MUNI FI

FreeRTOS

Real-time operating system for microcontrollers

Bedřich Said
409874@mail.muni.cz

Faculty of Informatics, Masaryk University

May 16, 2020

What you can find in this presentation

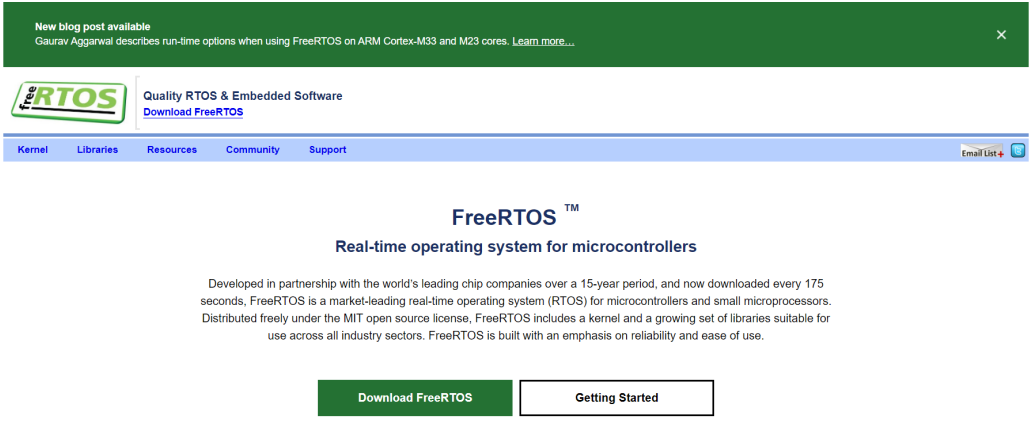
- FreeRTOS implementation in ESP32
- The basics of FreeRTOS in examples
- Concurrent data structures included in FreeRTOS

What is not included

- No deep theory and details about RTOS
- No other RTOS than FreeRTOS
- Nothing about how to compile and run FreeRTOS under your platform

Overview

FreeRTOS webpage



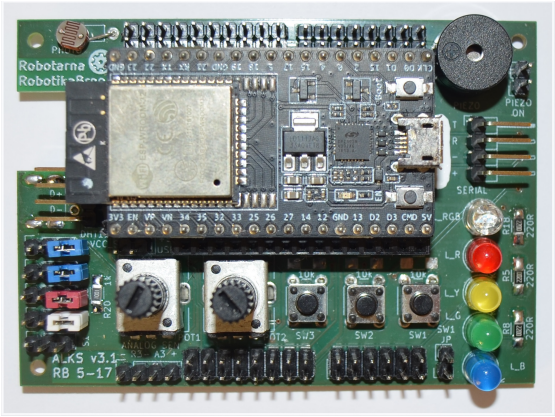
https://www.freertos.org/

We will work with ESP32 dual core processor

www.espressif.com/en/products/hardware/esp32-devkitc/overview

Hardware used for the following examples

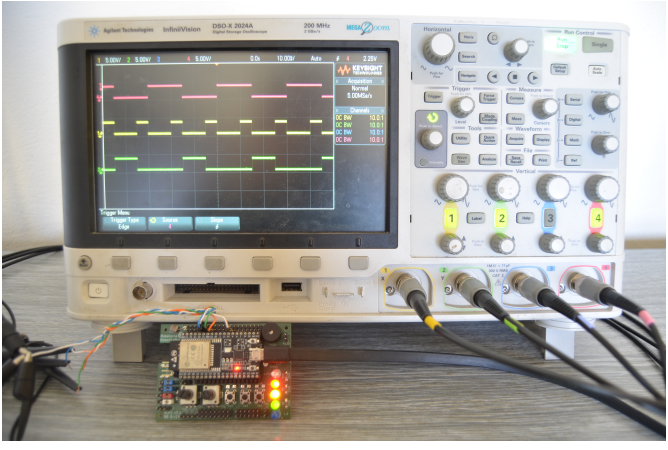
Arduino Learning Kit Starter with ESP32 microcontroller



https://github.com/RoboticsBrno/ArduinoLearningKitStarter

Hardware used for the following examples

... connected to oscilloscope

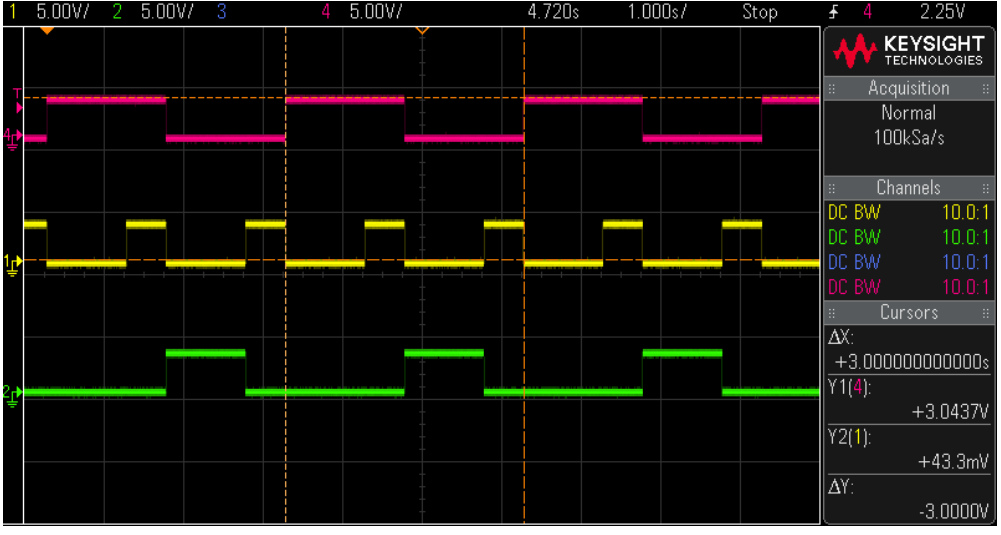


How the oscilloscope works

Presented in the video

- Oscilloscope measures voltage with time
- It displays a graph (X axis = time; Y axis = voltage)
- Our FreeRTOS tasks control LEDs
- We can see which task is running = which LED is blinking
- Fast changes can be seen by the oscilloscope

How the oscilloscope works

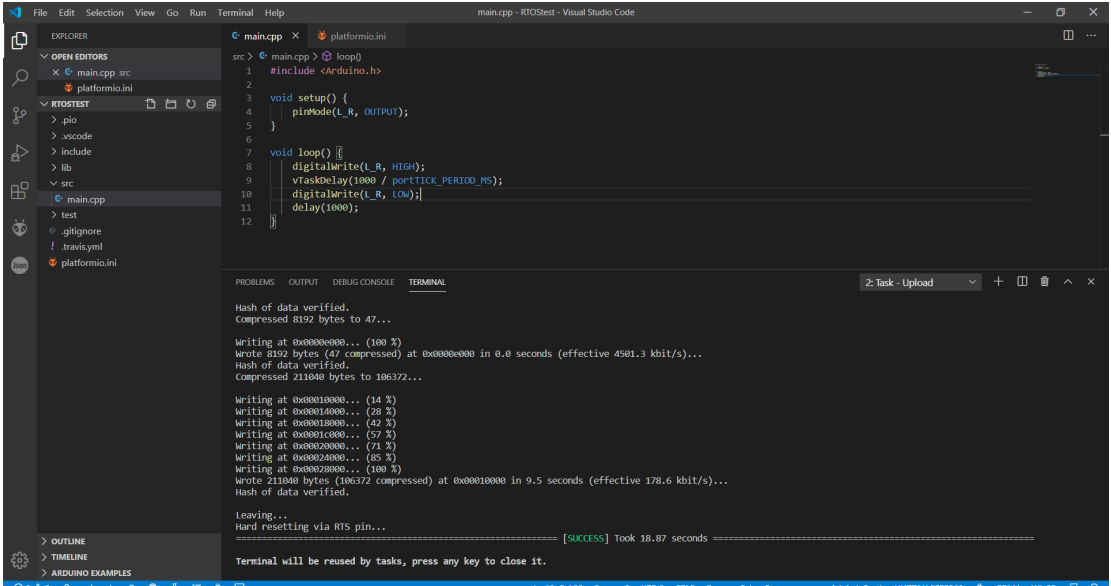


Overview

Minimal working example

```
1  #include <Arduino.h>
2
3  // called one time in the beginning
4  void setup() {
5     pinMode(L_R, OUTPUT); // Activate red LED
6  }
7
8  // repeats forever
9  void loop() {
10    digitalWrite(L_R, HIGH); // Red LED on
11    delay(1000); // wait 1000 ms
12    digitalWrite(L_R, LOW); // Red LED off
13    vTaskDelay(1000); // wait 1000 scheduler ticks
14 }
```

Minimal working example



delay() vs. vTaskDelay()

```
1 // Busy wait for 1000 ms
2 delay(1000);
```

vs.

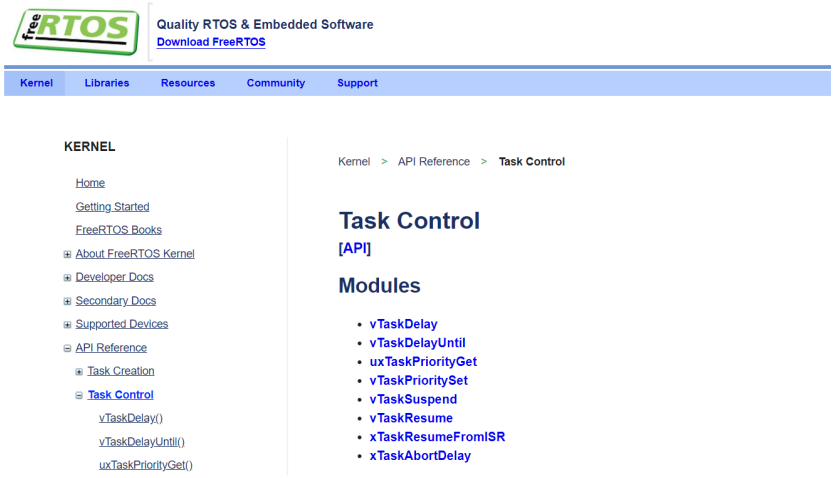
```
1 // Delay a task for a given number of RTOS ticks
2 vTaskDelay(1000);
```

vs.

```
1 // Delay a task for 1000 ms
2 vTaskDelay(1000 / portTICK_PERIOD_MS);
```

https://www.freertos.org/a00127.html

delay() vs. vTaskDelay()



https://www.freertos.org/a00127.html

Note: FreeRTOS naming convention

```
1 void vTaskDelay( const TickType_t xTicksToDelay );
2 BaseType_t xTaskCreate( ... );
```

- **v** – return type, here void
  - u unsigned
  - l long
  - s short
  - c char
  - p pointer
  - x variables of non stdint types
- **TaskDelay** – name in camel case

www.freertos.org/FreeRTOS-Coding-Standard-and-Style-Guide.html

Overview

New task creation

```
1 BaseType_t xTaskCreate(
2    TaskFunction_t pvTaskCode, // Called function
3    const char * const pcName, // Task name (string)
4    configSTACK_DEPTH_TYPE usStackDepth, // Stack size
5    void *pvParameters, // Parameters given to the task
6    UBaseType_t uxPriority, // Priority of the task
7    TaskHandle_t *pxCreatedTask // Task handle
8 );
```

https://www.freertos.org/a00125.html

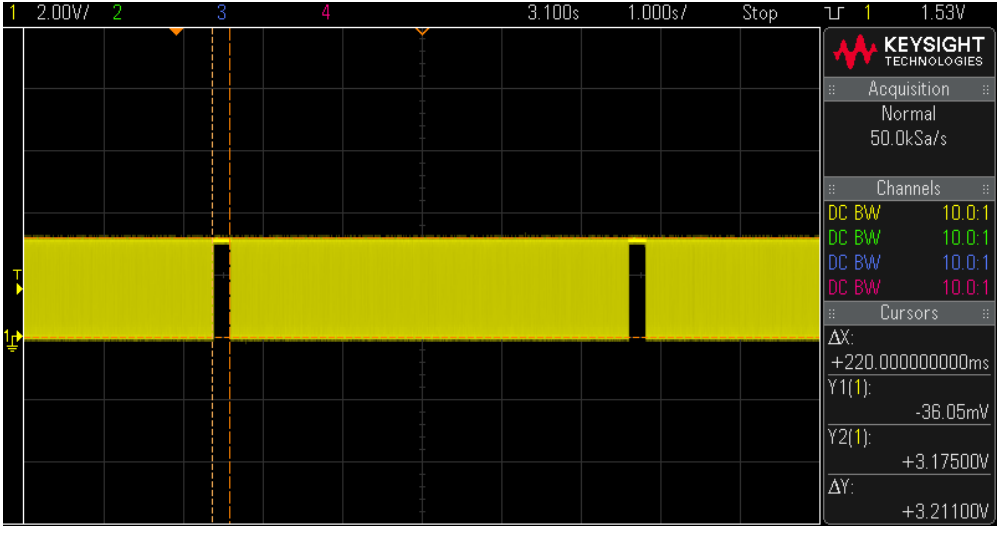
New task creation

Imagine a function

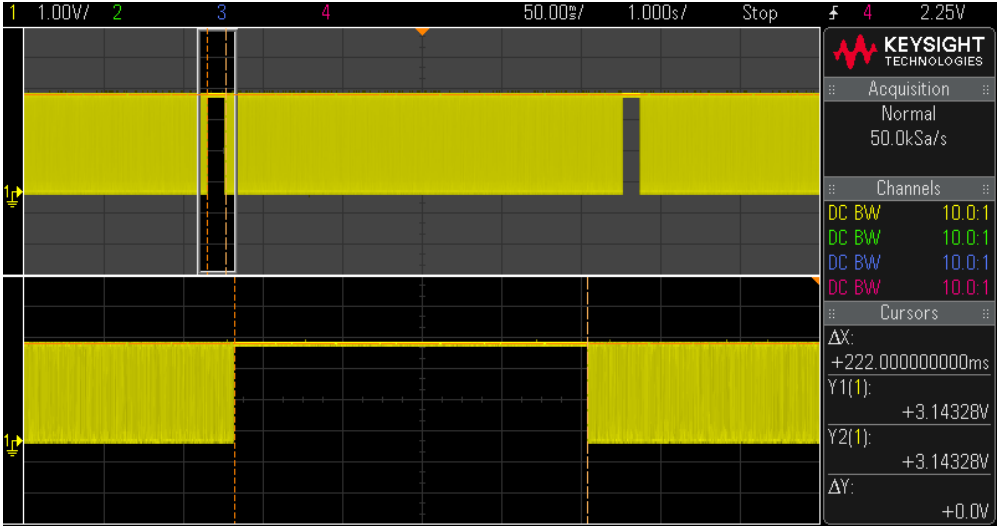
```
1 void blinkLedForever(int led) {
2    for(;;) { // repeat forever
3       digitalWrite(led, HIGH); // led on
4       digitalWrite(led, LOW); // led off
5    }
6 }
```

```
1  void yellowTask(void * pvParameters) {
2     blinkLedForever(L_Y);
3  }
4
5  void setup() {
6     pinMode(L_Y, OUTPUT);
7     xTaskCreate(
8        yellowTask, // Function to implement the task
9        "Yellow task", // Name of the task
10       10000, // Stack size in words
11       NULL, // Task input parameter
12       1, // Priority of the task
13       NULL // Task handle.
14    );
15 }
```

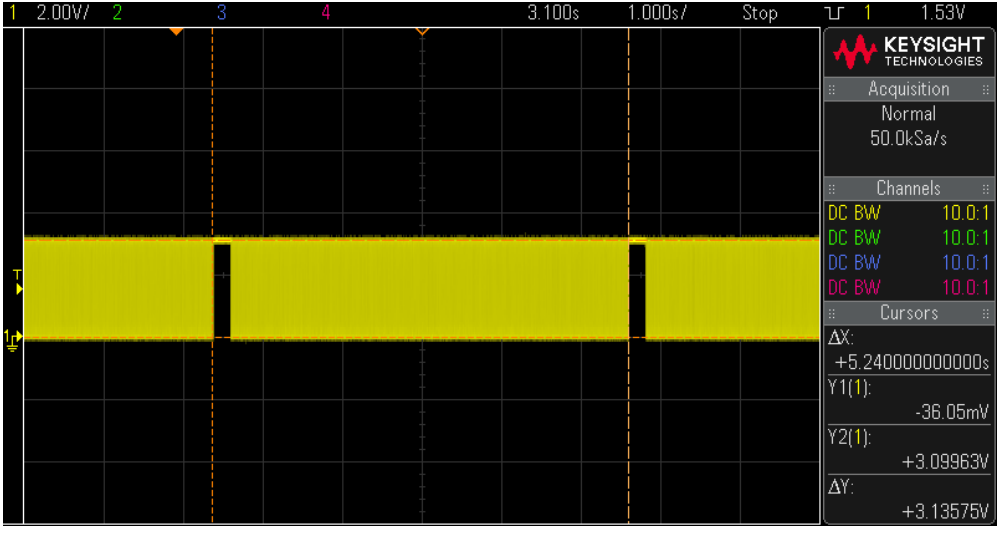
New task creation



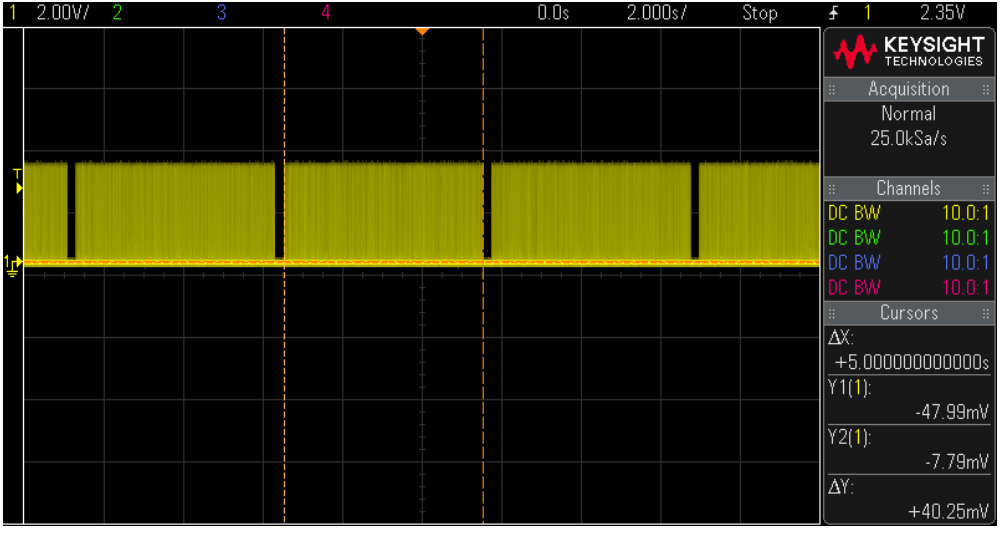
New task creation



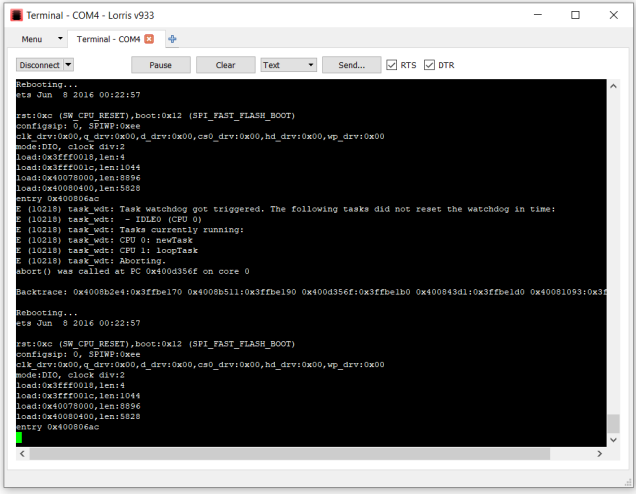
New task creation



New task creation



New task creation



New task creation

Single core

- Scheduler is running on the same core.
- FreeRTOS has some watchdogs.
- If the scheduler (or task) does not trigger the watchdog on time, the watchdog resets the processor.
- Watchdog can be disabled (not recommended).

vs.

Multi core

- One task can occupy the whole core.
- There must be a reserved space for the scheduler at one core.
- Keep in mind the watchdogs.

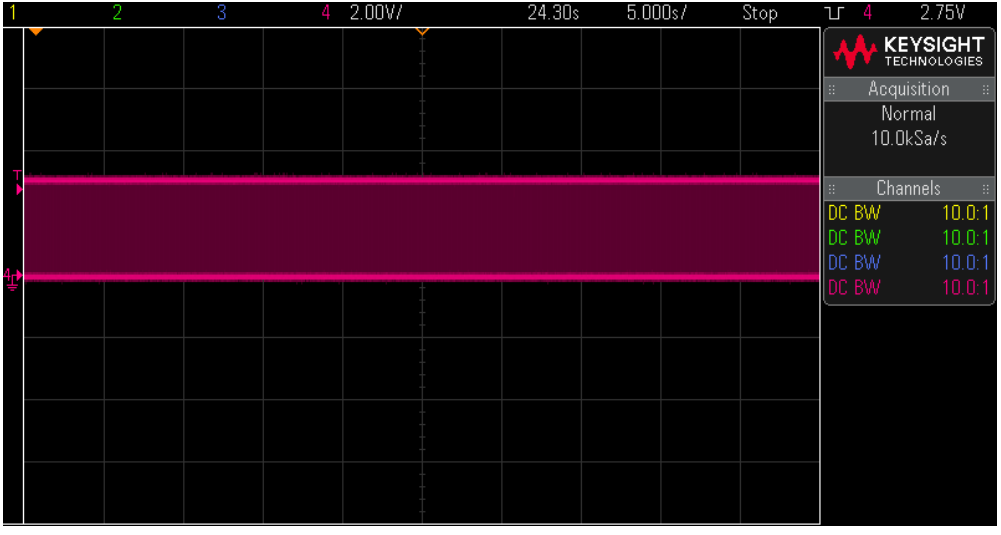
A task with waiting

```
1 void blinkLedForeverWithDelay(int led, uint32_t ticks) {
2    for(;;) {
3       digitalWrite(led, HIGH);
4       vTaskDelay(ticks);
5       digitalWrite(led, LOW);
6       vTaskDelay(ticks);
7    }
8 }
```

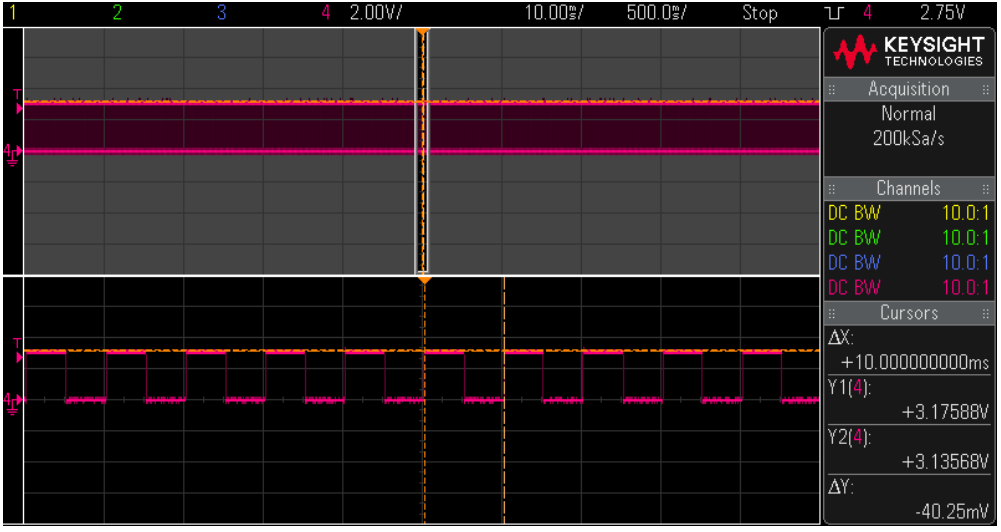
A task with waiting

```
1 void redTask(void * pvParameters) {
2    blinkLedForeverWithDelay(L_R, 5 /*ms*/);
3 }
4
5 void setup() {
6    esp_task_wdt_deinit();
7    pinMode(L_R, OUTPUT);
8    xTaskCreate(redTask, "redTask", 10000, NULL, 1, NULL);
9 }
```

A task with waiting



A task with waiting



The very very common mistakes

Do not forget to reserve a time for scheduler and context switching!

- Your tasks are interrupted when the scheduler is running.
- Context switching consumes time, too.

Do not forget the watch dogs!

- The CPU resets easily hide themselves behind the periodic tasks.

Do not forget the main task!

- If the main() function is still running, it is a task, too.

Overview

Task management

Changes from the previous example

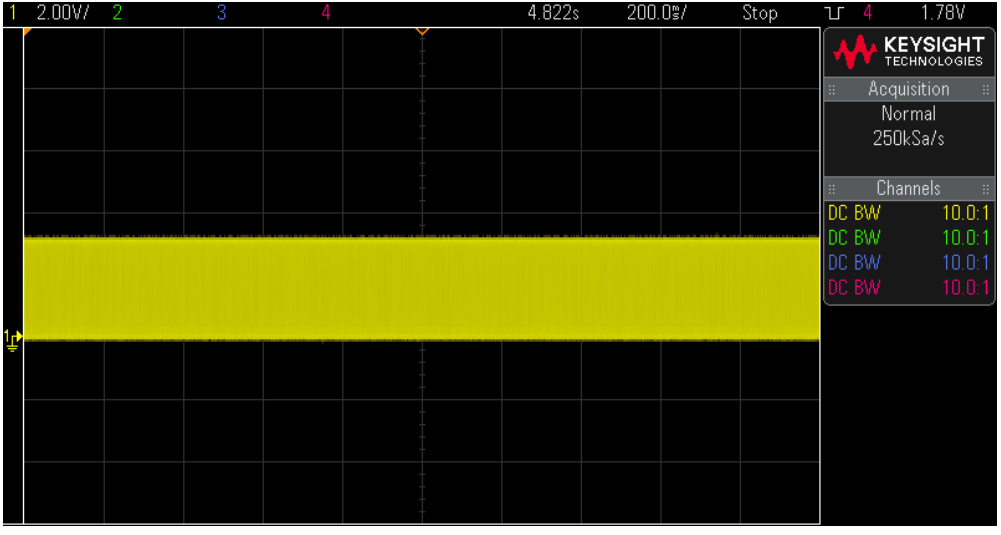
- Yellow task is pinned to Core 1.
- The scheduler is running on the Core 0.
- The task watch dog is disabled.

Remember previous functions

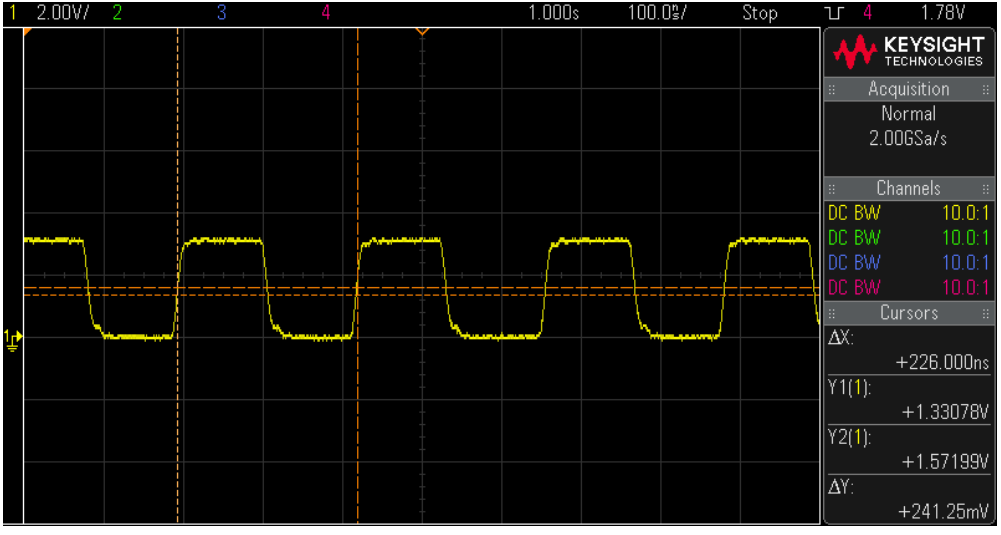
```
1  void blinkLedForever(int led) {
2     for(;;) { // repeat forever
3        digitalWrite(led, HIGH); // led on
4        digitalWrite(led, LOW); // led off
5     }
6  }
7
8  void yellowTask(void * pvParameters) {
9     blinkLedForever(L_Y);
10 }
```

```
1  void setup() {
2     esp_task_wdt_deinit();
3     pinMode(L_Y, OUTPUT);
4
5     xTaskCreatePinnedToCore(
6        yellowTask, // Function to implement the task
7        "yellowTask", // Name of the task
8        10000, // Stack size in words
9        NULL, // Task input parameter
10       2, // Priority of the task
11       NULL, // Task handle.
12       1 // CPU core ID
13    );
14 }
```

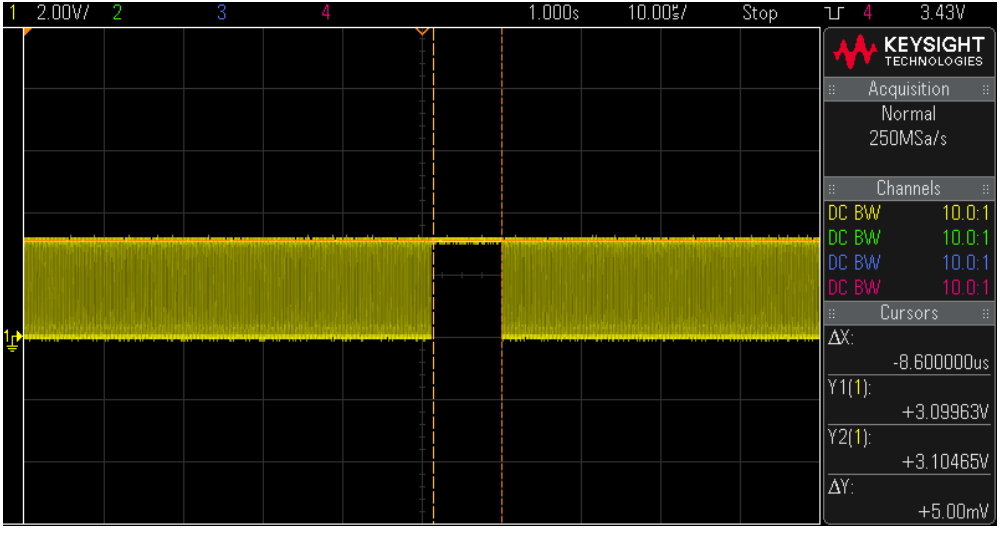
Task management



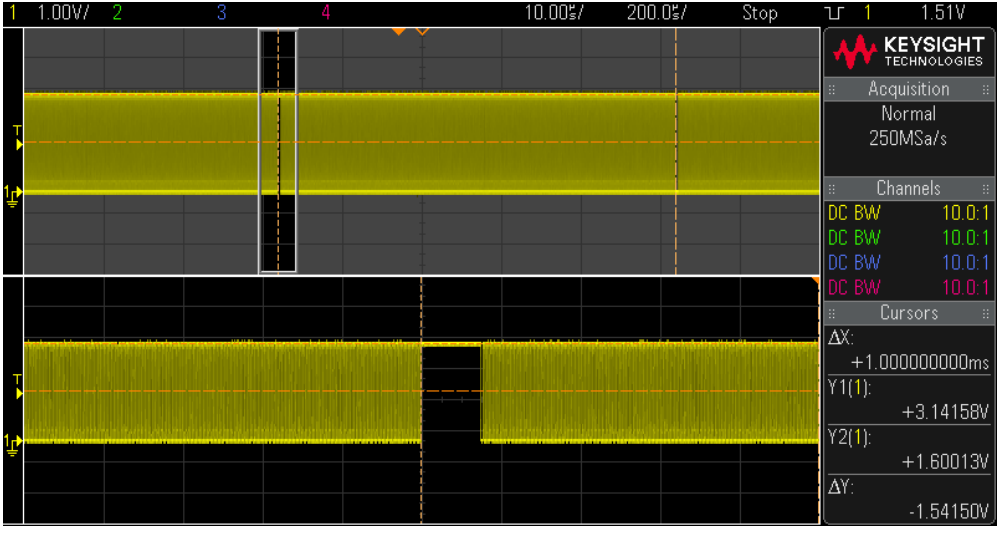
Task management



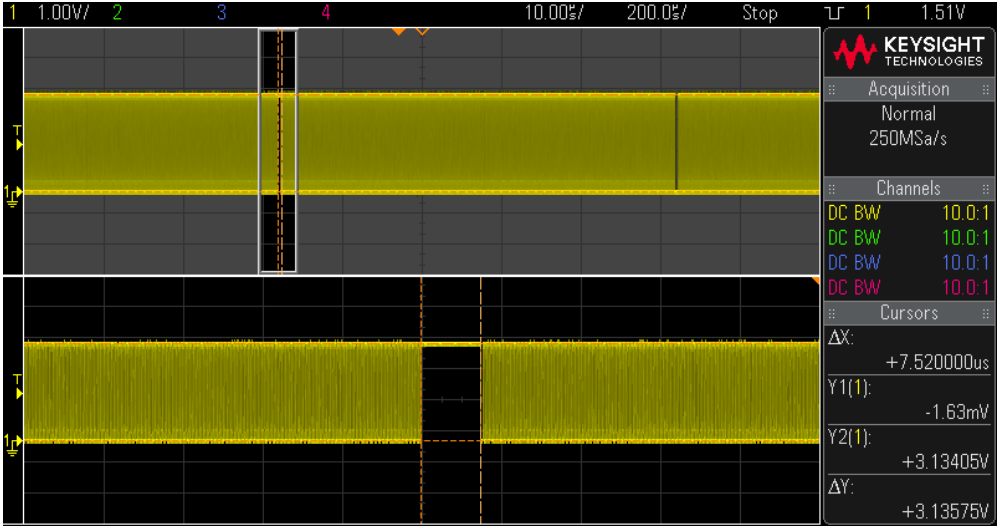
Task management



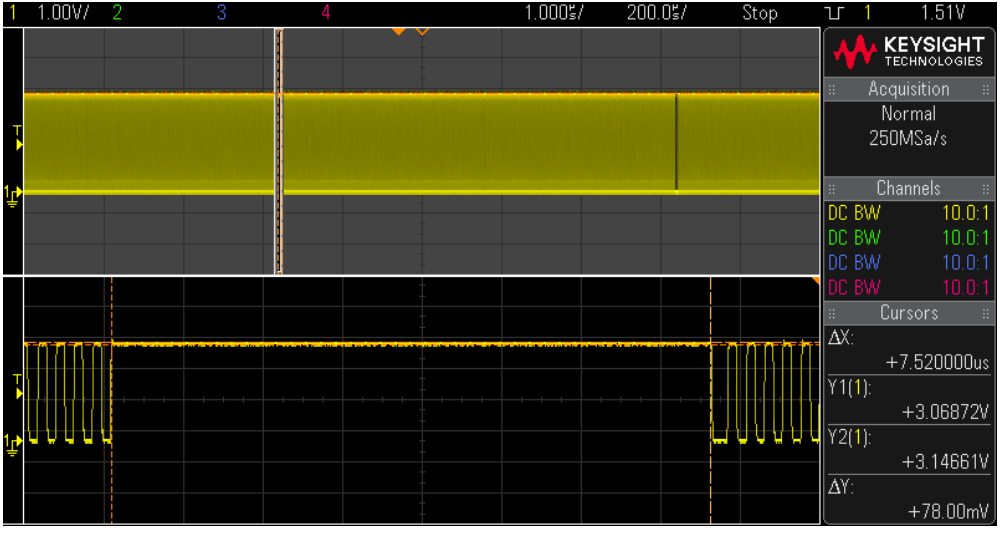
Task management



Task management



Task management



Task management

Properties of the task

- The task is interrupted by the scheduler and by defined SW or HW interrupts.
- If we want to run an uninterrupted thread on the CPU core, do not use RTOS on this CPU core.

Overview

Multiple tasks

Warning: the watchdog will reset the CPU in this example

```
1  void redTask(void * pvParameters) {
2     blinkLedForever(L_R);
3  }
4
5  void yellowTask(void * pvParameters) {
6     blinkLedForever(L_Y);
7  }
8
9  void greenTask(void * pvParameters) {
10    blinkLedForever(L_G);
11 }
```

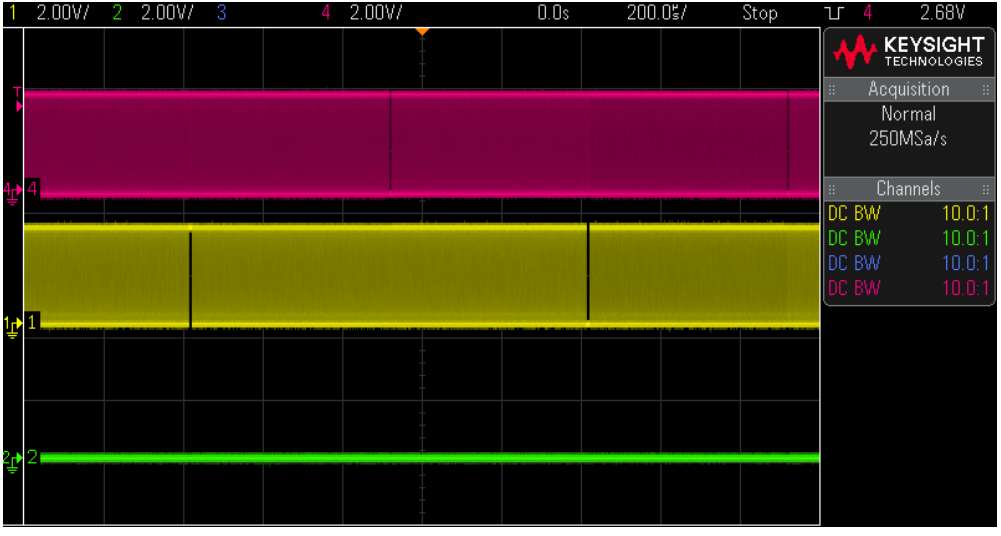
```
1  void setup() {
2     esp_task_wdt_deinit();
3     pinMode(L_R, OUTPUT);
4     pinMode(L_Y, OUTPUT);
5     pinMode(L_G, OUTPUT);
6
7     xTaskCreate(redTask, "redTask", 10000, NULL, 1, NULL);
8     xTaskCreate(yellowTask,"yellowTask",10000,NULL,1,NULL);
9     blinkLedForever(L_G);
10 }
```

Multiple tasks

Now let's change the task priorities

```
1 (...)
2 xTaskCreate(redTask, "redTask", 10000, NULL, 2, NULL);
3 xTaskCreate(yellowTask,"yellowTask",10000,NULL,3,NULL);
4 blinkLedForever(L_G);
5 (...)
```

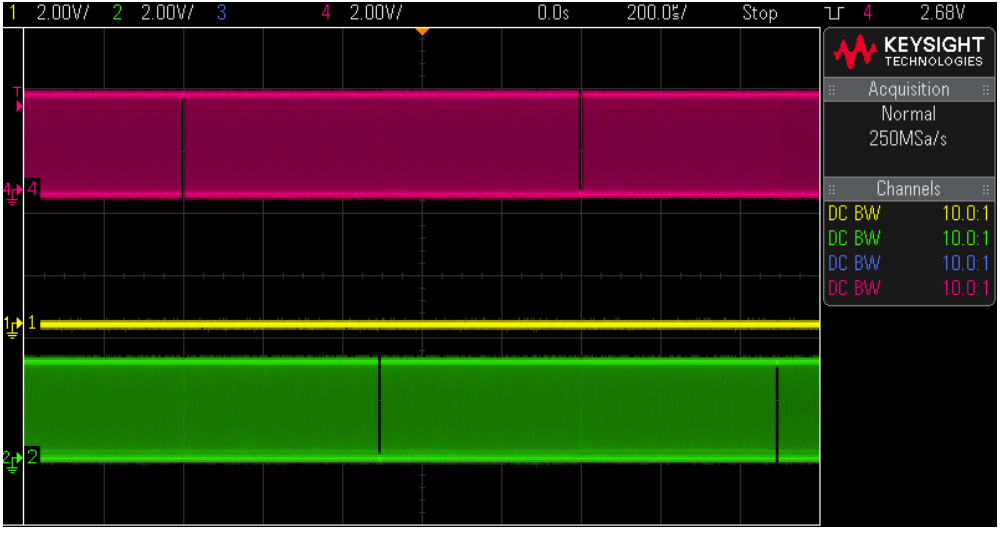
Multiple tasks



Now let's change the task priorities

```
1 (...)
2 xTaskCreate(redTask, "redTask", 10000, NULL, 0, NULL);
3 xTaskCreate(yellowTask,"yellowTask",10000,NULL,0,NULL);
4 blinkLedForever(L_G);
5 (...)
```

Multiple tasks



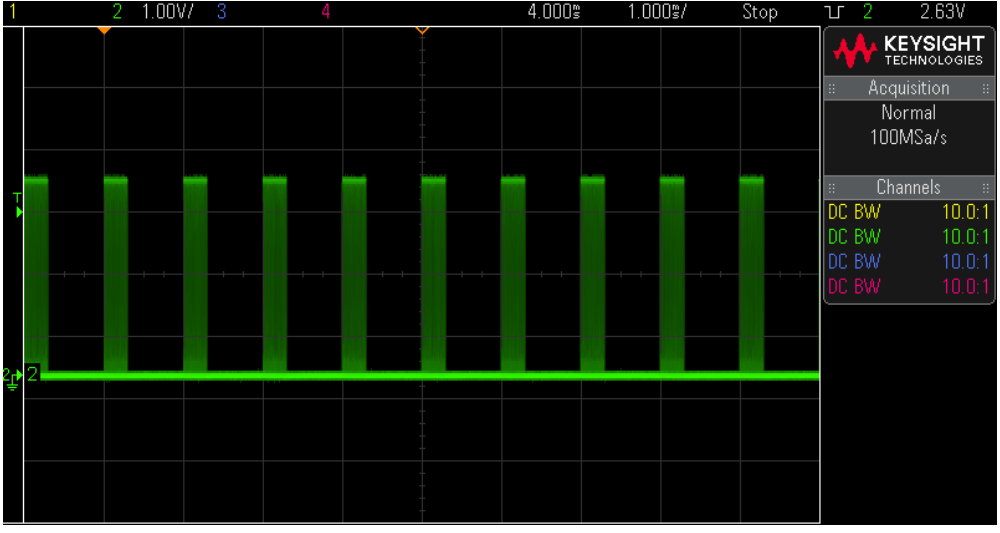
Overview

Tasks and jobs

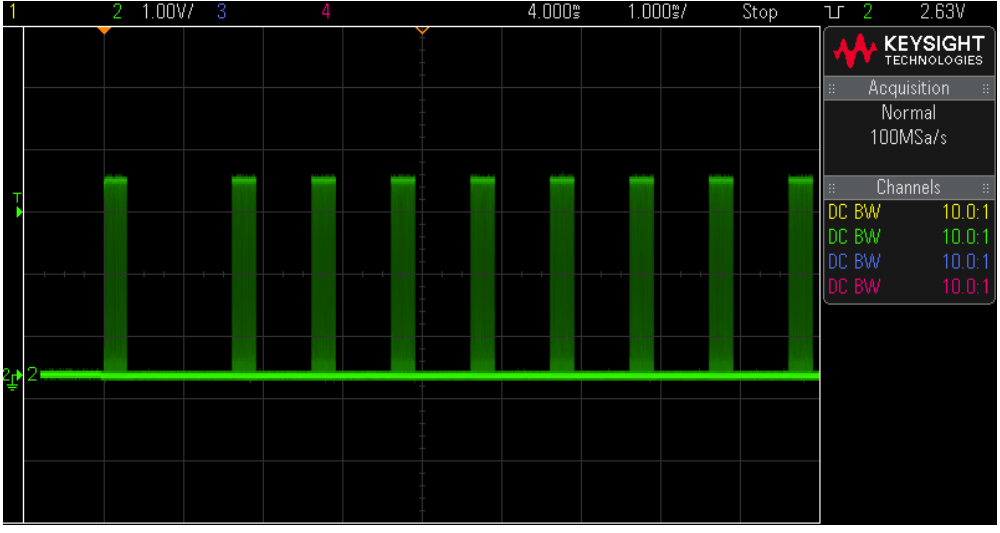
Imagine a function

```
1  void blinkLedForTime(uint8_t led,
2                       uint64_t run_us,
3                       uint64_t wait_ms) {
4     for(;;) {
5        // Blinking for specified time in microseconds
6        for(uint64_t t = micros(); t + run_us > micros();) {
7           digitalWrite(led, HIGH);
8           digitalWrite(led, LOW);
9        }
10       vTaskDelay(wait_ms);
11    }
12 }
```

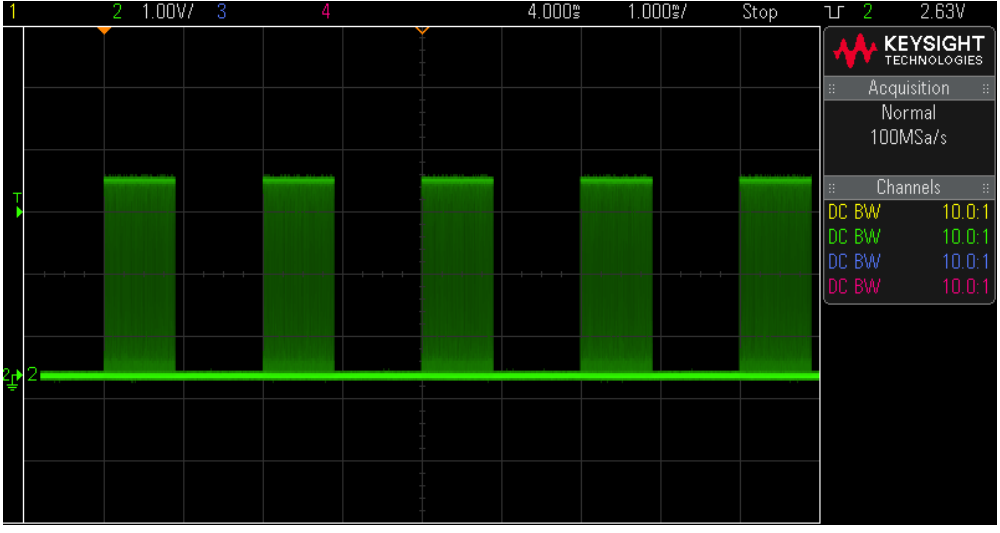
```
1 blinkLedForTime(L_G, 300, 1);
```



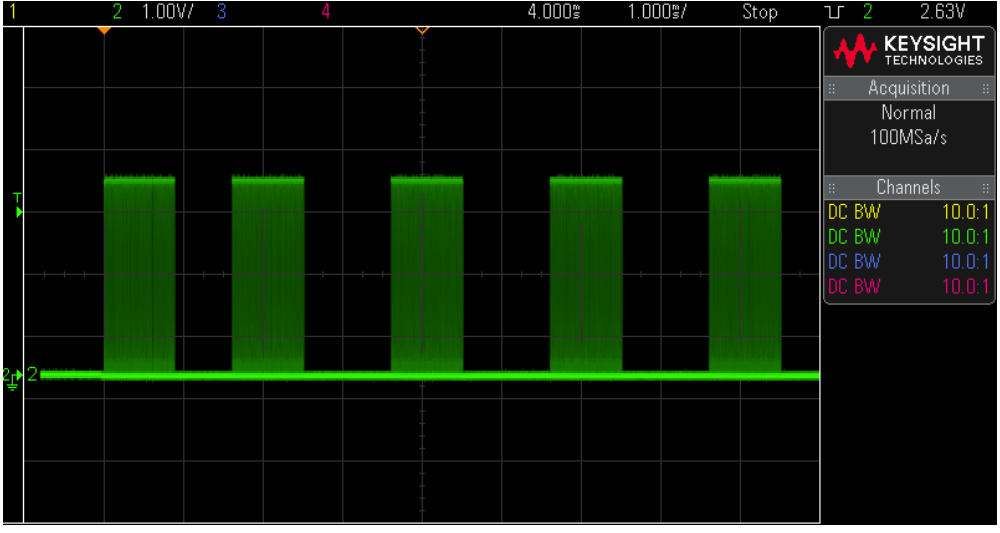
```
1 blinkLedForTime(L_G, 300, 1);
```



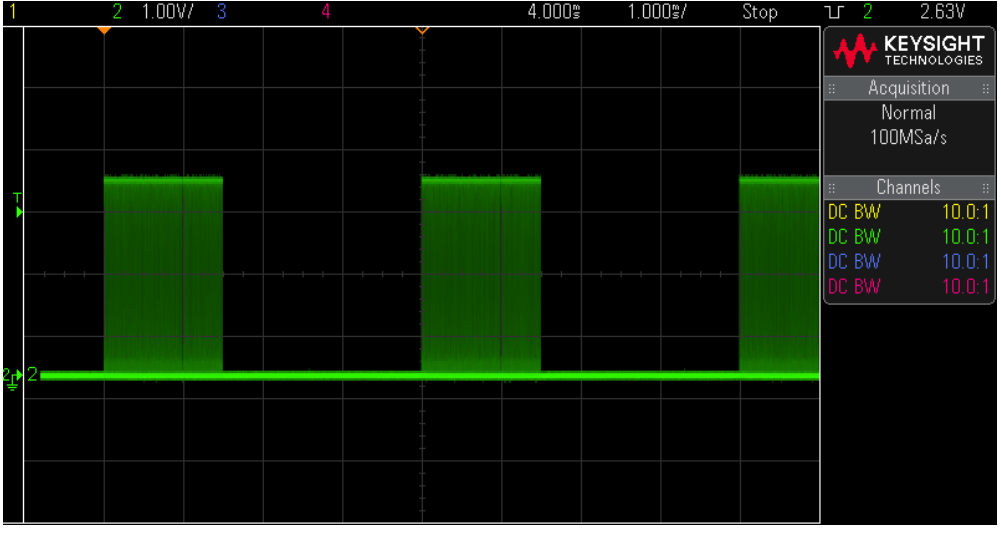
```
1 blinkLedForTime(L_G, 900, 1);
```



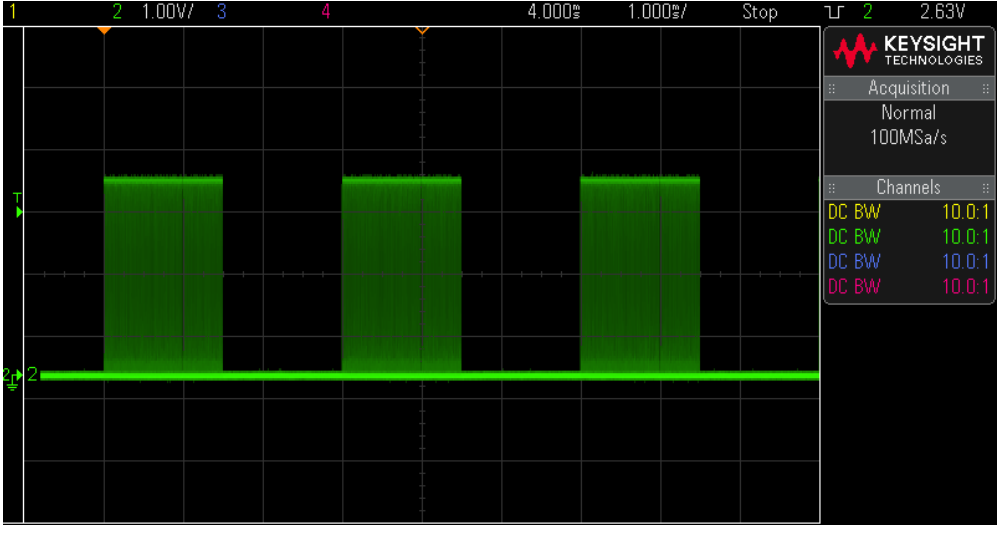
```
1 blinkLedForTime(L_G, 900, 1);
```



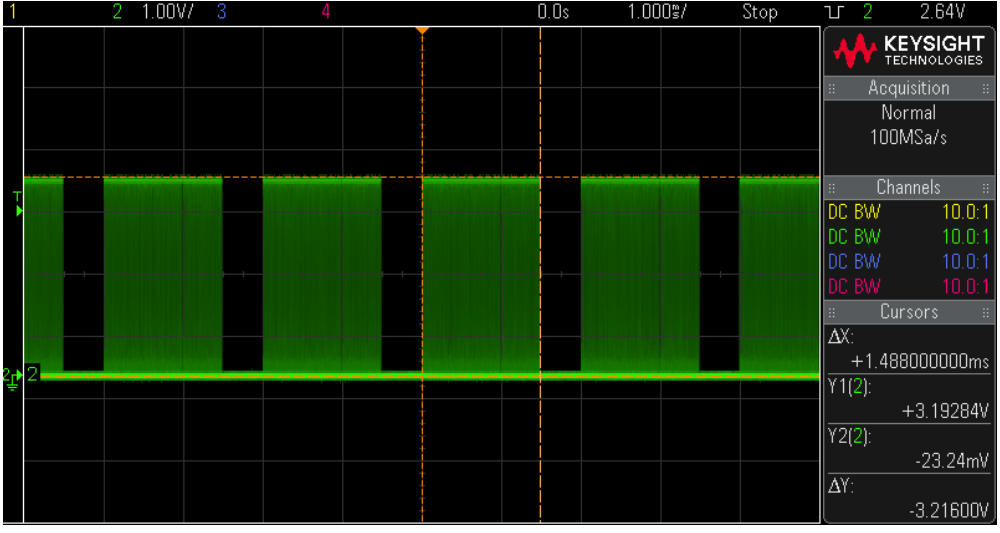
```
1 blinkLedForTime(L_G, 1500, 2);
```



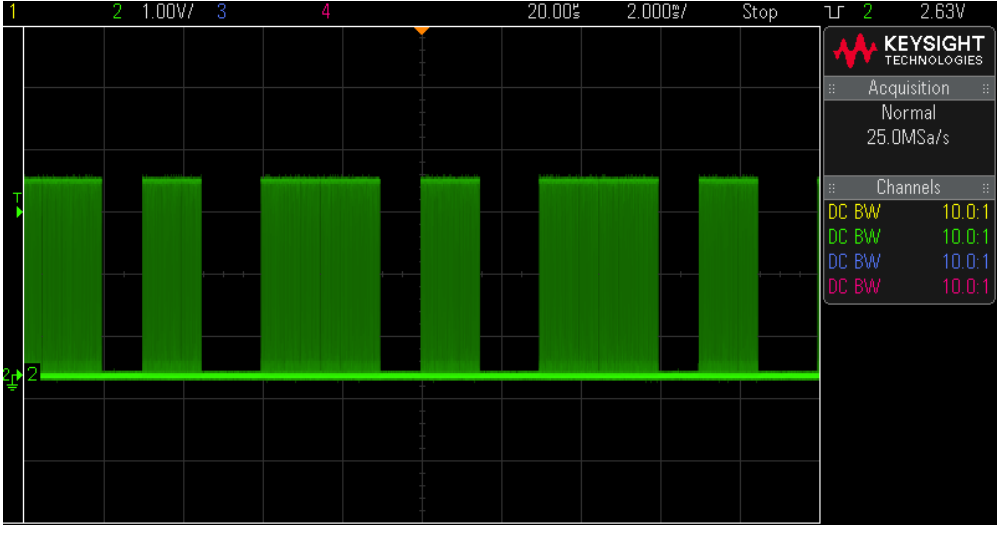
```
1 blinkLedForTime(L_G, 1500, 1);
```



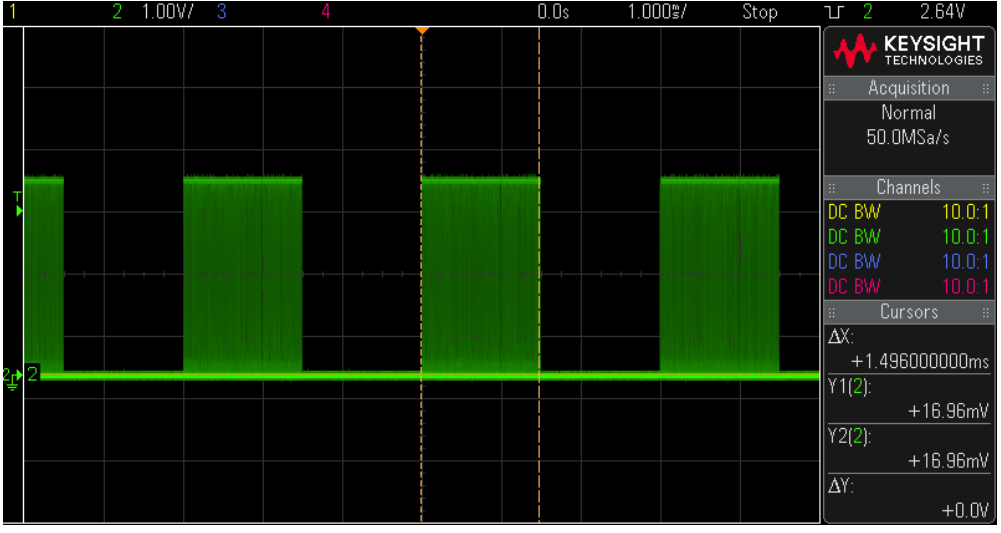
```
1 blinkLedForTime(L_G, 1488, 1);
```



```
1 blinkLedForTime(L_G, 1489, 1);
```



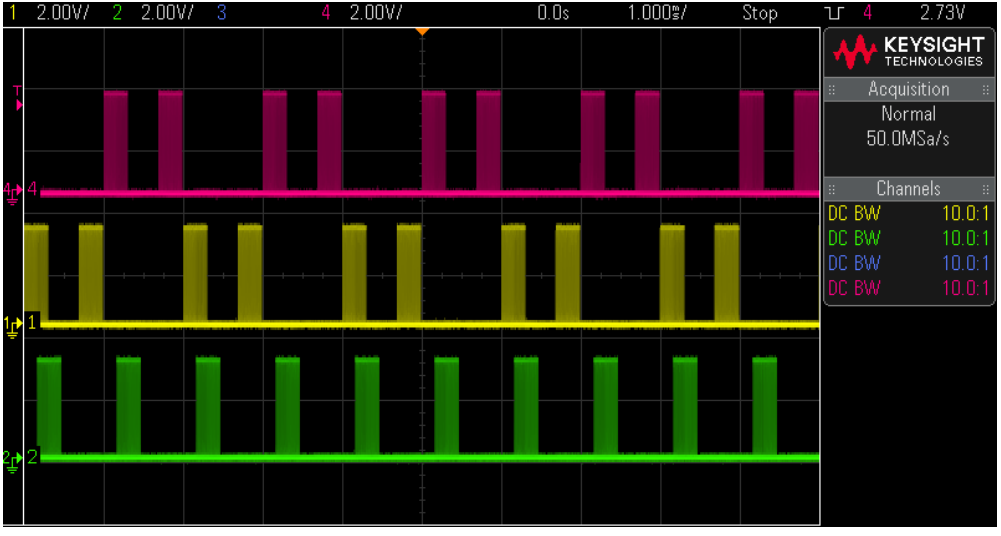
```
1 blinkLedForTime(L_G, 1490, 1);
```



3 periodic tasks on 2 CPU cores

```
1  void redTask(void * pvParameters) {
2     blinkLedForTime(L_R, 300, 1);
3  }
4
5  void yellowTask(void * pvParameters) {
6     blinkLedForTime(L_Y, 300, 1);
7  }
8
9  void setup() {
10 (...)
11    xTaskCreate(redTask,"redTask",10000,NULL,3,NULL,0);
12    xTaskCreate(yellowTask,"yellowTask",10000,NULL,2,NULL,0);
13    blinkLedForTime(L_G, 300, 1);
14 }
```

3 periodic tasks on 2 CPU cores



Task control functions

- xTaskCreate(...)
- xTaskCreatePinnedToCore(...)
- vTaskDelete(...)
- vTaskDelay(...)
- xTaskDelayUntil(...)
- vTaskSuspend(...)
- vTaskResume(...)
- taskYIELD()
- ...

Overview

Timers

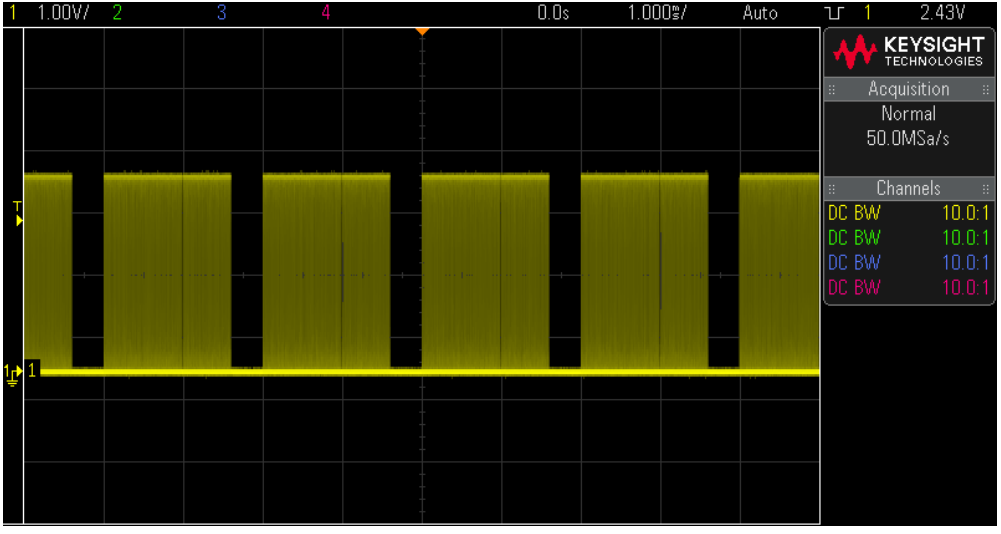
- Good for periodic tasks
- Limited number of hardware timers
- https://www.freertos.org/RTOS-software-timer.html

```
1 TimerHandle_t xTimerCreate(
2    const char * const pcTimerName,
3    const TickType_t xTimerPeriod,
4    const UBaseType_t uxAutoReload,
5    void * const pvTimerID,
6    TimerCallbackFunction_t pxCallbackFunction
7 );
```

Timers

```
1  void vTimerCallback(TimerHandle_t xTimer) {
2     blinkLedOnce(L_Y, 1600);
3  }
4
5  void setup() {
6     pinMode(L_Y, OUTPUT);
7     TimerHandle_t xTimer = xTimerCreate(
8        "Timer1", 2, pdTRUE, ( void * ) 0, vTimerCallback
9     );
10    xTimerStart(xTimer, 0);
11 }
```

Timers


1 1.00V/ 2 3 4 0.0s 1.000s/ Auto 1 2.43V
KEYSIGHT TECHNOLOGIES
Acquisition
Normal
50.0MSa/s
Channels
DC BW 10.0:1
DC BW 10.0:1
DC BW 10.0:1
DC BW 10.0:1

Overview

Imagine a function

```
1  void blinkLedForTimeCritical(
2     uint8_t led, uint64_t run_us,
3     uint64_t wait_ms, portMUX_TYPE *myMutex
4  ) {
5     for(;;) {
6  //  portENTER_CRITICAL(myMutex);
7        blinkLedOnce(led, run_us);
8  //  portEXIT_CRITICAL(myMutex);
9        vTaskDelay(wait_ms);
10    }
11 }
```

Imagine a function

```
1  void blinkLedForTimeCritical(
2     uint8_t led, uint64_t run_us,
3     uint64_t wait_ms, portMUX_TYPE *myMutex
4  ) {
5     for(;;) {
6        portENTER_CRITICAL(myMutex);
7        blinkLedOnce(led, run_us);
8        portEXIT_CRITICAL(myMutex);
9        vTaskDelay(wait_ms);
10    }
11 }
```

Critical sections

```
1 portMUX_TYPE myMutex = portMUX_INITIALIZER_UNLOCKED;
2
3 void redTask(void * pvParameters) {
4    blinkLedForTimeCritical(L_R, 300, 1, &myMutex);
5 }
6
7 void yellowTask(void * pvParameters) {
8    blinkLedForTimeCritical(L_Y, 300, 1, &myMutex);
9 }
```

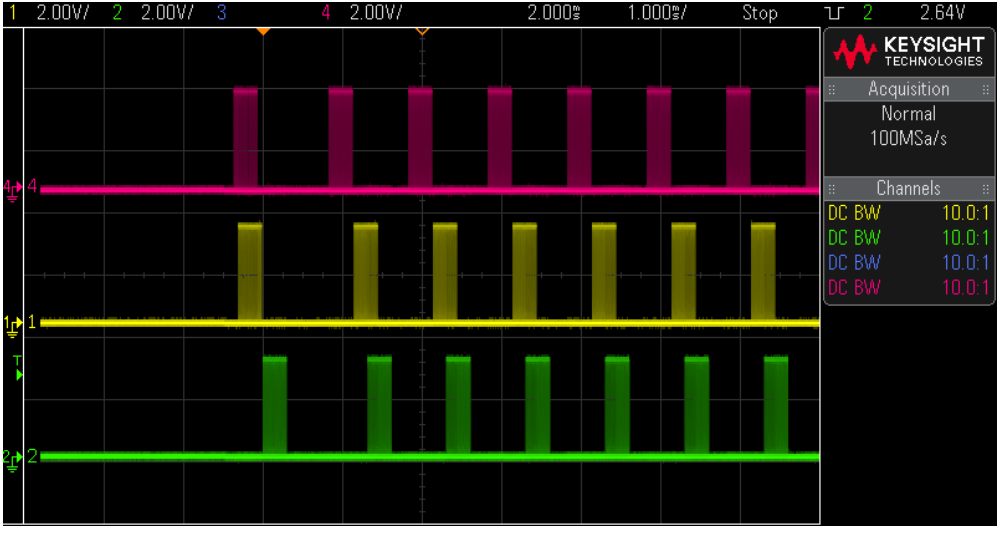
https://www.freertos.org/taskENTER_CRITICAL_taskEXIT_CRITICAL.html

Critical sections

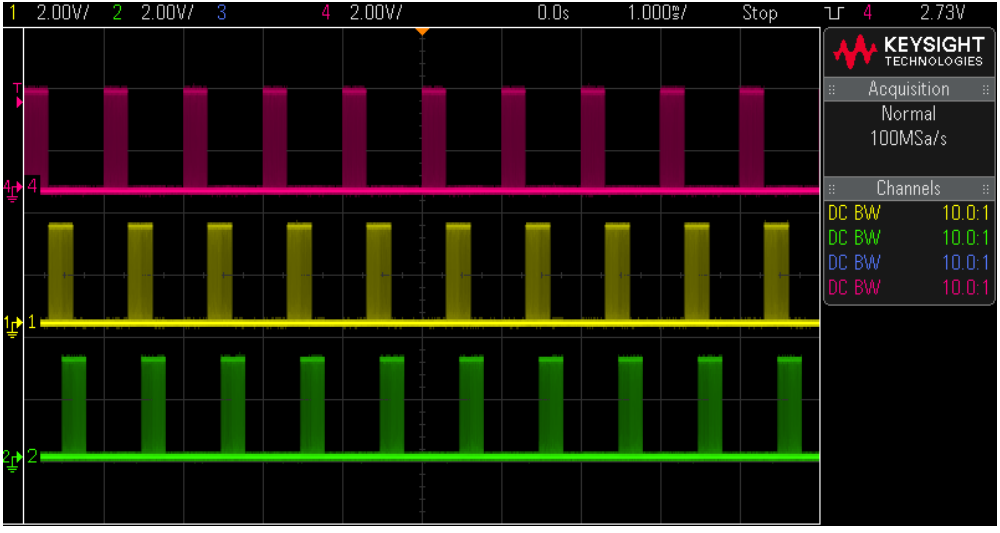
```
1 void setup() {
2    initLEDs();
3
4    xTaskCreate(redTask, "redTask", 10000, NULL, 3, NULL);
5    xTaskCreate(yellowTask,"yellowTask",10000,NULL,2,NULL);
6    blinkLedForTimeCritical(L_G, 300, 1, &myMutex);
7 }
```

https://www.freertos.org/taskENTER_CRITICAL_taskEXIT_CRITICAL.html

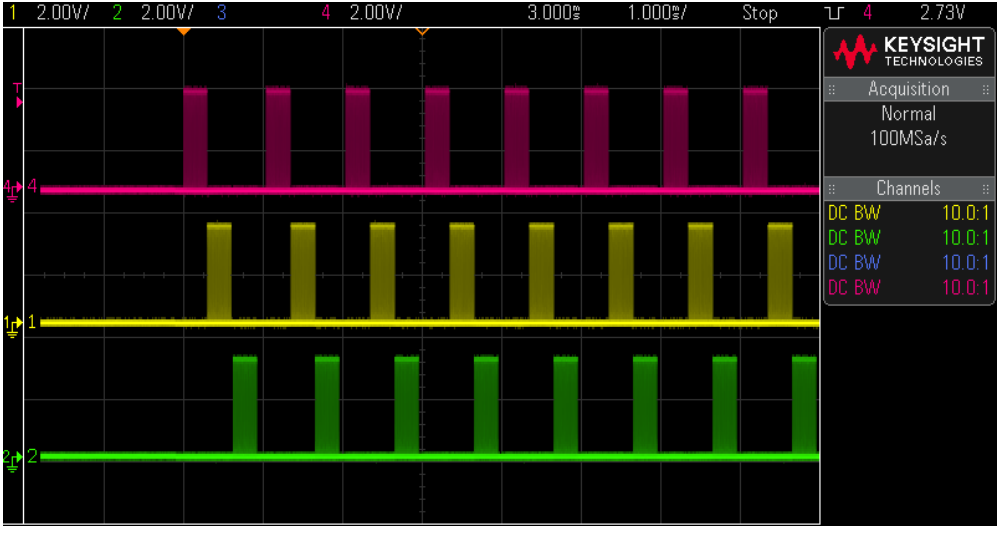
No critical sections



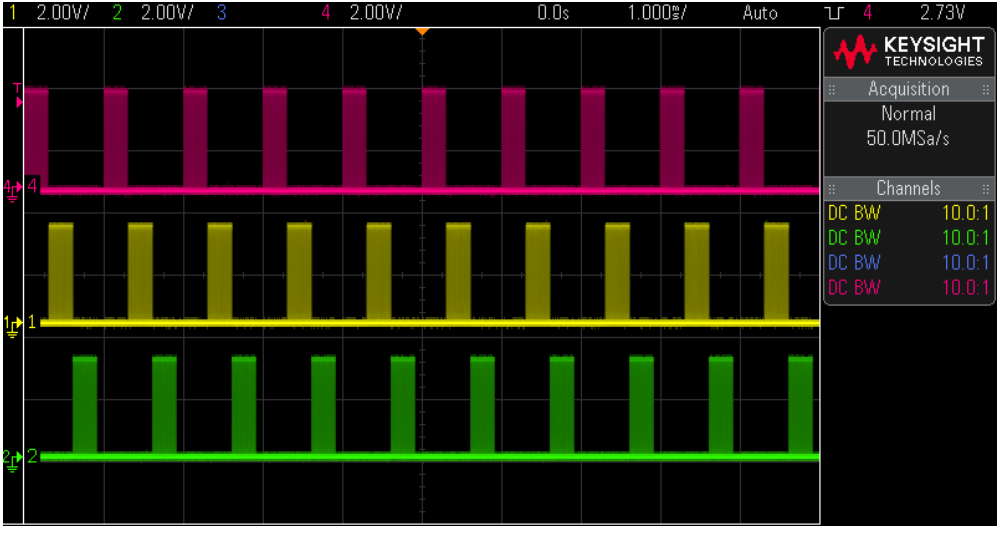
No critical sections



Critical sections



Critical sections



Overview

Queues

- Producer/consumer layout
- More tasks can use the same queue simultaneously

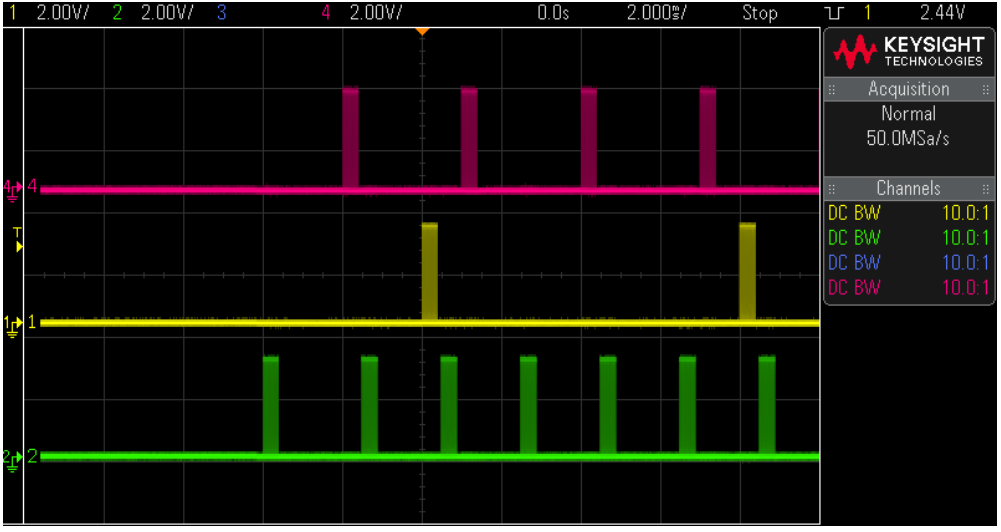
```
1 QueueHandle_t myQueue = xQueueCreate(10, sizeof(uint32_t));
2
3 xQueueSend(myQueue, (void*) &data, (TickType_t) 0);
4
5 xQueueReceive(myQueue, &data, (TickType_t) 0);
```

https://www.freertos.org/Embedded-RTOS-Queues.html

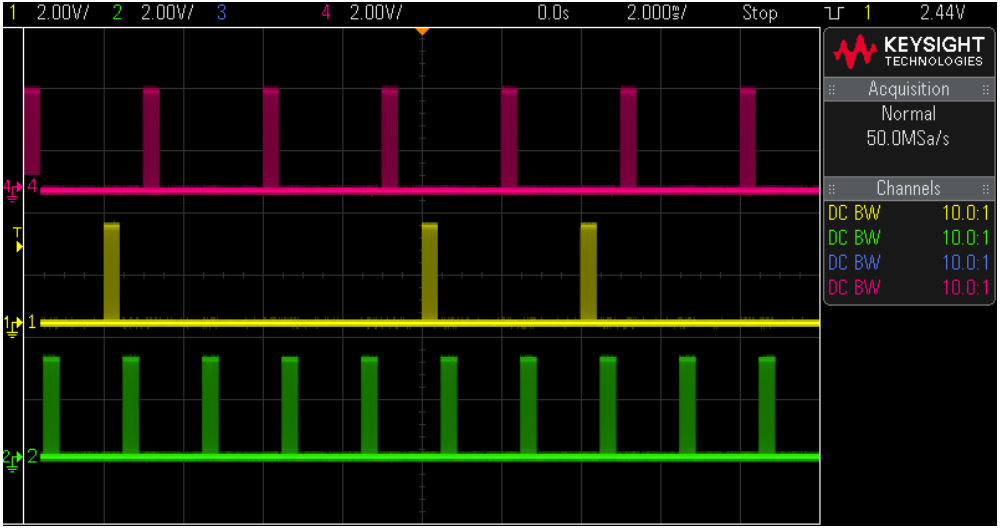
Queues (example)

- Green task sends every 2 ms
- Red task listens every 3 ms
- Yellow task listens every 4 ms

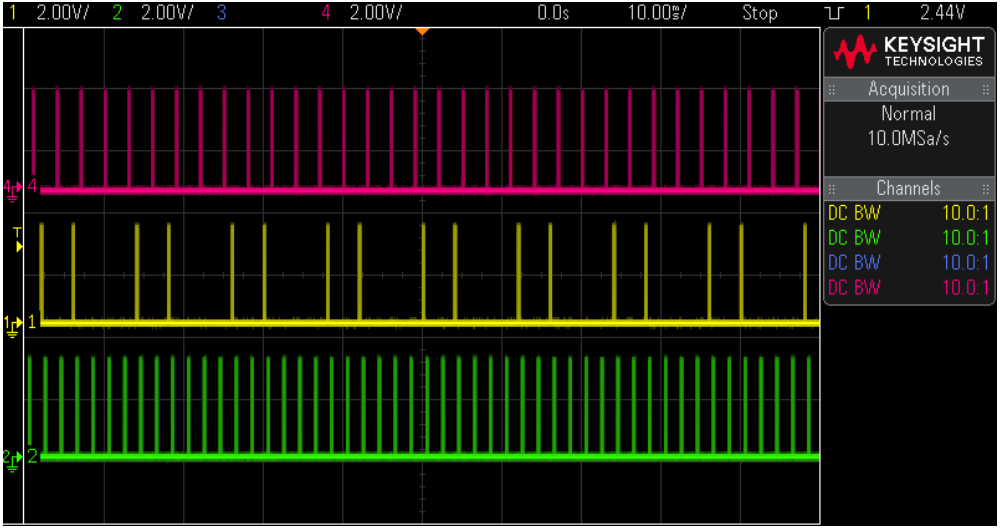
Queues (example)

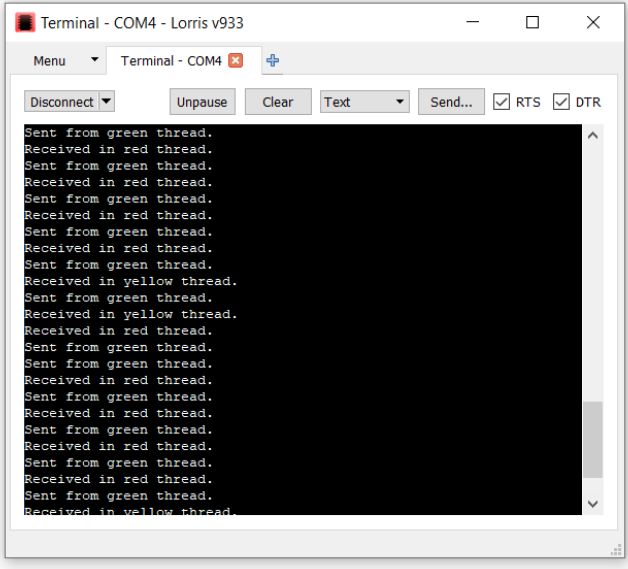


Queues (example)

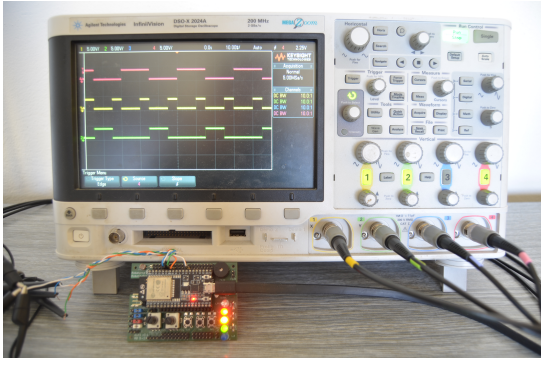


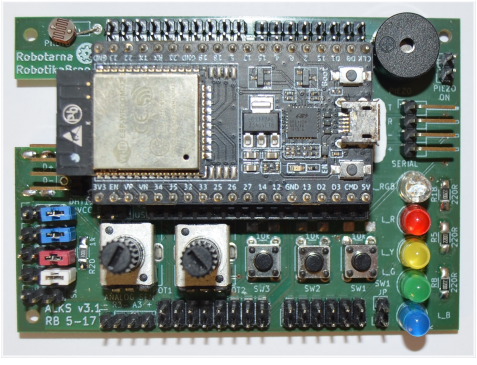
Queues (example)




Terminal - COM4 - Lorris v933
Menu
Terminal - COM4
Disconnect
Unpause
Clear
Text
Send...
RTS
DTR
Sent from green thread.
Received in red thread.
Sent from green thread.
Received in red thread.
Sent from green thread.
Received in red thread.
Sent from green thread.
Received in red thread.
Sent from green thread.
Received in yellow thread.
Sent from green thread.
Received in yellow thread.
Received in red thread.
Sent from green thread.
Sent from green thread.
Received in red thread.
Sent from green thread.
Received in red thread.
Sent from green thread.
Received in red thread.
Sent from green thread.
Received in red thread.
Sent from green thread.
Received in yellow thread.

Thank you!





Questions?

Bedřich Said: 409874@mail.muni.cz

MUNI
FACULTY
OF INFORMATICS