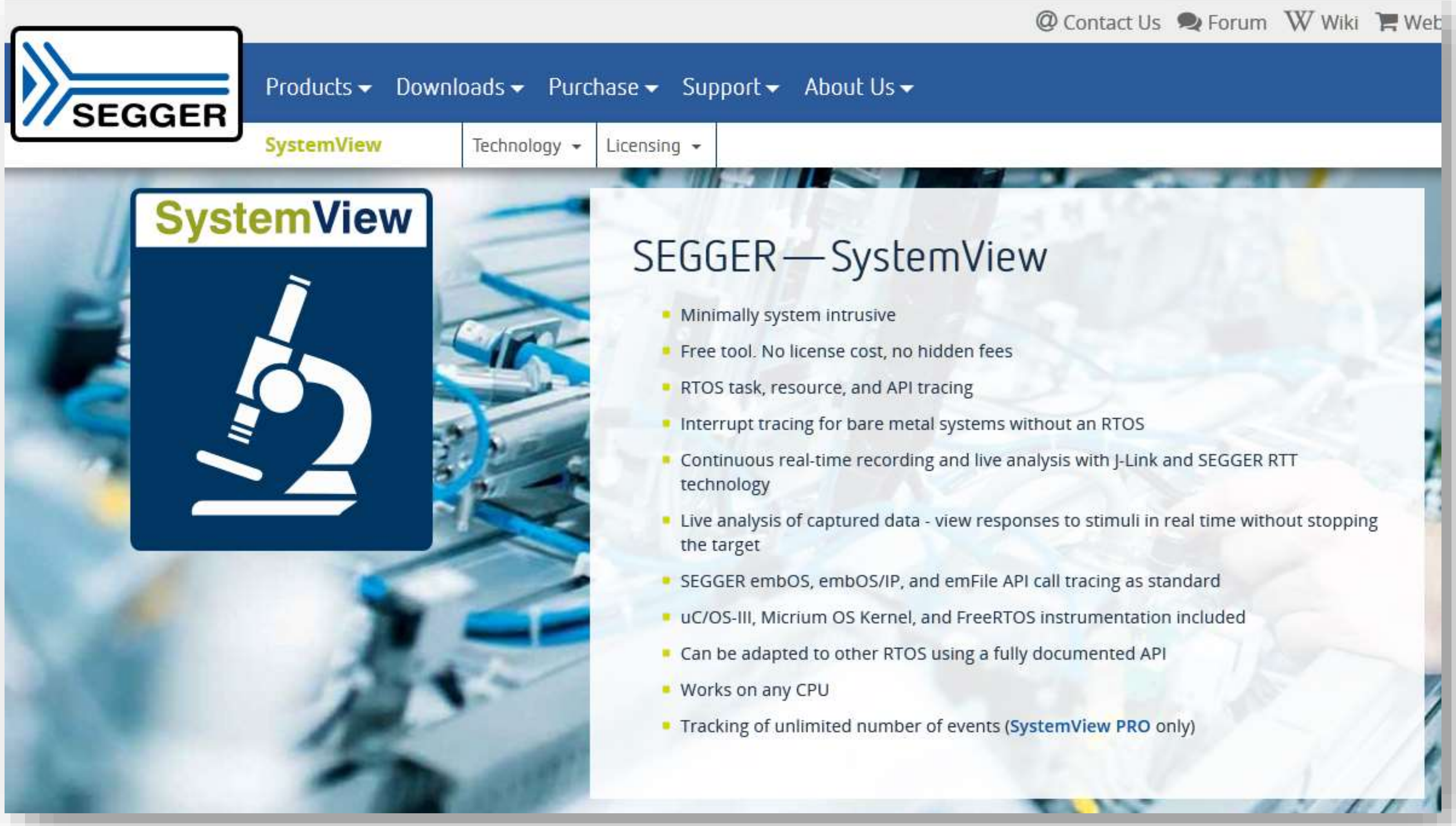
Name	Type	Stack Information	Run Count	Frequency	Last Run Time	Min Run Time	Max Run Time	Total Run Time	Run Time %
Scheduler			800	124 Hz	0.0125 ms	0.0118 ms (#963)	0.0152 ms (#2245)	10.0087 ms	1.3398 ms 0.18%
Tmr Svc	@5	168 @ 0x1fff[illegible]	16	2 Hz	0.0649 ms	0.0646 ms (#1860)	0.0666 ms (#2244)	0.9781 ms	0.1286 ms 0.01%
usb device	@5	1185 @ 0x1fff[illegible]	0	0 Hz	0.0 ms			0.0 ms	0.0 ms 0.00%
USB task	@4	1173 @ 0x1fff[illegible]	16	2 Hz	0.0138 ms	0.0134 ms (#715)	0.0136 ms (#484)	0.2030 ms	0.0272 ms 0.00%
Buttons	@2	145 @ 0x1fff[illegible]	840	100 Hz	0.0148 ms	0.0144 ms (#1874)	437.7204 ms (#2741)	1200.8077 ms	1.4946 ms 0.15%
App	@1	122 @ 0x1fff[illegible]	130	20 Hz	0.0256 ms	0.024 ms (#962)	0.0266 ms (#2173)	3.2420 ms	0.5064 ms 0.05%

Context	Message	Timestamp
Buttons	Push butt...	00:03:[illegible]
Buttons	Push butt...	00:03:[illegible]
Buttons	Push butt...	00:03:[illegible]
Buttons	Push butt...	00:03:[illegible]

4 054 Events 00:00:07.610.104

Segger SystemView

- https://www.segger.com/jlink-software.html
- https://www.segger.com/systemview.html

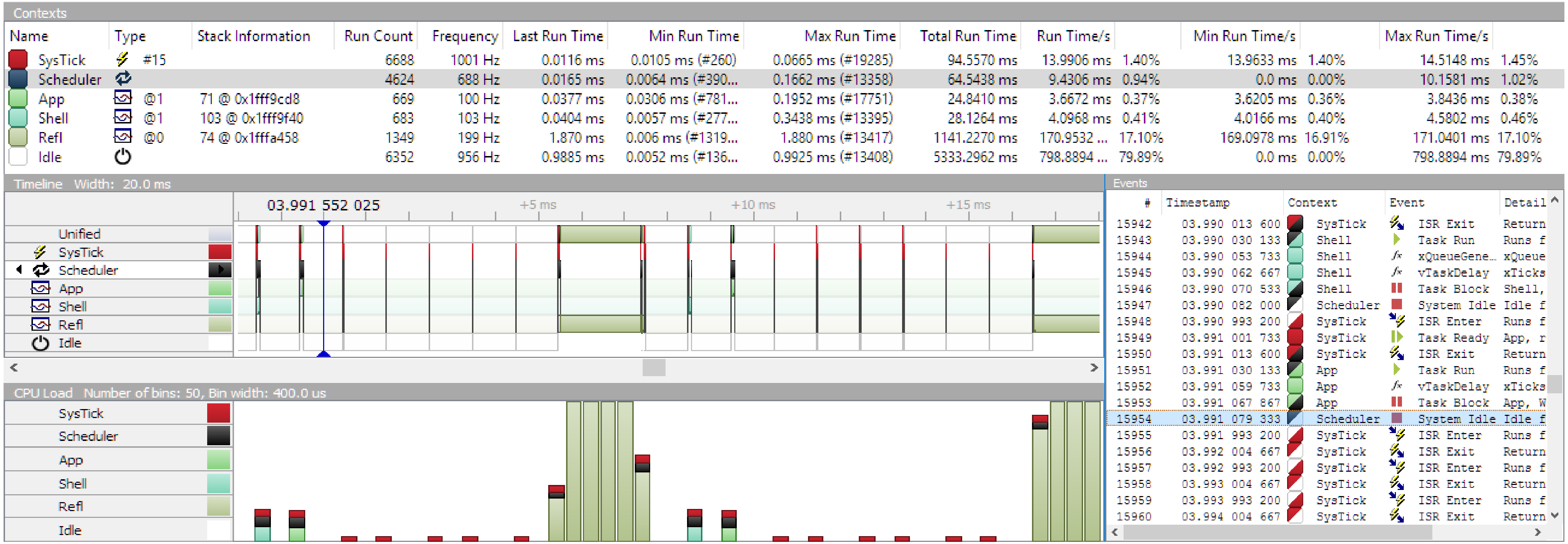


SEGGER — SystemView

- Minimally system intrusive
- Free tool. No license cost, no hidden fees
- RTOS task, resource, and API tracing
- Interrupt tracing for bare metal systems without an RTOS
- Continuous real-time recording and live analysis with J-Link and SEGGER RTT technology
- Live analysis of captured data - view responses to stimuli in real time without stopping the target
- SEGGER embOS, embOS/IP, and emFile API call tracing as standard
- uC/OS-III, Micrium OS Kernel, and FreeRTOS instrumentation included
- Can be adapted to other RTOS using a fully documented API
- Works on any CPU
- Tracking of unlimited number of events (SystemView PRO only)

SEGGER SystemView

- Install SystemView
  - SEGGER\Setup_SystemView_V240.exe



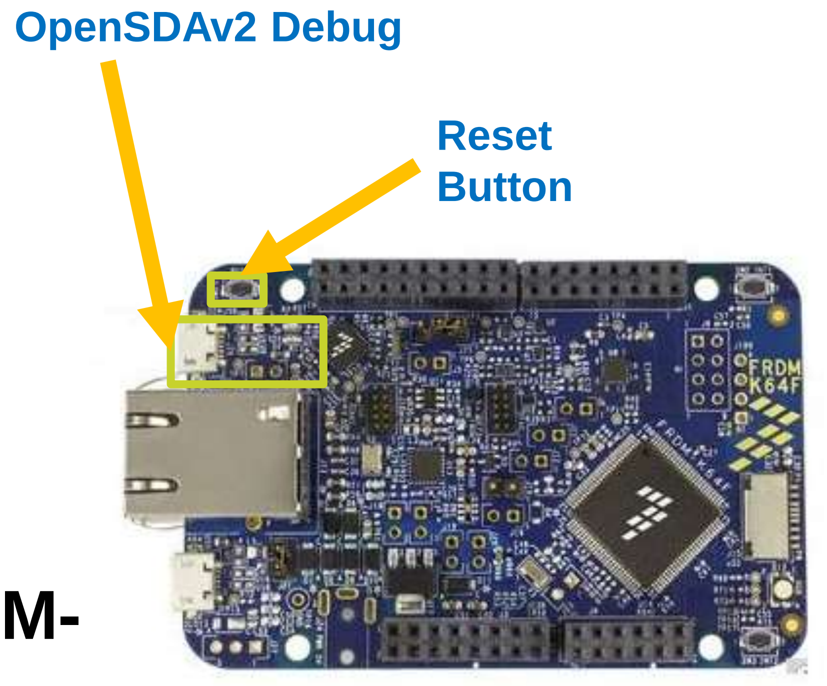
Name	Type		Stack Information	Run Count	Frequency	Last Run Time	Min Run Time	Max Run Time	Total Run Time	Run Time/s		Min Run Time/s		Max Run Time/s	
🟥 SysTick	⚡	#15		6688	1001 Hz	0.0116 ms	0.0105 ms (#260)	0.0665 ms (#19285)	94.5570 ms	13.9906 ms	1.40%	13.9633 ms	1.40%	14.5148 ms	1.45%
■ Scheduler				4624	688 Hz	0.0165 ms	0.0064 ms (#390...	0.1662 ms (#13358)	64.5438 ms	9.4306 ms	0.94%	0.0 ms	0.00%	10.1581 ms	1.02%
🟩 App		@1	71 @ 0x1fff9cd8	669	100 Hz	0.0377 ms	0.0306 ms (#781...	0.1952 ms (#17751)	24.8410 ms	3.6672 ms	0.37%	3.6205 ms	0.36%	3.8436 ms	0.38%
🟩 Shell		@1	103 @ 0x1fff9f40	683	103 Hz	0.0404 ms	0.0057 ms (#277...	0.3438 ms (#13395)	28.1264 ms	4.0968 ms	0.41%	4.0166 ms	0.40%	4.5802 ms	0.46%
🟩 Refl		@0	74 @ 0x1fffa458	1349	199 Hz	1.870 ms	0.006 ms (#1319...	1.880 ms (#13417)	1141.2270 ms	170.9532 ...	17.10%	169.0978 ms	16.91%	171.0401 ms	17.10%
□ Idle	⏻			6352	956 Hz	0.9885 ms	0.0052 ms (#136...	0.9925 ms (#13408)	5333.2962 ms	798.8894 ...	79.89%	0.0 ms	0.00%	798.8894 ms	79.89%

Events

#	Timestamp	Context	Event	Detail
15942	03.990 013 600	SysTick	ISR Exit	Return
15943	03.990 030 133	Shell	Task Run	Runs f
15944	03.990 053 733	Shell	xQueueGene...	xQueue
15945	03.990 062 667	Shell	vTaskDelay	xTicks
15946	03.990 070 533	Shell	Task Block	Shell,
15947	03.990 082 000	Scheduler	System Idle	Idle f
15948	03.990 993 200	SysTick	ISR Enter	Runs f
15949	03.991 001 733	SysTick	Task Ready	App, r
15950	03.991 013 600	SysTick	ISR Exit	Return
15951	03.991 030 133	App	Task Run	Runs f
15952	03.991 059 733	App	vTaskDelay	xTicks
15953	03.991 067 867	App	Task Block	App, W
15954	03.991 079 333	Scheduler	System Idle	Idle f
15955	03.991 993 200	SysTick	ISR Enter	Runs f
15956	03.992 004 667	SysTick	ISR Exit	Return
15957	03.992 993 200	SysTick	ISR Enter	Runs f
15958	03.993 004 667	SysTick	ISR Exit	Return
15959	03.993 993 200	SysTick	ISR Enter	Runs f
15960	03.994 004 667	SysTick	ISR Exit	Return

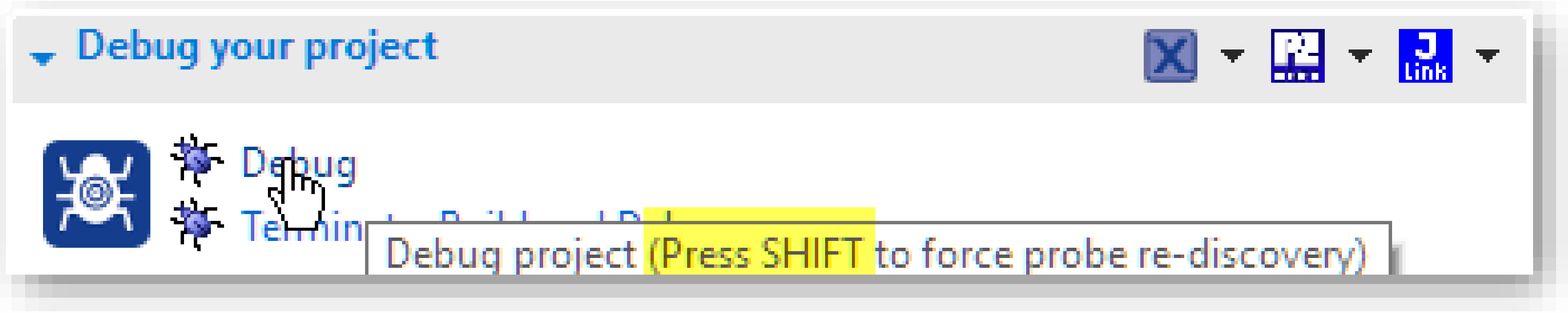
OpenSDA with Segger J-Link Firmware

- SystemView uses SEGGER RTT
  - Install SEGGER OpenSDA firmware on board
- Press (and hold) Reset Button
- Power board with OpenSDAv2 Debug USB connector
- Board enumerates as MAINTENANCE drive
- Copy **OpenSDA\SEGGER_02_OpenSDA_FRDM-K64F.bin** to drive
- Unplug USB cable
- Power/plug the USB cable



Force Probe Re-Discovery

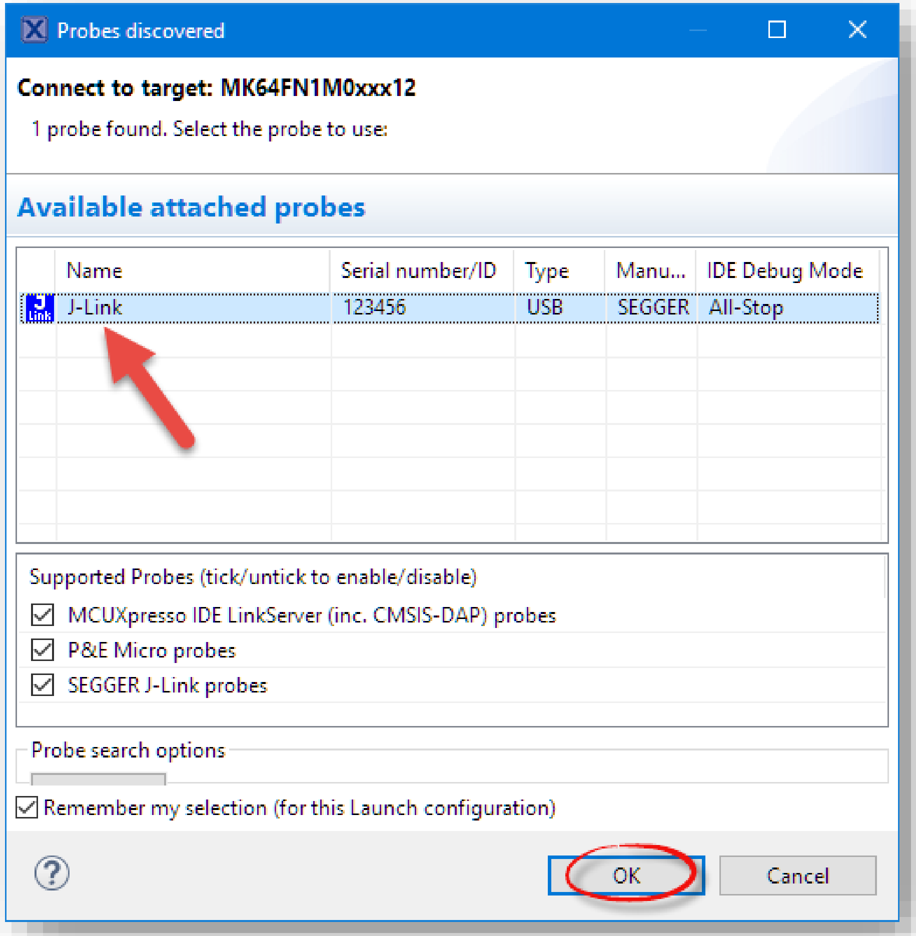
- To debug board with different probe connection ➔ force re-discovery
- Press SHIFT while using Quickstart Debug icon



Debug project (Press SHIFT to force probe re-discovery)

J-Link Probe Discovery

- Discovers attached debug probes
- Accept Terms of use (check for only once a day)



Probes discovered

Connect to target: MK64FN1M0xxx12

1 probe found. Select the probe to use:

Available attached probes

Name	Serial number/ID	Type	Manu...	IDE Debug Mode
J-Link	123456	USB	SEGGER	All-Stop

Supported Probes (tick/untick to enable/disable)

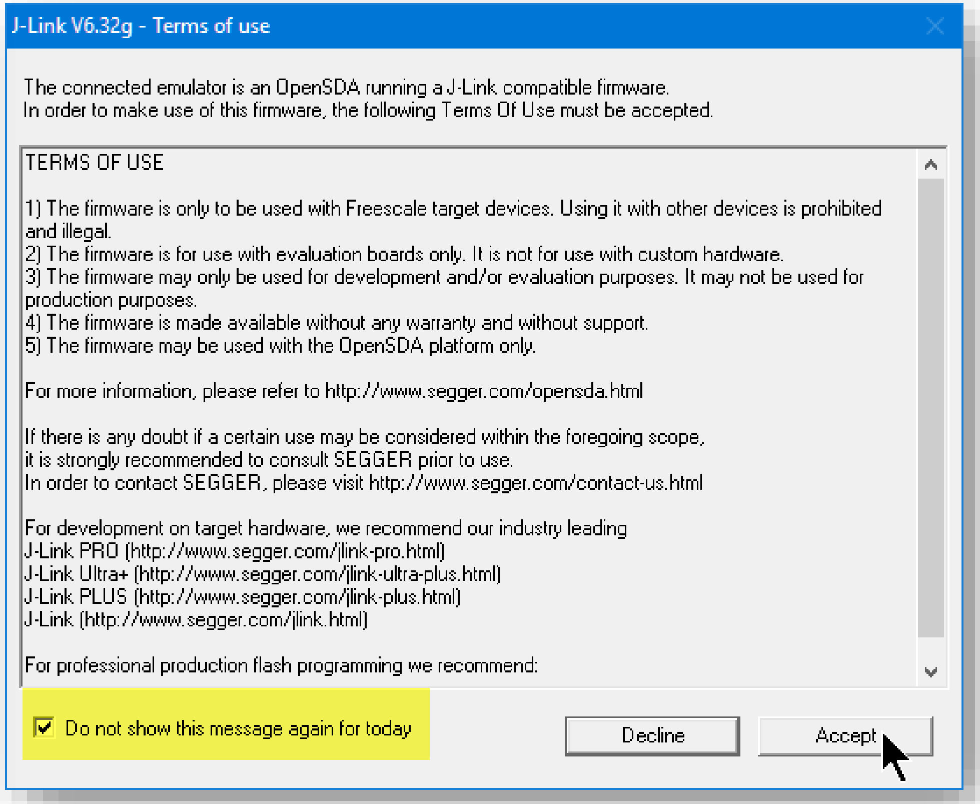
☑ MCUXpresso IDE LinkServer (inc. CMSIS-DAP) probes

☑ P&E Micro probes

☑ SEGGER J-Link probes

Probe search options

☑ Remember my selection (for this Launch configuration)



J-Link V6.32g - Terms of use

The connected emulator is an OpenSDA running a J-Link compatible firmware.
In order to make use of this firmware, the following Terms Of Use must be accepted.

TERMS OF USE

1) The firmware is only to be used with Freescale target devices. Using it with other devices is prohibited and illegal.
2) The firmware is for use with evaluation boards only. It is not for use with custom hardware.
3) The firmware may only be used for development and/or evaluation purposes. It may not be used for production purposes.
4) The firmware is made available without any warranty and without support.
5) The firmware may be used with the OpenSDA platform only.

For more information, please refer to http://www.segger.com/opensda.html

If there is any doubt if a certain use may be considered within the foregoing scope,
it is strongly recommended to consult SEGGER prior to use.
In order to contact SEGGER, please visit http://www.segger.com/contact-us.html

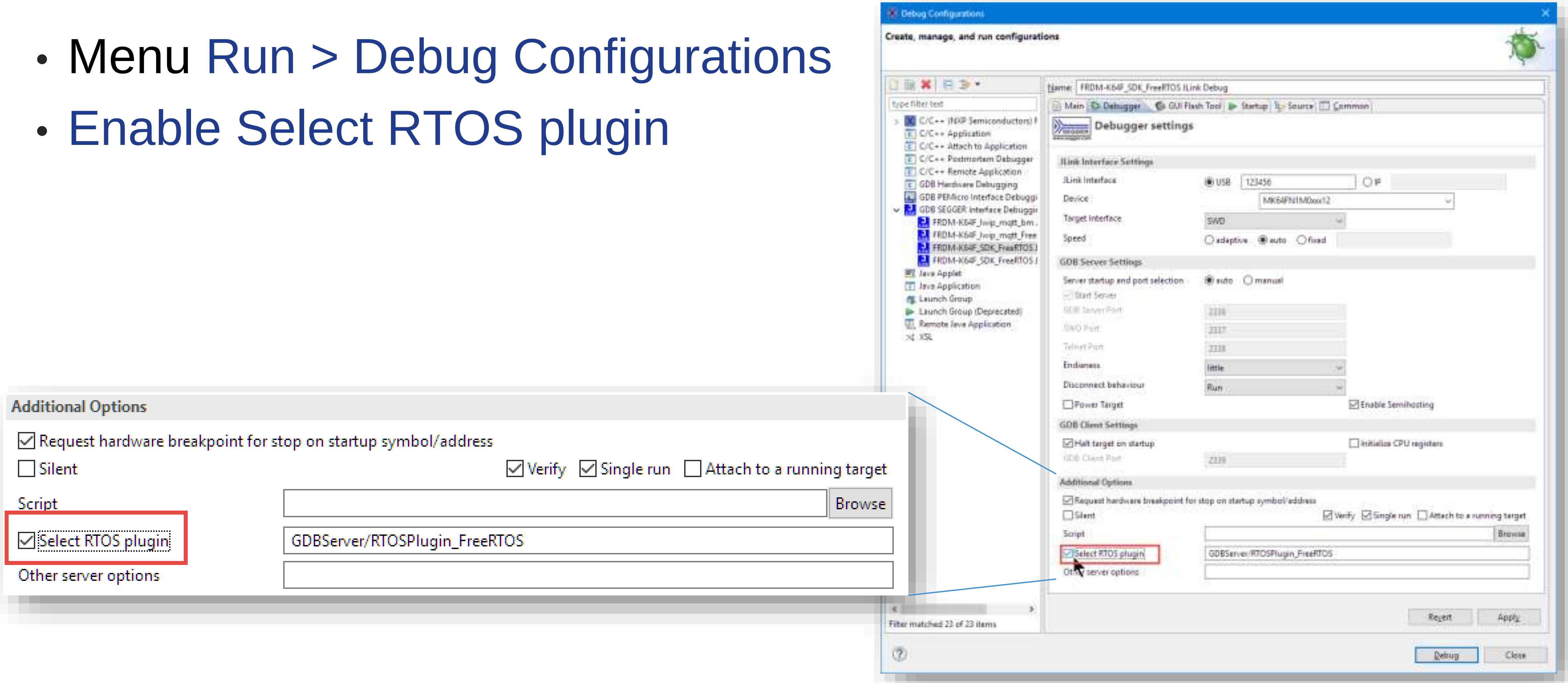
For development on target hardware, we recommend our industry leading
J-Link PRO (http://www.segger.com/jlink-pro.html)
J-Link Ultra+ (http://www.segger.com/jlink-ultra-plus.html)
J-Link PLUS (http://www.segger.com/jlink-plus.html)
J-Link (http://www.segger.com/jlink.html)

For professional production flash programming we recommend:

☑ Do not show this message again for today

FreeRTOS Thread Awareness with J-Link

- Menu Run > Debug Configurations
- Enable Select RTOS plugin



Additional Options

☑ Request hardware breakpoint for stop on startup symbol/address

☐ Silent ☑ Verify ☑ Single run ☐ Attach to a running target

Script: [ ] Browse

☑ Select RTOS plugin: GDBServer/RTOSPlugin_FreeRTOS

Other server options: [ ]

Debug Configurations

Create, manage, and run configurations

Name: FRDM-K64F_SDK_FreeRTOS JLink Debug

Debugger settings

JLink Interface Settings

JLink Interface: ● USB 123456 ○ IP

Device: MK64FN1M0xxx12

Target Interface: SWD

Speed: ○ adaptive ● auto ○ fixed

GDB Server Settings

Server startup and port selection: ● auto ○ manual

☑ Start Server

GDB Server Port: 2331

SWO Port: 2332

Telnet Port: 2333

Endianess: little

Disconnect behaviour: Run

☐ Power Target ☑ Enable Semihosting

GDB Client Settings

☑ Halt target on startup ☐ Initialize CPU registers

GDB Client Port: 2331

Additional Options

☑ Request hardware breakpoint for stop on startup symbol/address

☐ Silent ☑ Verify ☑ Single run ☐ Attach to a running target

Script: [ ] Browse

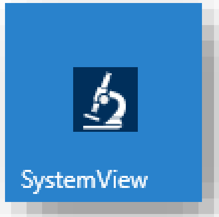
☑ Select RTOS plugin: GDBServer/RTOSPlugin_FreeRTOS

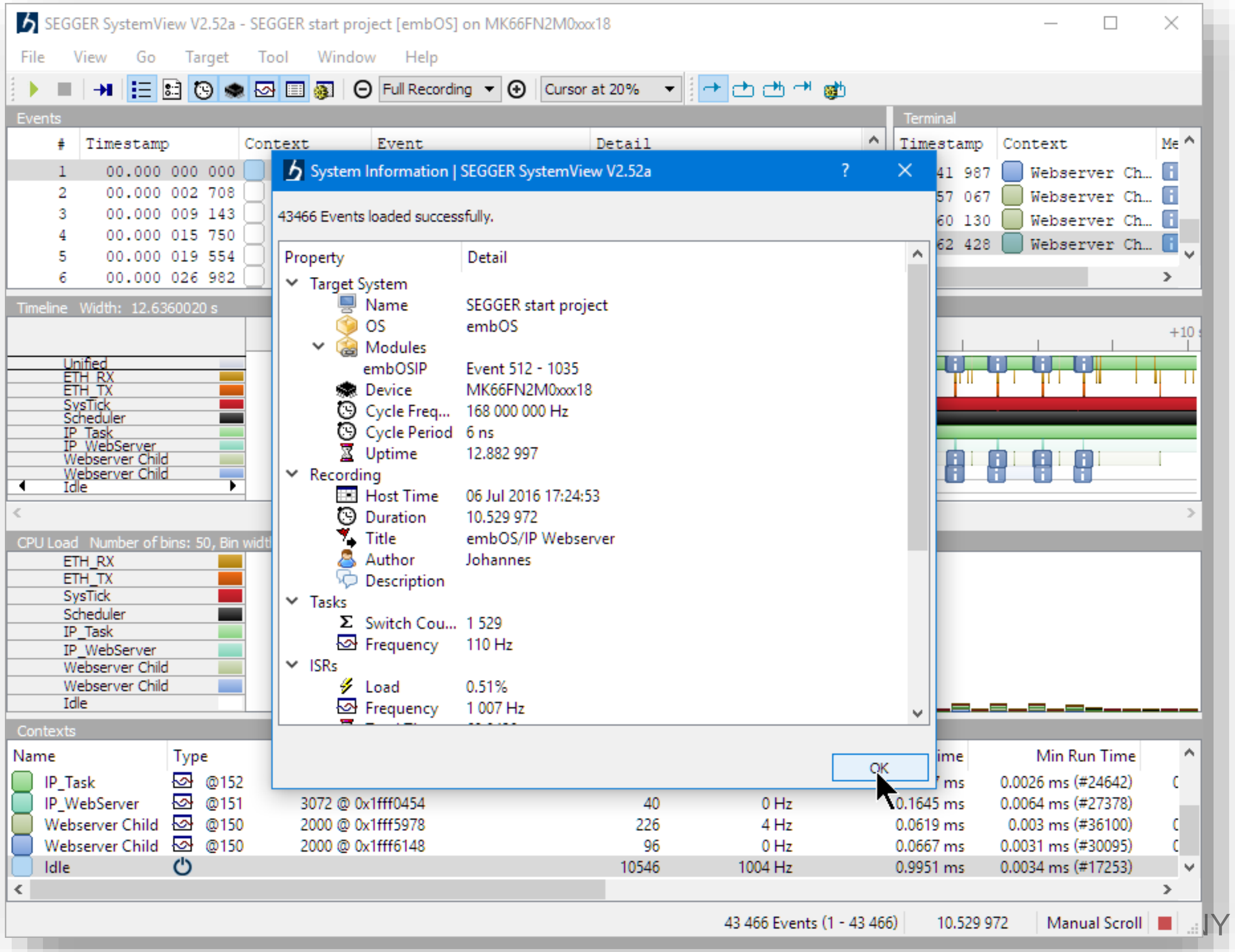
Other server options: [ ]

Filter matched 23 of 23 items

Running SystemView

- Launch SystemView (Shortcut)
- Click OK on System Information Dialog





#	Timestamp	Context	Event	Detail
1	00.000 000 000			
2	00.000 002 708			
3	00.000 009 143			
4	00.000 015 750			
5	00.000 019 554			
6	00.000 026 982			

Timestamp	Context	Me
41 987	Webserver Ch...	
57 067	Webserver Ch...	
60 130	Webserver Ch...	
62 428	Webserver Ch...	

System Information | SEGGER SystemView V2.52a

43466 Events loaded successfully.

Property	Detail
Target System	
Name	SEGGER start project
OS	embOS
Modules	
embOSIP	Event 512 - 1035
Device	MK66FN2M0xxx18
Cycle Freq...	168 000 000 Hz
Cycle Period	6 ns
Uptime	12.882 997
Recording	
Host Time	06 Jul 2016 17:24:53
Duration	10.529 972
Title	embOS/IP Webserver
Author	Johannes
Description	
Tasks	
Switch Cou...	1 529
Frequency	110 Hz
ISRs	
Load	0.51%
Frequency	1 007 Hz

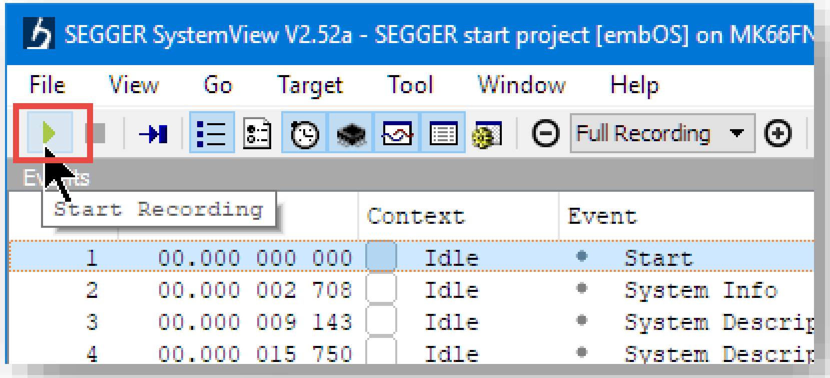
OK

Name	Type				ime	Min Run Time
IP_Task	@152				ms	0.0026 ms (#24642)
IP_WebServer	@151	3072 @ 0x1fff0454	40	0 Hz	0.1645 ms	0.0064 ms (#27378)
Webserver Child	@150	2000 @ 0x1fff5978	226	4 Hz	0.0619 ms	0.003 ms (#36100)
Webserver Child	@150	2000 @ 0x1fff6148	96	0 Hz	0.0667 ms	0.0031 ms (#30095)
Idle	⏻		10546	1004 Hz	0.9951 ms	0.0034 ms (#17253)

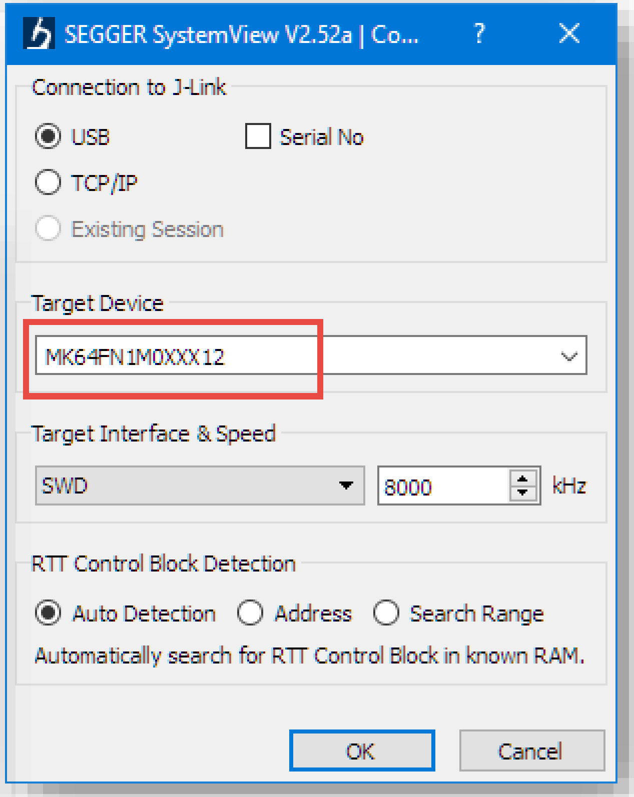
43 466 Events (1 - 43 466) | 10.529 972 | Manual Scroll

Collecting Data

- Run FreeRTOS application with Debugger
- Press ‘Start Recording’
- Specify target device
  - MK64FN1M0XXX12
- Records data
- Press ‘Stop Recording’


SEGGER SystemView V2.52a - SEGGER start project [embOS] on MK66FN
File
View
Go
Target
Tool
Window
Help
Full Recording
Events
Start Recording

#	Timestamp	Context	Event
1	00.000 000 000	Idle	Start
2	00.000 002 708	Idle	System Info
3	00.000 009 143	Idle	System Descrip
4	00.000 015 750	Idle	System Descrip



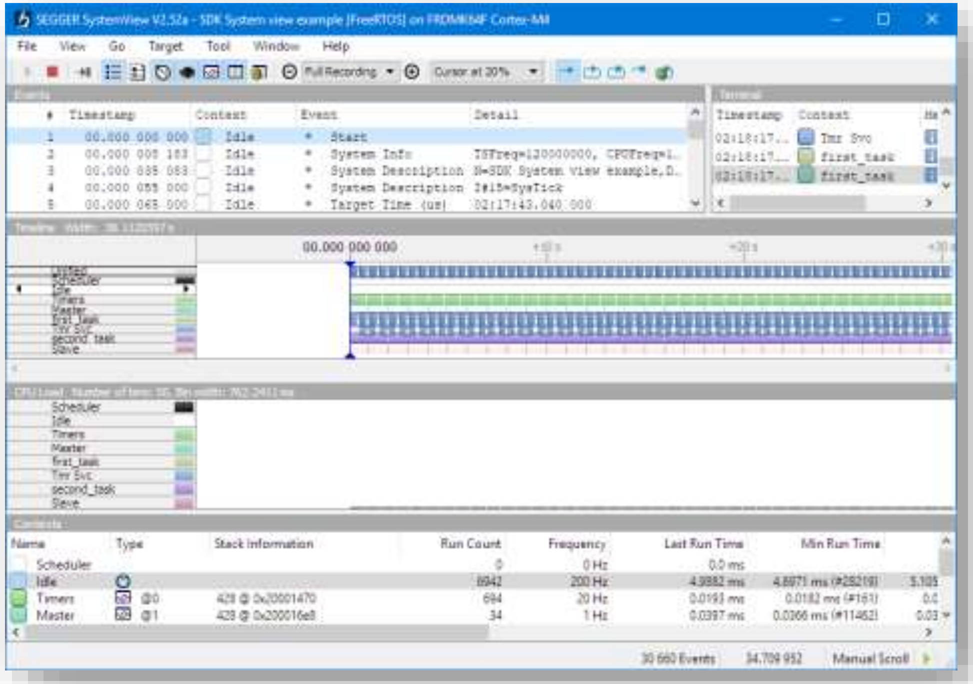
● USB □ Serial No
○ TCP/IP
○ Existing Session

Target Device: MK64FN1M0XXX12

Target Interface & Speed: SWD 8000 kHz

RTT Control Block Detection: ● Auto Detection ○ Address ○ Search Range

Automatically search for RTT Control Block in known RAM.

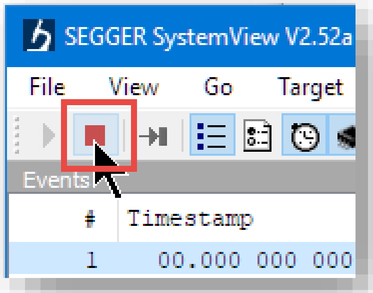


#	Timestamp	Context	Event	Detail
1	00.000 000 000	Idle	Start	
2	00.000 005 183	Idle	System Info	TSFreq=120000000, CPUFreq=1...
3	00.000 035 083	Idle	System Description	N=SDK System view example,D...
4	00.000 055 000	Idle	System Description	I#15=SysTick
5	00.000 065 000	Idle	Target Time (us)	02:17:43.040 000

Timestamp	Context
02:18:17...	Tmr Svc
02:18:17...	first_task
02:18:17...	first_task

Name	Type	Stack Information	Run Count	Frequency	Last Run Time	Min Run Time
Scheduler			0	0 Hz	0.0 ms	
Idle			6942	200 Hz	4.9882 ms	4.8971 ms (#28219)
Timers	@0	428 @ 0x20001470	694	20 Hz	0.0193 ms	0.0182 ms (#161)
Master	@1	428 @ 0x200016e8	34	1 Hz	0.0397 ms	0.0366 ms (#11462)

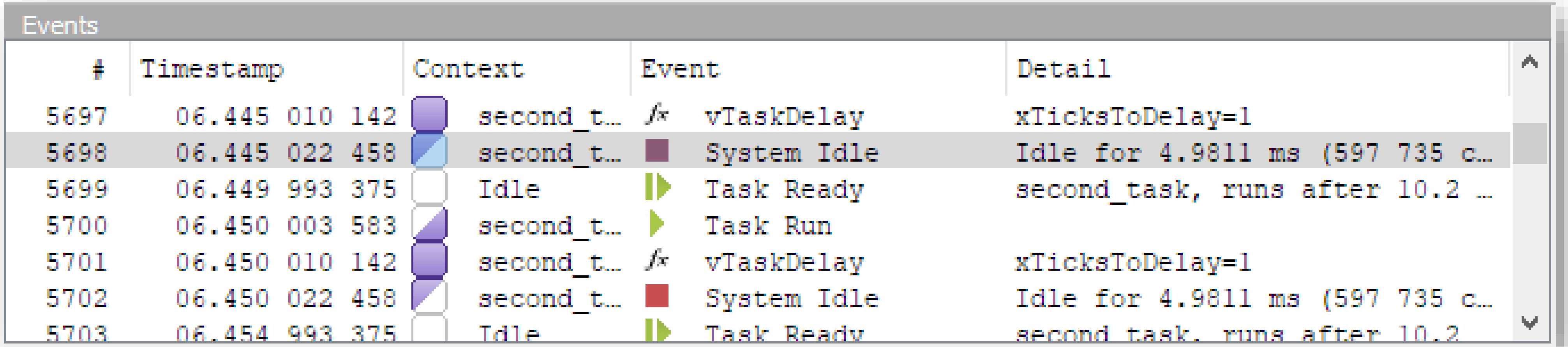
30 660 Events 34.709 952 Manual Scroll



#	Timestamp
1	00.000 000 000

Events

- List of Events recorded
- Click to show in Timeline

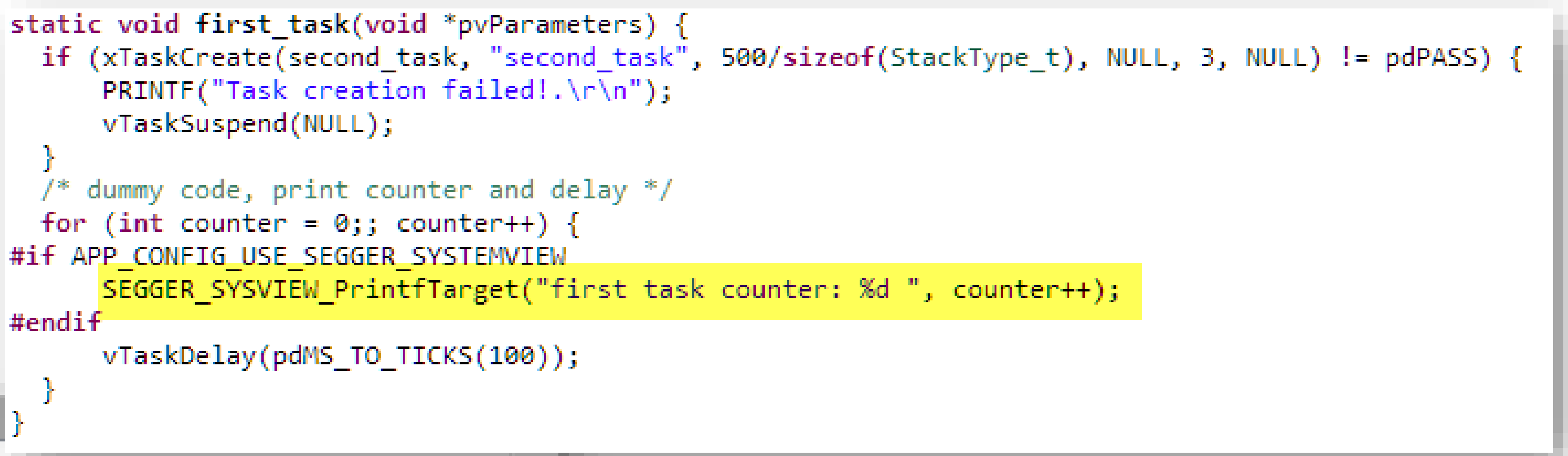


Events

#	Timestamp	Context	Event	Detail
5697	06.445 010 142	second_t…	vTaskDelay	xTicksToDelay=1
5698	06.445 022 458	second_t…	System Idle	Idle for 4.9811 ms (597 735 c…
5699	06.449 993 375	Idle	Task Ready	second_task, runs after 10.2 …
5700	06.450 003 583	second_t…	Task Run	
5701	06.450 010 142	second_t…	vTaskDelay	xTicksToDelay=1
5702	06.450 022 458	second_t…	System Idle	Idle for 4.9811 ms (597 735 c…
5703	06.454 993 375	Idle	Task Ready	second_task, runs after 10.2

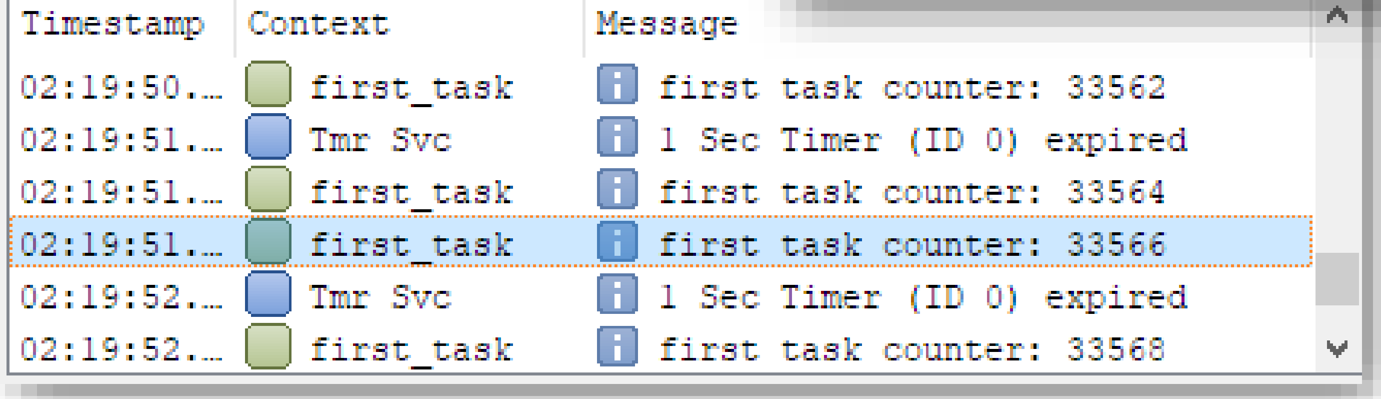
Terminal

- Messages produced by application
- Click to show in Timeline



```
static void first_task(void *pvParameters) {
  if (xTaskCreate(second_task, "second_task", 500/sizeof(StackType_t), NULL, 3, NULL) != pdPASS) {
      PRINTF("Task creation failed!.\r\n");
      vTaskSuspend(NULL);
  }
  /* dummy code, print counter and delay */
  for (int counter = 0;; counter++) {
#if APP_CONFIG_USE_SEGGER_SYSTEMVIEW
      SEGGER_SYSVIEW_PrintfTarget("first task counter: %d ", counter++);
#endif
      vTaskDelay(pdMS_TO_TICKS(100));
  }
}
```

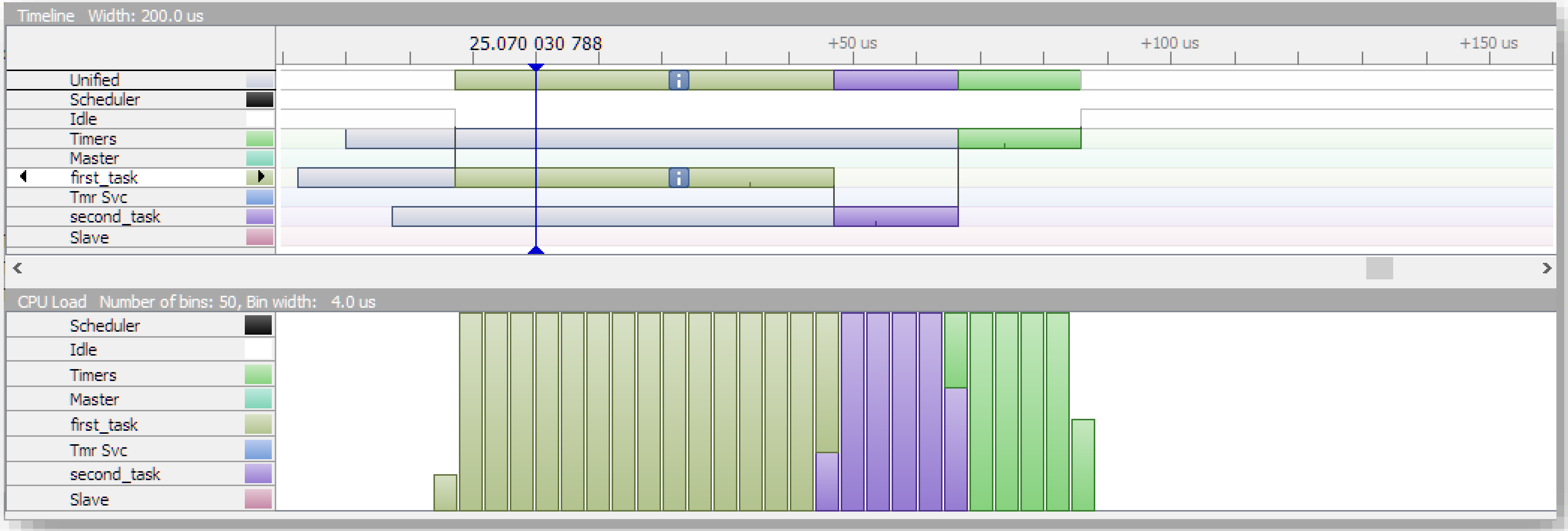
Terminal



```
Timestamp     Context       Message
02:19:50....  first_task    first task counter: 33562
02:19:51....  Tmr Svc       1 Sec Timer (ID 0) expired
02:19:51....  first_task    first task counter: 33564
02:19:51....  first_task    first task counter: 33566
02:19:52....  Tmr Svc       1 Sec Timer (ID 0) expired
02:19:52....  first_task    first task counter: 33568
```

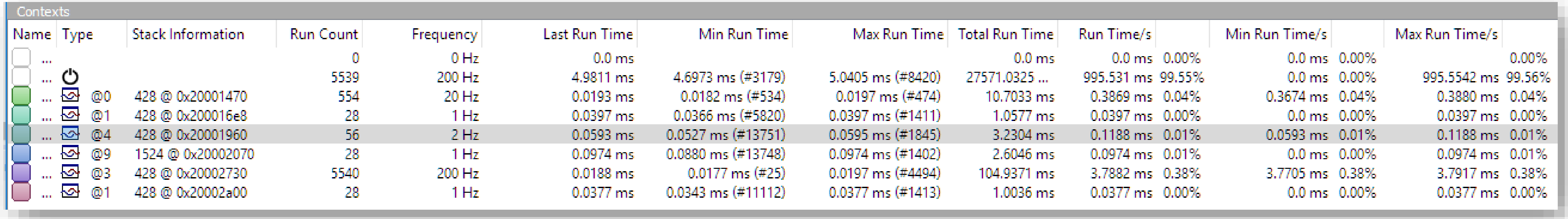
Timeline & CPU Load

- Shows task sequence and CPU load
- Use mouse wheel to zoom in/out
- Use mouse to move



Contexts

- List of Tasks with priorities
- Run count, stack size, task frequency, runtime statistics



Contexts

Name	Type	Stack Information	Run Count	Frequency	Last Run Time	Min Run Time	Max Run Time	Total Run Time	Run Time/s		Min Run Time/s		Max Run Time/s	
□ ...			0	0 Hz	0.0 ms			0.0 ms	0.0 ms	0.00%	0.0 ms	0.00%		0.00%
□ ...	⏻		5539	200 Hz	4.9811 ms	4.6973 ms (#3179)	5.0405 ms (#8420)	27571.0325 ...	995.531 ms	99.55%	0.0 ms	0.00%	995.5542 ms	99.56%
■ ...	@0	428 @ 0x20001470	554	20 Hz	0.0193 ms	0.0182 ms (#534)	0.0197 ms (#474)	10.7033 ms	0.3869 ms	0.04%	0.3674 ms	0.04%	0.3880 ms	0.04%
■ ...	@1	428 @ 0x200016e8	28	1 Hz	0.0397 ms	0.0366 ms (#5820)	0.0397 ms (#1411)	1.0577 ms	0.0397 ms	0.00%	0.0 ms	0.00%	0.0397 ms	0.00%
■ ...	@4	428 @ 0x20001960	56	2 Hz	0.0593 ms	0.0527 ms (#13751)	0.0595 ms (#1845)	3.2304 ms	0.1188 ms	0.01%	0.0593 ms	0.01%	0.1188 ms	0.01%
■ ...	@9	1524 @ 0x20002070	28	1 Hz	0.0974 ms	0.0880 ms (#13748)	0.0974 ms (#1402)	2.6046 ms	0.0974 ms	0.01%	0.0 ms	0.00%	0.0974 ms	0.01%
■ ...	@3	428 @ 0x20002730	5540	200 Hz	0.0188 ms	0.0177 ms (#25)	0.0197 ms (#4494)	104.9371 ms	3.7882 ms	0.38%	3.7705 ms	0.38%	3.7917 ms	0.38%
■ ...	@1	428 @ 0x20002a00	28	1 Hz	0.0377 ms	0.0343 ms (#11112)	0.0377 ms (#1413)	1.0036 ms	0.0377 ms	0.00%	0.0 ms	0.00%	0.0377 ms	0.00%

Tick Rate

```
#define configTICK_RATE_HZ          ((TickType_t)1000)
```

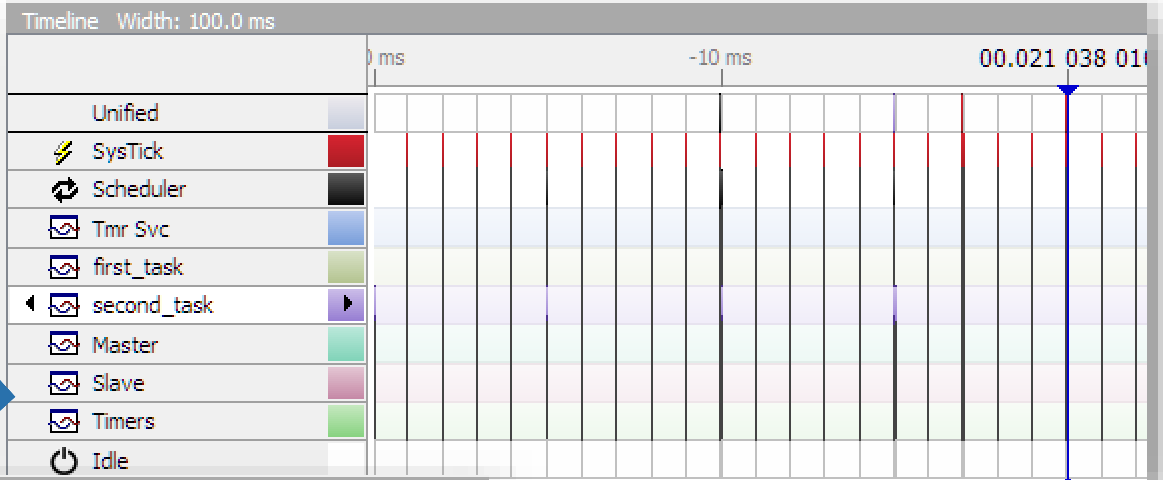
- Typical tick rates of 100 Hz, 50 Hz or 1 kHz
- All RTOS timing depends on it
- Too high: higher interrupt load
- Too low: bigger timing granularity

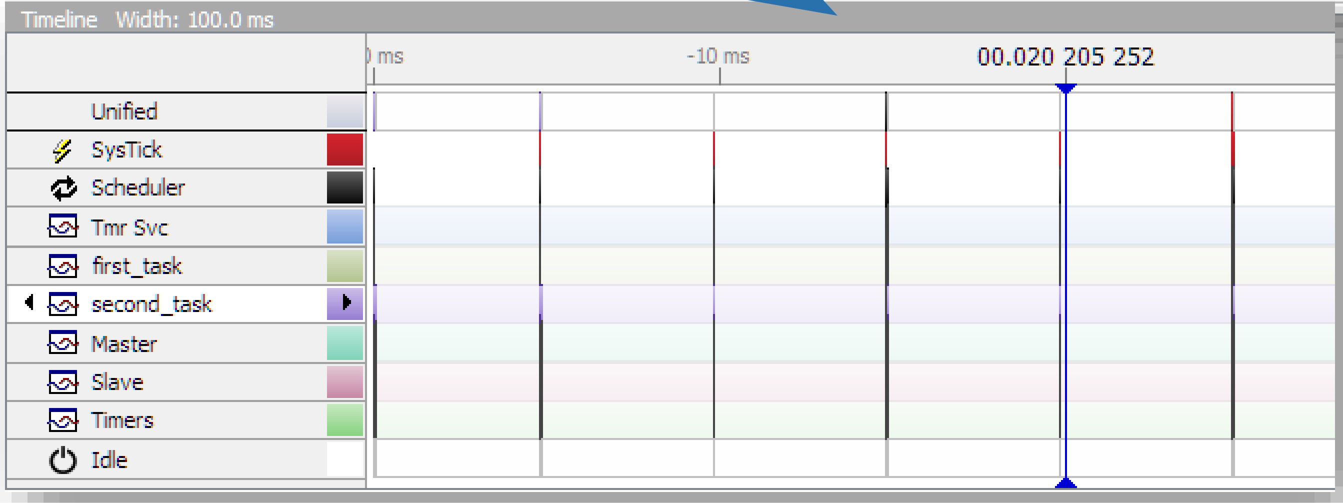
- *Recommendation*
  - *Tick rate as low as possible*
  - *Impact: System interrupt load*

Tick Rate

TODO 09

- Inspect SysTick in SystemView ➔ every 1 ms
- Application waits for 5, 50, 100 and 1000 ms
  - Can reduce tick period to 5 ms (200 Hz)
- Reduce tick rate/frequency
- Build and debug
- Check reduced tick frequency





Tickless IDLE Mode

```
#define configUSE_TICKLESS_IDLE                         0
```

- SysTick wakes up CPU from low power mode (timing, preemption)
- Extends interrupt periods to reduce interrupts for low-power applications

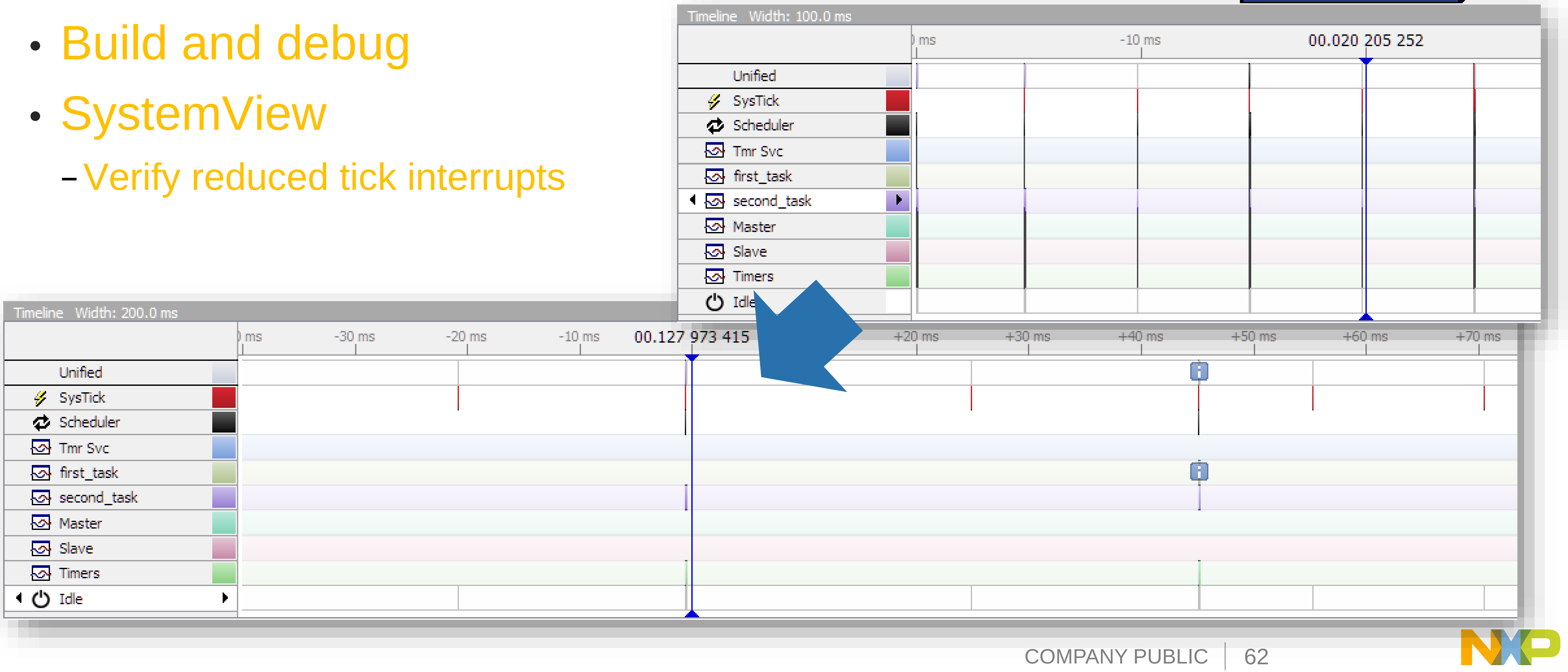
- *Recommendation*
  - *Enable for low power applications*
  - *Impact: reduced power consumption, reduced interrupt load, time slippage*

- Details: Low Power with FreeRTOS: Tickless Idle Mode

Tickless Idle Mode

TODO 10

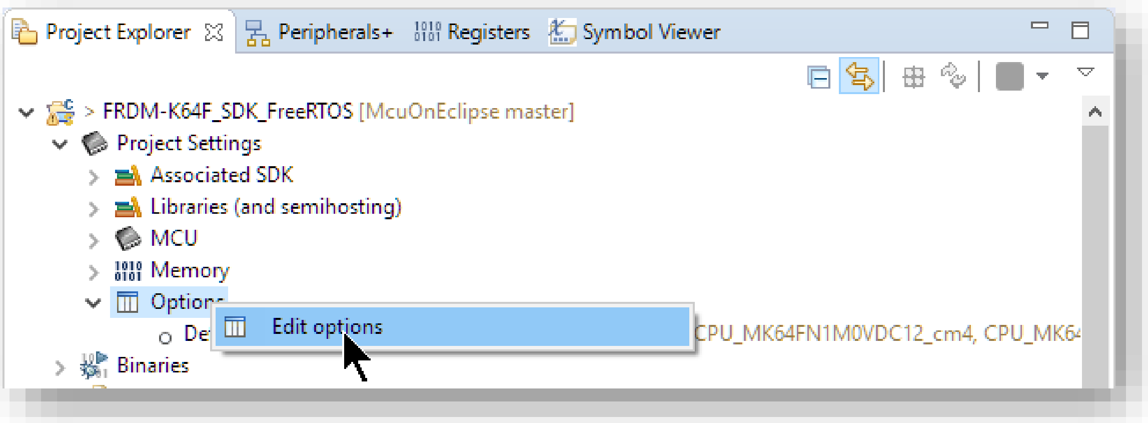
- Enable `configUSE_TICKLESS_IDLE`
- Build and debug
- SystemView
  - Verify reduced tick interrupts

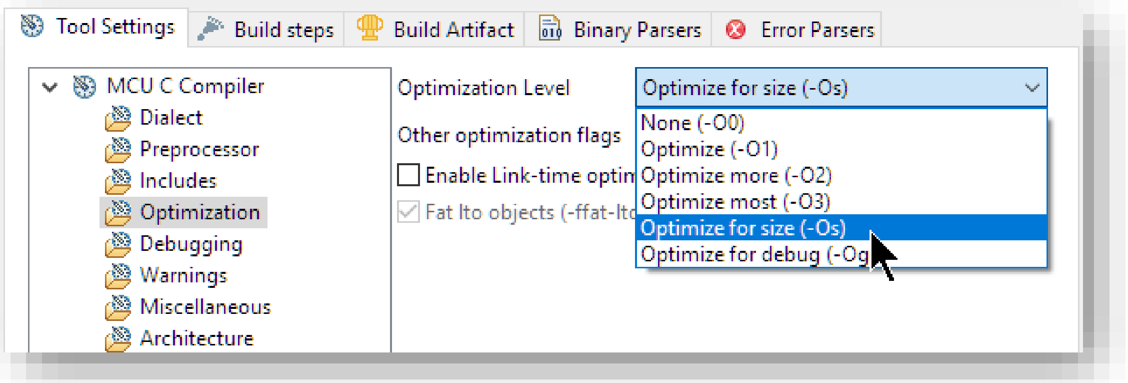


Compiler & Linker Optimizations

Compiler Optimizations

- By default, projects are typically using **–O0**
  - no optimization, easy debugging
- More aggressive optimization with **–Os**
  - Keeps variables in registers
  - Does branch tail merging
  - Might impact debugging
- Set optimization level to –Os and check code size impact





Optimization Level: Optimize for size (-Os)

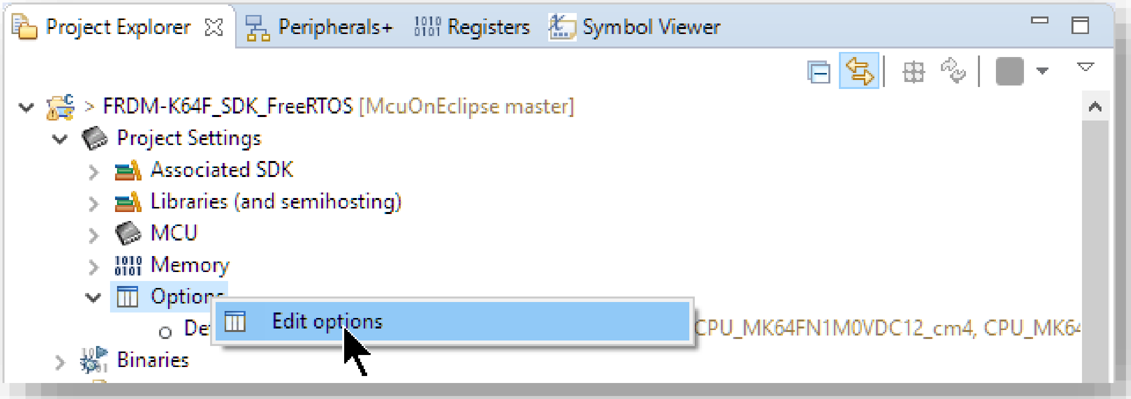
Other optimization flags

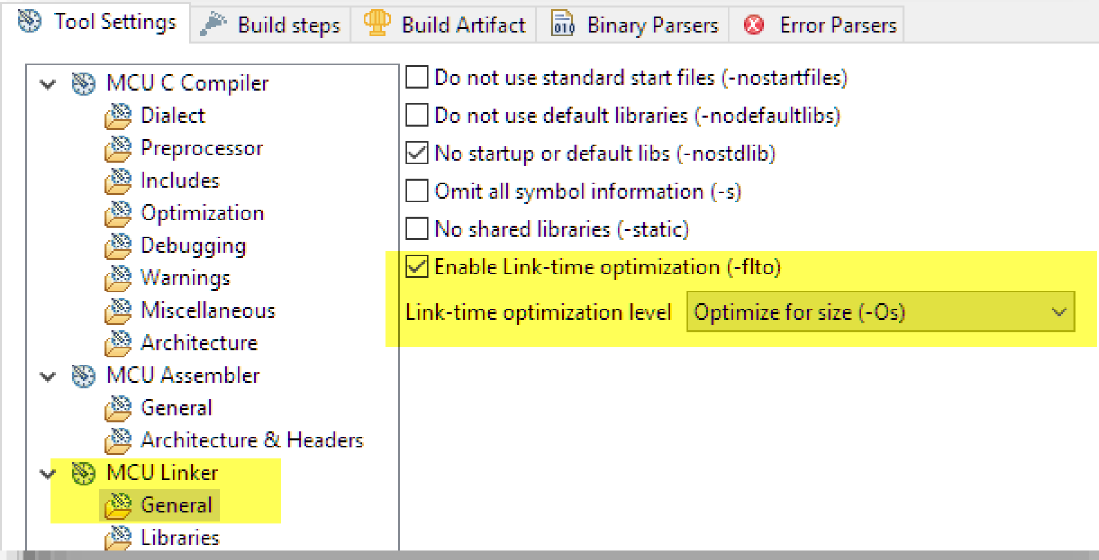
□ Enable Link-time optim

☑ Fat lto objects (-ffat-lto

Link-Time Optimization

- Linker can optimize across multiple modules
  - Inlining, constant propagation
  - Parameter propagation
  - Might affect debugging
- Turn on **–flto** and check code size impact
  - Linker & Compiler setting
- Note: might affect debugging





☐ Do not use standard start files (-nostartfiles)

☐ Do not use default libraries (-nodefaultlibs)

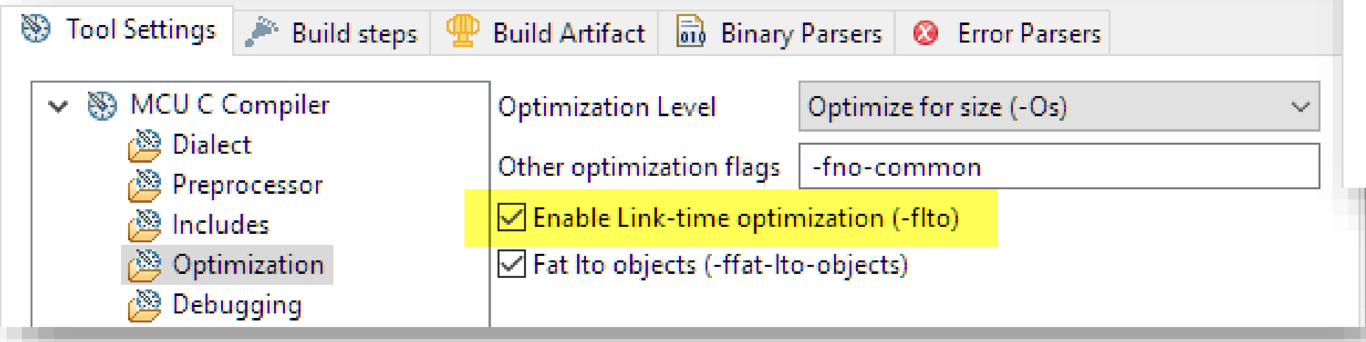
☑ No startup or default libs (-nostdlib)

☐ Omit all symbol information (-s)

☐ No shared libraries (-static)

☑ Enable Link-time optimization (-flto)

Link-time optimization level: Optimize for size (-Os)



Optimization Level: Optimize for size (-Os)

Other optimization flags: -fno-common

☑ Enable Link-time optimization (-flto)

☑ Fat lto objects (-ffat-lto-objects)

Summary

Summary

- NXP FreeRTOS Enablement
  - MCUXpresso IDE
  - MCUXpresso SDK
  - MCUXpresso Config Tools
- Optimizing FreeRTOS
  - FreeRTOS Configuration
  - Segger RTT and SystemView
  - NXP Kernel and Thread Awareness
  - Compiler and Linker Optimizations

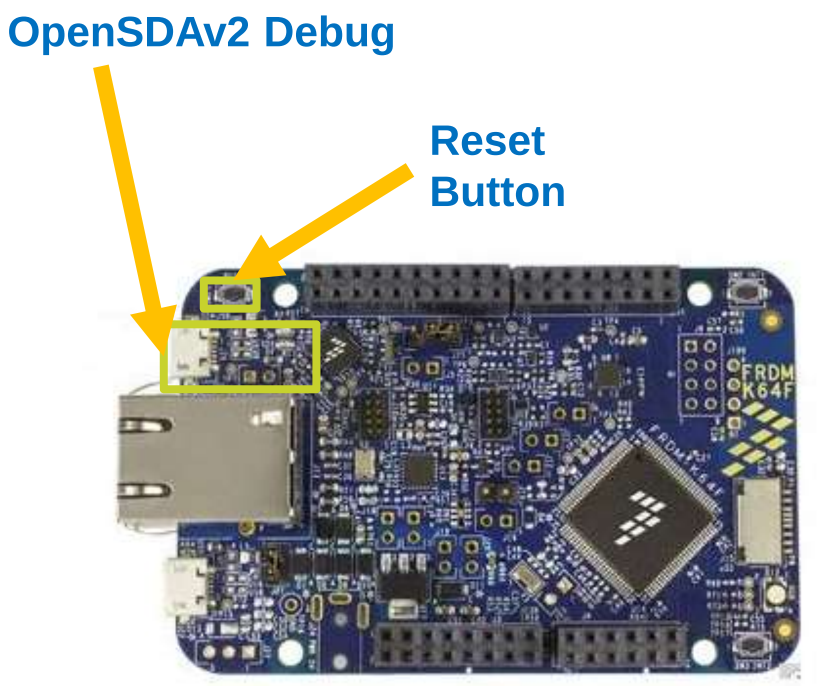
NXP
MCUXpresso
Software and Tools
COMMON TOOLKIT FOR THOUSANDS OF KINETIS® & LPC MICROCONTROLLERS
IDE
SDK
CFG
www.nxp.com/mcuxpresso

Additional Resources

- Web pages
  - MCUXpresso Software and Tools – www.nxp.com/mcuxpresso
    - MCUXpresso SDK – www.nxp.com/mcuxpresso/sdk
    - MCUXpresso IDE – www.nxp.com/mcuxpresso/ide
    - MCUXpresso Config Tools – www.nxp.com/mcuxpresso/config
  - Supported Devices Table (Community Doc)
- Communities
  - MCUXpresso Software and Tools - https://community.nxp.com/community/mcuxpresso
    - MCUXpresso SDK - https://community.nxp.com/community/mcuxpresso/mcuxpresso-sdk
    - MCUXpresso IDE – http://www.nxp.com/mcuxpresso/ide/forum
    - MCUXpresso Config Tools - https://community.nxp.com/community/mcuxpresso/mcuxpresso-config

Restore LinkServer/CMSIS-DAP OpenSDA Firmware

- Press (and hold) Reset Button
- Power board with OpenSDAv2 Debug USB connector
- Board enumerates as MAINTENANCE drive
- Copy **DAPLINK_k20dx_frdmk64f_if_crc_legacy_0x5000.bin** to drive
- Unplug USB cable
- Power/plug the USB cable

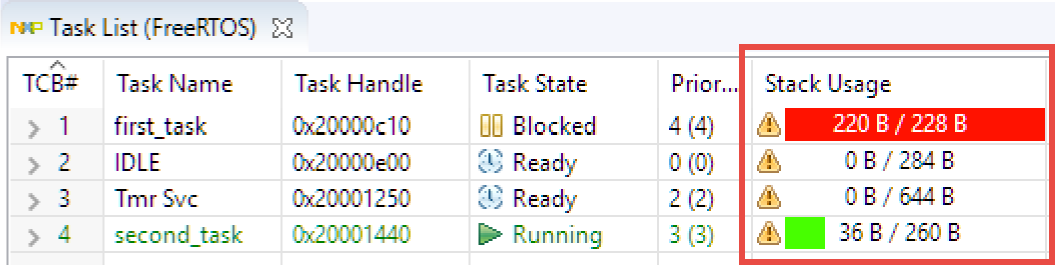


Backup

Error Hooks

```
#define configCHECK_FOR_STACK_OVERFLOW          1
#define configUSE_MALLOC_FAILED_HOOK            1
```

- Trap errors stack overflows
  - disabled (0), Method1 (1) and Method2 (2)
- Trap for ‘out of heap’
- *Recommendation*
  - *Turn on during development*
  - *Disable for ‘release’ version*
  - *Impact: reduced code size, improved context switch time*



Task List (FreeRTOS)

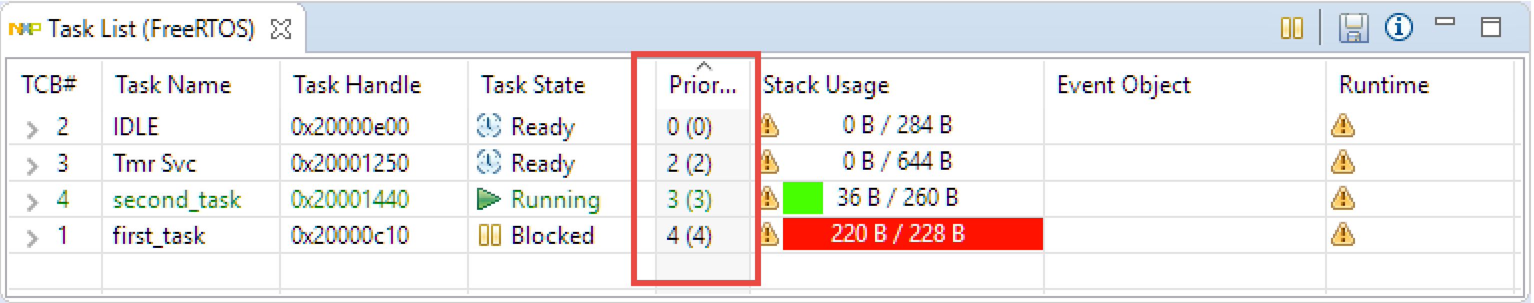
TCB#	Task Name	Task Handle	Task State	Prior...	Stack Usage
1	first_task	0x20000c10	Blocked	4 (4)	⚠ 220 B / 228 B
2	IDLE	0x20000e00	Ready	0 (0)	⚠ 0 B / 284 B
3	Tmr Svc	0x20001250	Ready	2 (2)	⚠ 0 B / 644 B
4	second_task	0x20001440	Running	3 (3)	⚠ 36 B / 260 B

Maximum Task Priorities

```
#define configMAX_PRIORITIES                              5
```

- Task priorities from 0 up to N-1
- Kernel maintains a list for each priority

- *Recommendation*
  - *As small as possible*
  - *No gaps in task priorities*
  - *Share priorities*
  - *Impact: reduced RAM size*



Task List (FreeRTOS)

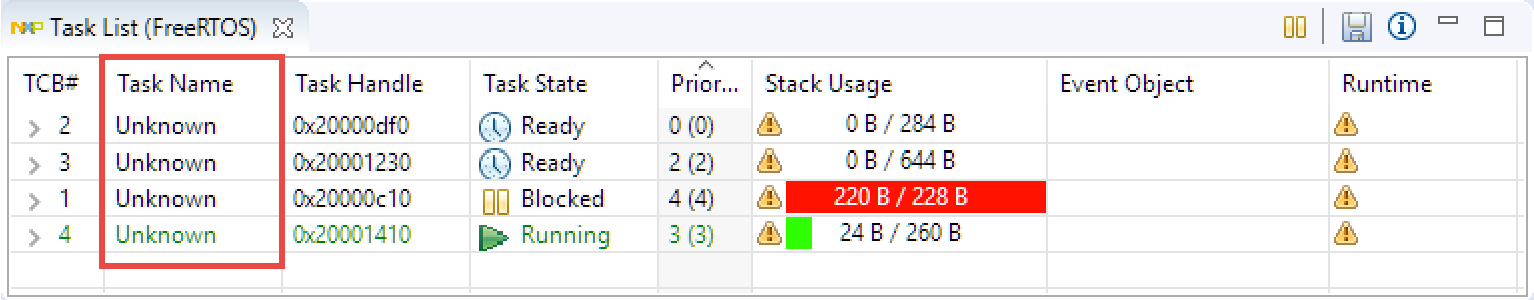
TCB#	Task Name	Task Handle	Task State	Prior...	Stack Usage	Event Object	Runtime
2	IDLE	0x20000e00	Ready	0 (0)	⚠ 0 B / 284 B		⚠
3	Tmr Svc	0x20001250	Ready	2 (2)	⚠ 0 B / 644 B		⚠
4	second_task	0x20001440	Running	3 (3)	⚠ 36 B / 260 B		⚠
1	first_task	0x20000c10	Blocked	4 (4)	⚠ 220 B / 228 B		⚠

Task Name Length

```
#define configMAX_TASK_NAME_LEN                           20
```

- Used as name for tasks at creation time
- Name stored in task descriptor

- *Recommendation*
  - *As small as possible, or 1 to disable*
  - *Impact: reduced RAM size*
    Limited or no task name in Task List



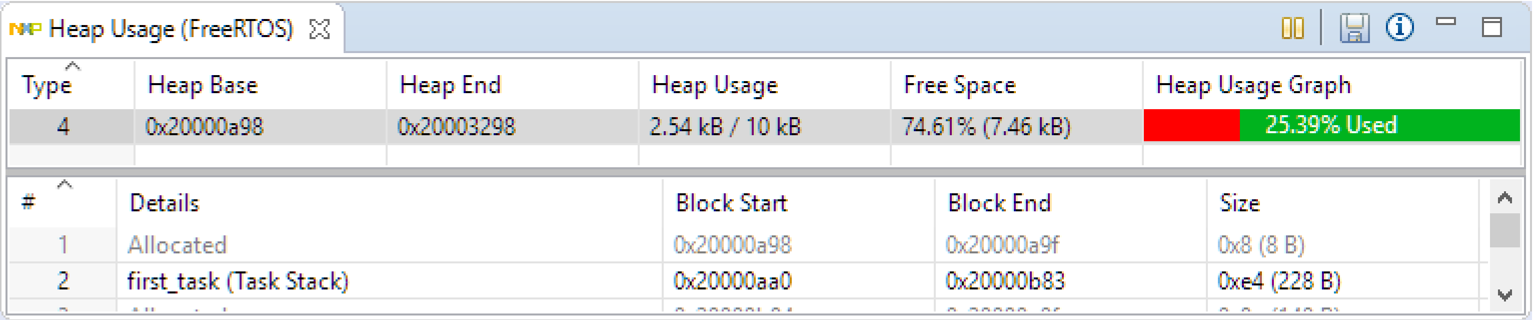
TCB#	Task Name	Task Handle	Task State	Prior...	Stack Usage	Event Object	Runtime
2	Unknown	0x20000df0	Ready	0 (0)	⚠ 0 B / 284 B		⚠
3	Unknown	0x20001230	Ready	2 (2)	⚠ 0 B / 644 B		⚠
1	Unknown	0x20000c10	Blocked	4 (4)	⚠ 220 B / 228 B		⚠
4	Unknown	0x20001410	Running	3 (3)	⚠ 24 B / 260 B		⚠

Heap Size

```
#define configSUPPORT_STATIC_ALLOCATION    0
#define configSUPPORT_DYNAMIC_ALLOCATION   1
#define configTOTAL_HEAP_SIZE              ((size_t)(10 * 1024))
```

- Dynamic memory for task stack, queues, semaphore, ...

- *Recommendation*
  - *As small as possible, static allocation* (configSUPPORT_STATIC_ALLOCATIO 1) *with no dynamic allocation* (configSUPPORT_DYNAMIC_ALLOCATION 0)
  - *Impact: reduced RAM size, reduced code size*



Type	Heap Base	Heap End	Heap Usage	Free Space	Heap Usage Graph
4	0x20000a98	0x20003298	2.54 kB / 10 kB	74.61% (7.46 kB)	25.39% Used

#	Details	Block Start	Block End	Size
1	Allocated	0x20000a98	0x20000a9f	0x8 (8 B)
2	first_task (Task Stack)	0x20000aa0	0x20000b83	0xe4 (228 B)

Cortex-M Interrupts

```
#define configUSE_PORT_OPTIMISED_TASK_SELECTION  1
```

- Optimized task selection using bit instructions
- Supports up to 32 task priorities

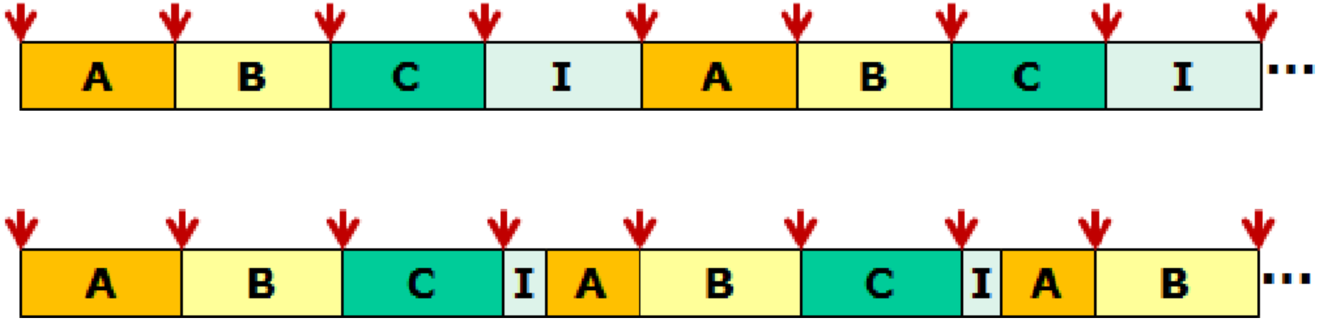
- *Recommendation*
  - *Enable for Cortex-M4/M7*
  - *Impact: improved application performance (~1%)*

Idle Yielding

```
#define configIDLE_SHOULD_YIELD                                  1
```

- In preemptive mode allows IDLE task to give back time to tasks

- *Recommendation*
  - *Enable IDLE yielding*
  - *Impact: improved application performance*



Application Hooks

```
#define configUSE_IDLE_HOOK                    1
#define configUSE_TICK_HOOK                    1
#define configUSE_DAEMON_TASK_STARTUP_HOOK     0
```

- Application hooks for IDLE, tick interrupt or timer daemon startup

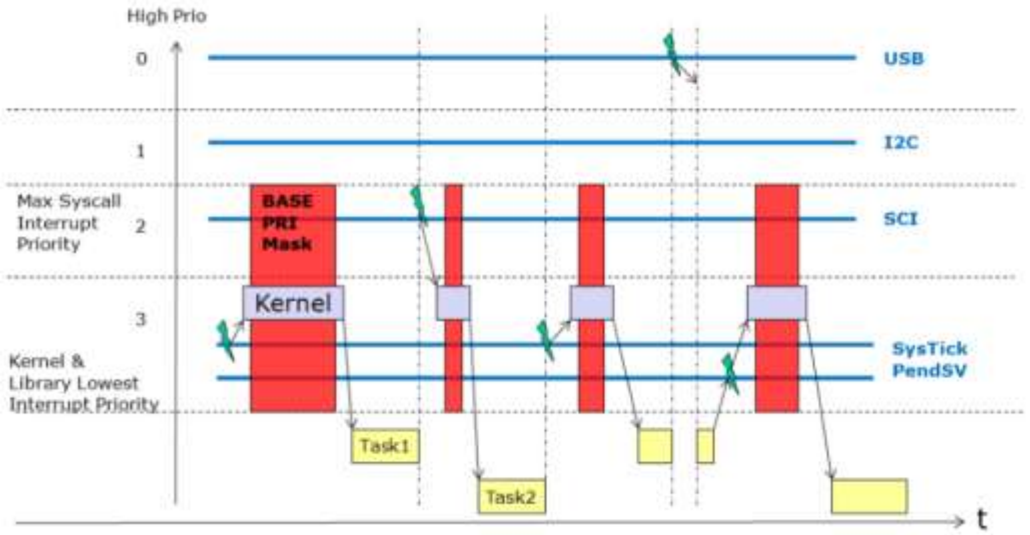
- *Recommendation*
  - *Use IDLE hook to enter low power mode*
  - *Use tick hook instead of periodic timer interrupt*
  - *Disable Daemon hook if not used*
  - *Impact: reduced code size, reduced hardware timer usage*

Cortex-M Interrupts

```
#define configLIBRARY_MAX_SYSCALL_INTERRUPT_PRIORITY 2
```

- Cortex-M0+: Scheduler masks all interrupts; Cortex-M4(F): only SYSCALL and below (less urgent)

- *Recommendation*
  - *Put interrupts which do **not** use RTOS API above SYSCALL level*
  - *Impact: improved application performance, less interrupt latency*

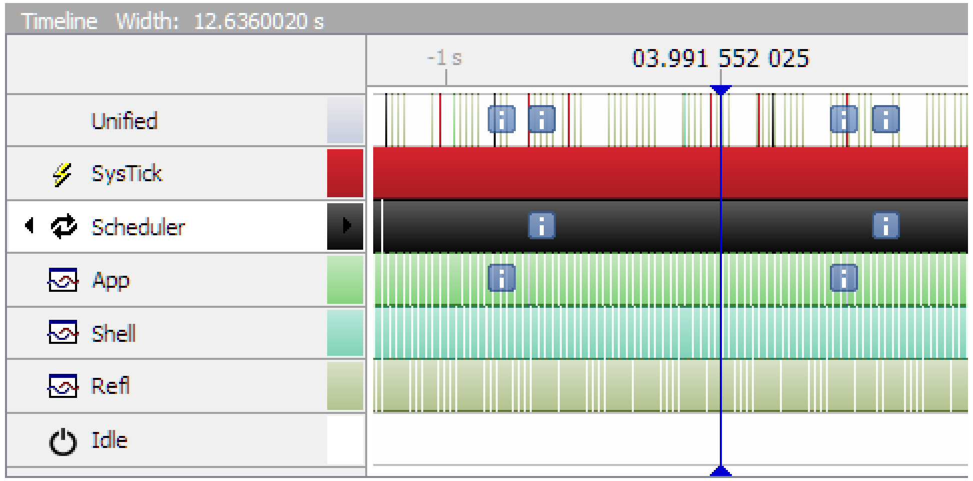

High Prio
0
1
Max Syscall Interrupt Priority
2
3
Kernel & Library Lowest Interrupt Priority
USB
I2C
SCI
SysTick
PendSV
BASE PRI Mask
Kernel
Task1
Task2
t

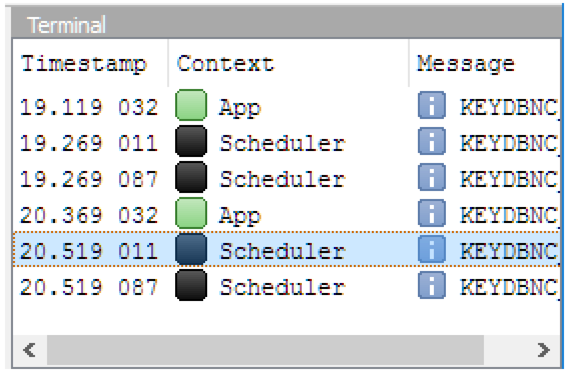
User SystemViewer Events

```
SEGGER_SYSVIEW_RecordEnterISR();
...
SEGGER_SYSVIEW_RecordExitISR();
```

- Ability to instrument application and interrupts
- Log messages and event markers

- *Recommendation*
  - *Use for measurement and debugging*
  - *Turn off for release*
  - *Impact: improved application*

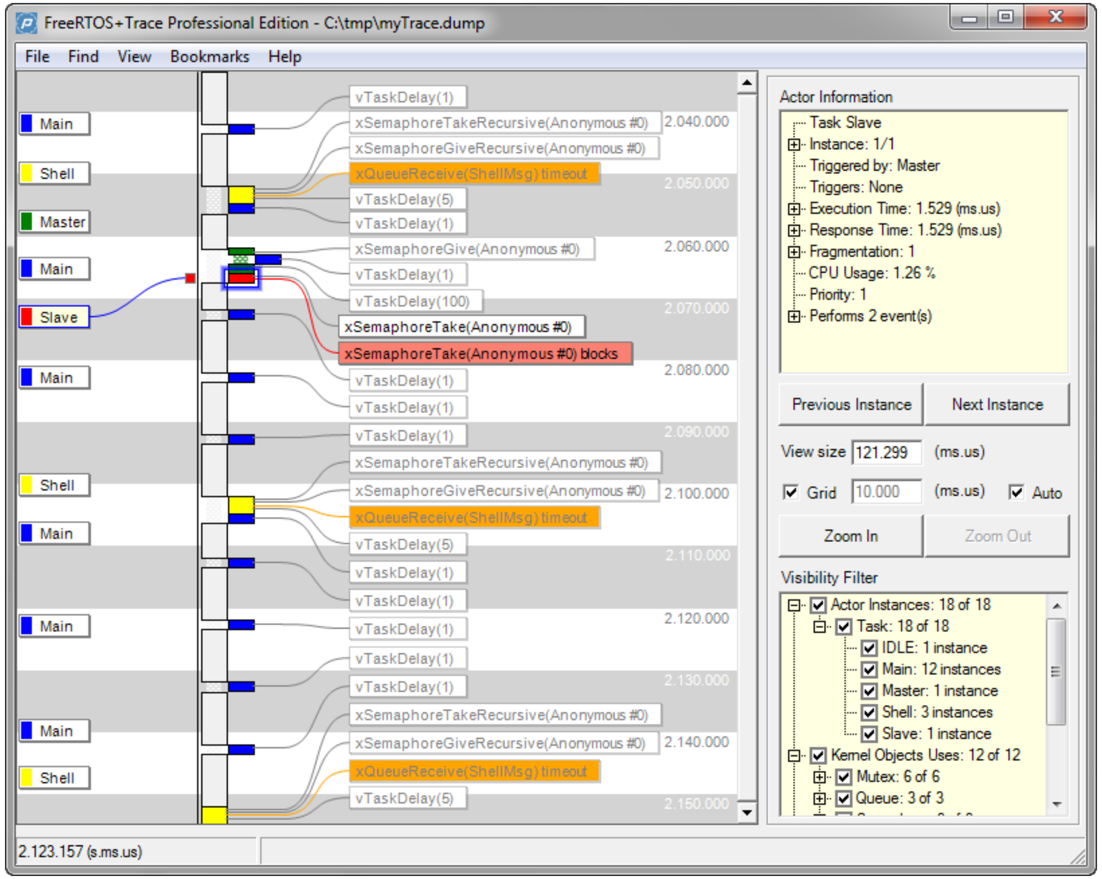




Timestamp	Context	Message
19.119 032	🟩 App	ℹ KEYDBNC
19.269 011	⬛ Scheduler	ℹ KEYDBNC
19.269 087	⬛ Scheduler	ℹ KEYDBNC
20.369 032	🟩 App	ℹ KEYDBNC
20.519 011	⬛ Scheduler	ℹ KEYDBNC
20.519 087	⬛ Scheduler	ℹ KEYDBNC

Percepio Tracealizer

- Percepio (http://www.percepio.com)
- Free/Professional (Paid) 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
- Eclipse launcher plugin



FreeRTOS+Trace Professional Edition - C:\tmp\myTrace.dump

File
Find
View
Bookmarks
Help
Main
Shell
Master
Main
Slave
Main
Shell
Main
Main
Main
Shell
vTaskDelay(1)
xSemaphoreTakeRecursive(Anonymous #0)
xSemaphoreGiveRecursive(Anonymous #0)
xQueueReceive(ShellMsg) timeout
vTaskDelay(5)
vTaskDelay(1)
xSemaphoreGive(Anonymous #0)
vTaskDelay(1)
vTaskDelay(100)
xSemaphoreTake(Anonymous #0)
xSemaphoreTake(Anonymous #0) blocks
vTaskDelay(1)
vTaskDelay(1)
vTaskDelay(1)
xSemaphoreTakeRecursive(Anonymous #0)
xSemaphoreGiveRecursive(Anonymous #0)
xQueueReceive(ShellMsg) timeout
vTaskDelay(5)
vTaskDelay(1)
vTaskDelay(1)
vTaskDelay(1)
vTaskDelay(1)
vTaskDelay(1)
xSemaphoreTakeRecursive(Anonymous #0)
xSemaphoreGiveRecursive(Anonymous #0)
xQueueReceive(ShellMsg) timeout
vTaskDelay(5)
2.040.000
2.050.000
2.060.000
2.070.000
2.080.000
2.090.000
2.100.000
2.110.000
2.120.000
2.130.000
2.140.000
2.150.000

Actor Information

- Task Slave
- Instance: 1/1
- Triggered by: Master
- Triggers: None
- Execution Time: 1.529 (ms.us)
- Response Time: 1.529 (ms.us)
- Fragmentation: 1
- CPU Usage: 1.26 %
- Priority: 1
- Performs 2 event(s)

View size 121.299 (ms.us)

☑ Grid 10.000 (ms.us) ☑ Auto

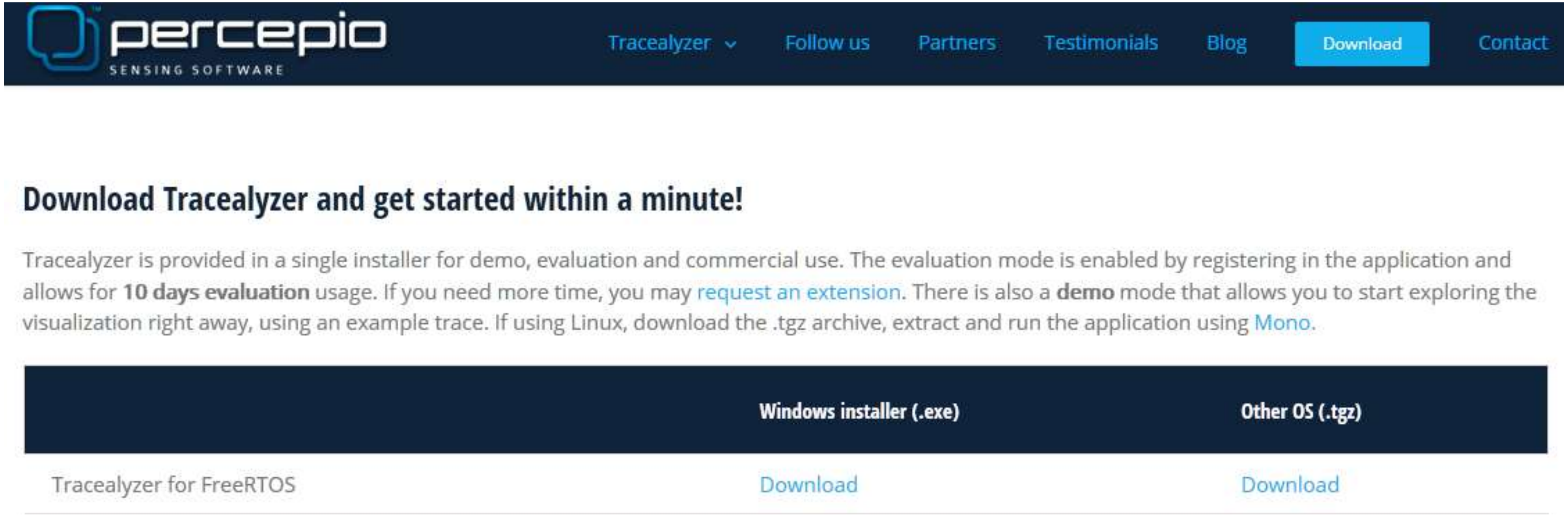
Visibility Filter

- ☑ Actor Instances: 18 of 18
  - ☑ Task: 18 of 18
    - ☑ IDLE: 1 instance
    - ☑ Main: 12 instances
    - ☑ Master: 1 instance
    - ☑ Shell: 3 instances
    - ☑ Slave: 1 instance
- ☑ Kernel Objects Uses: 12 of 12
  - ☑ Mutex: 6 of 6
  - ☑ Queue: 3 of 3

2.123.157 (s.ms.us)

FreeRTOS+Trace Tracealyzer from Percepio

- Tracealyzer for FreeRTOS: http://percepio.com/download/
- Free version (task scheduling only)
- 30 day evaluation (Professional Edition) license



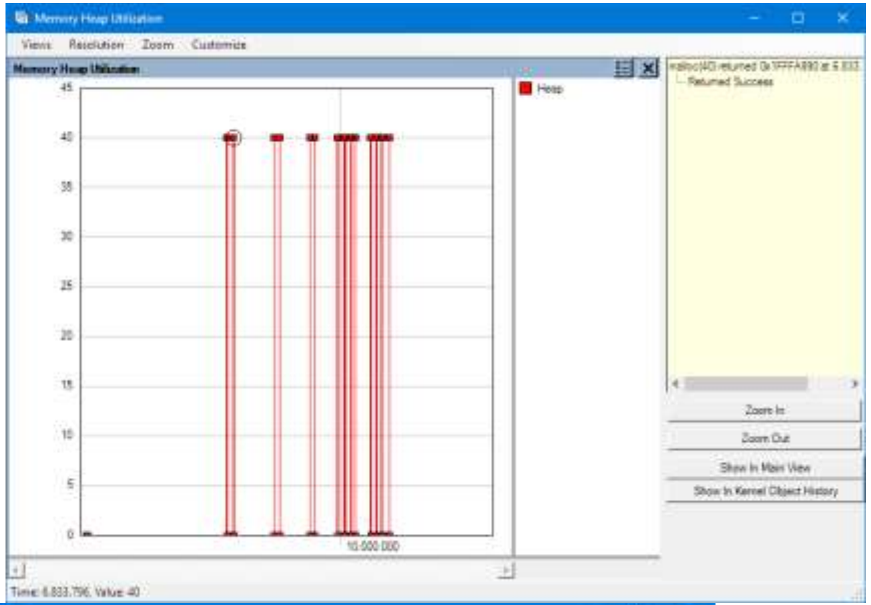
Download Tracealyzer and get started within a minute!

Tracealyzer is provided in a single installer for demo, evaluation and commercial use. The evaluation mode is enabled by registering in the application and allows for **10 days evaluation** usage. If you need more time, you may request an extension. There is also a **demo** mode that allows you to start exploring the visualization right away, using an example trace. If using Linux, download the .tgz archive, extract and run the application using Mono.

	Windows installer (.exe)	Other OS (.tgz)
Tracealyzer for FreeRTOS	Download	Download

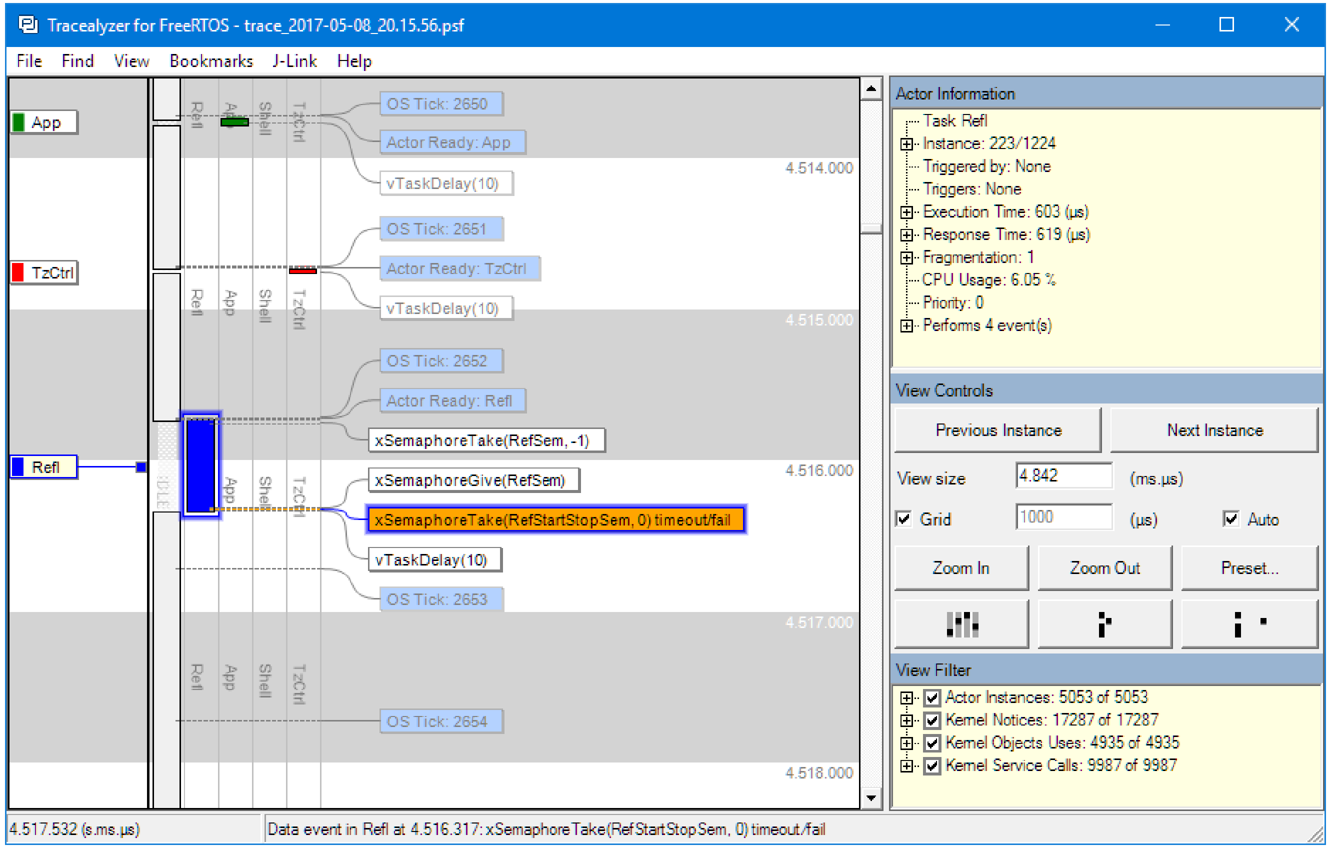
Tracealyzer Views

- Memory Heap Utilization (memory leaks)
- Communication Flow (usage of queues)
- Timeouts



malloc(40) returned 0x1FFFA890 at 6.833
Returned Success

Time: 6.833.796, Value: 40



Actor Information

- Task Refl
- Instance: 223/1224
- Triggered by: None
- Triggers: None
- Execution Time: 603 (µs)
- Response Time: 619 (µs)
- Fragmentation: 1
- CPU Usage: 6.05 %
- Priority: 0
- Performs 4 event(s)

View Controls

Previous Instance | Next Instance

View size 4.842 (ms.µs)

☑ Grid 1000 (µs) ☑ Auto

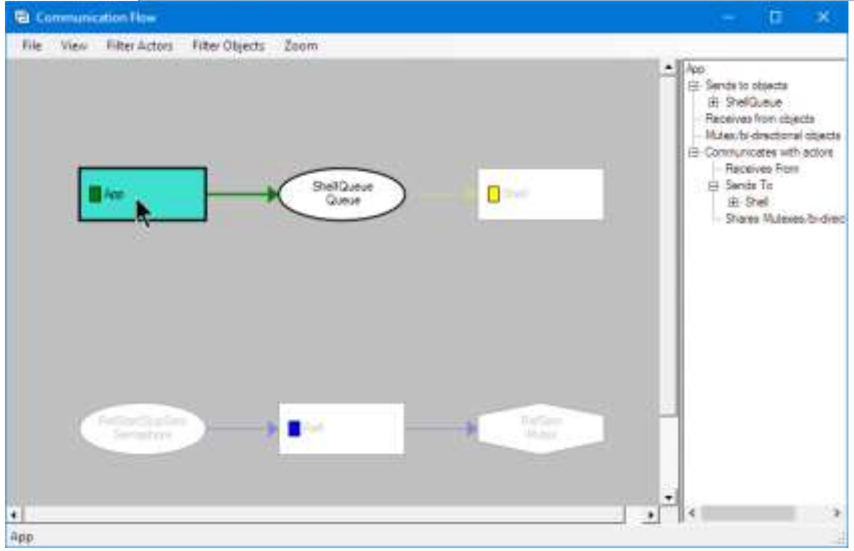
Zoom In | Zoom Out | Preset...

View Filter

- ☑ Actor Instances: 5053 of 5053
- ☑ Kernel Notices: 17287 of 17287
- ☑ Kernel Objects Uses: 4935 of 4935
- ☑ Kernel Service Calls: 9987 of 9987

4.517.532 (s.ms.µs)

Data event in Refl at 4.516.317: xSemaphoreTake(RefStartStopSem, 0) timeout/fail



App
- Sends to objects
  - ShellQueue
- Receives from objects
- Mutex/bi-directional objects
- Communicates with actors
  - Receives From
  - Sends To
    - Shell
  - Shares Mutexes/bi-direc

App

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