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Luis Ubieda
Lead Firmware Engineer

700 N Wickham Rd. Suite 105
Melbourne, FL 32935

croxel.com

Real-Time Sensor Performance with Zephyr

CogniPilot Conference 2025

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Agenda

1. Introduction
2. Basics of RTIO
3. The Async Paradigm
4. Sensor RTIO-based API
5. RTIO and Real-Time
6. Sensor Performance Benchmarks
7. Real-Time Sensors in CogniPilot
8. Q&A

Introduction

RTIO (Real-Time I/O)

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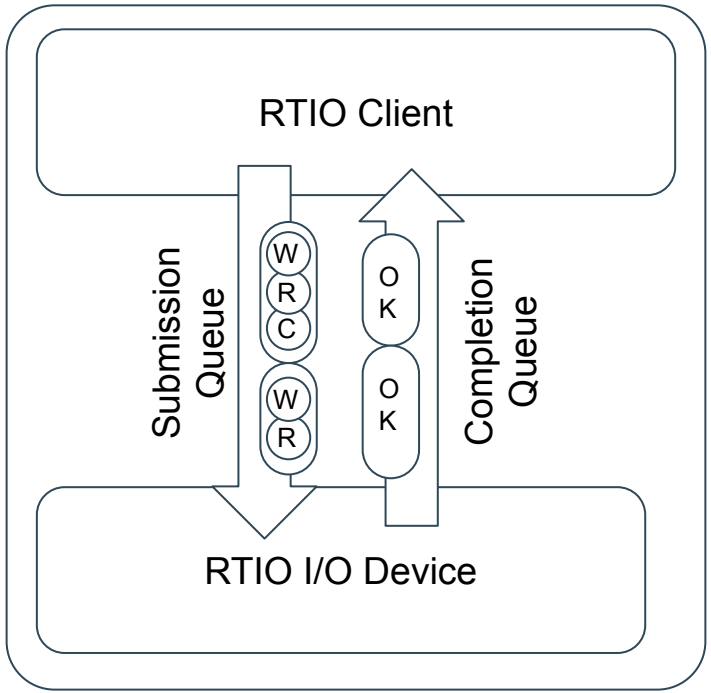
Basics of RTIO

Elements of an RTIO

- RTIO Client
- RTIO I/O Device
- RTIO Executor
- Optional: a Memory Pool.
- A Submission Queue
- A Completion Queue

Types of Operations:

- Write
- Read
- Callback
- Delay



Examples of I/O Devices:

- Sensors
- I/O Buses (e.g: SPI, I2C, I3C, etc)

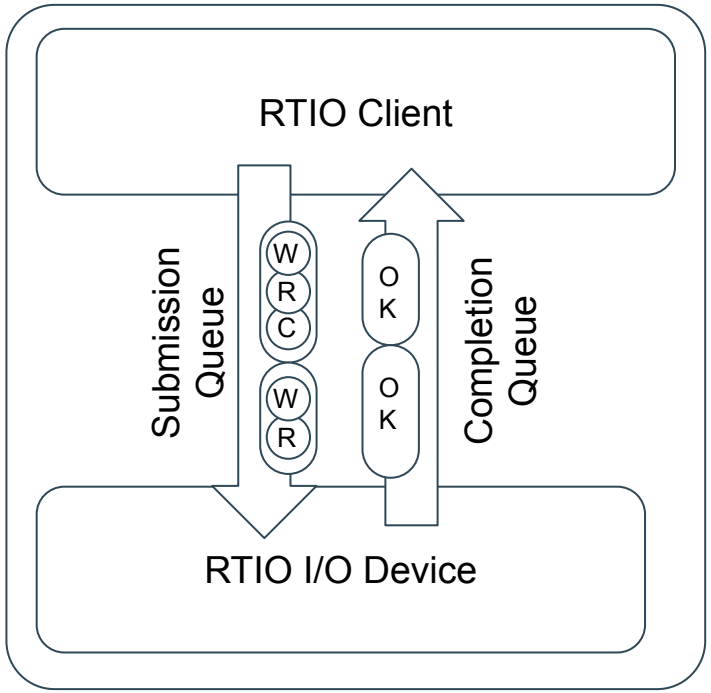
Example Applications:

- Control Systems (e.g: Robotics)
- High-Bandwidth Data-Acquisition Systems

Basics of RTIO

Design Goals of RTIO

- Minimize thread context switching
- Minimize data copying
- Optimize batch gathering and processing of multiple data-streams
- Compatible with Userspace-based applications
- Side-effect: serves as a IODEV abstraction (e.g: Bus-driver)



The Async Paradigm

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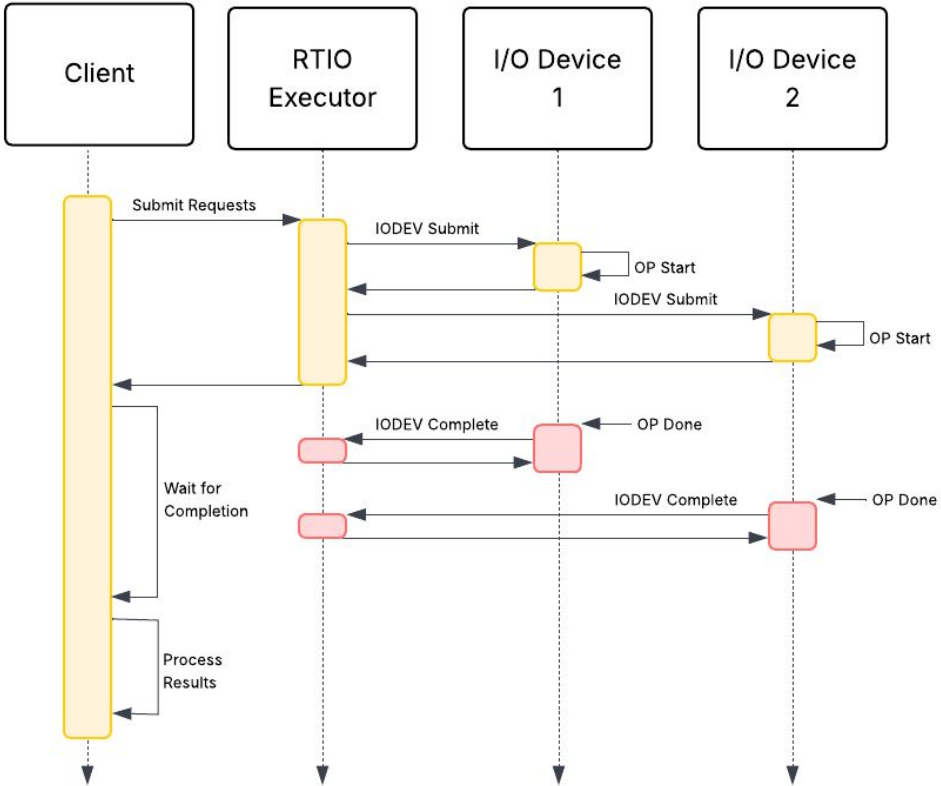
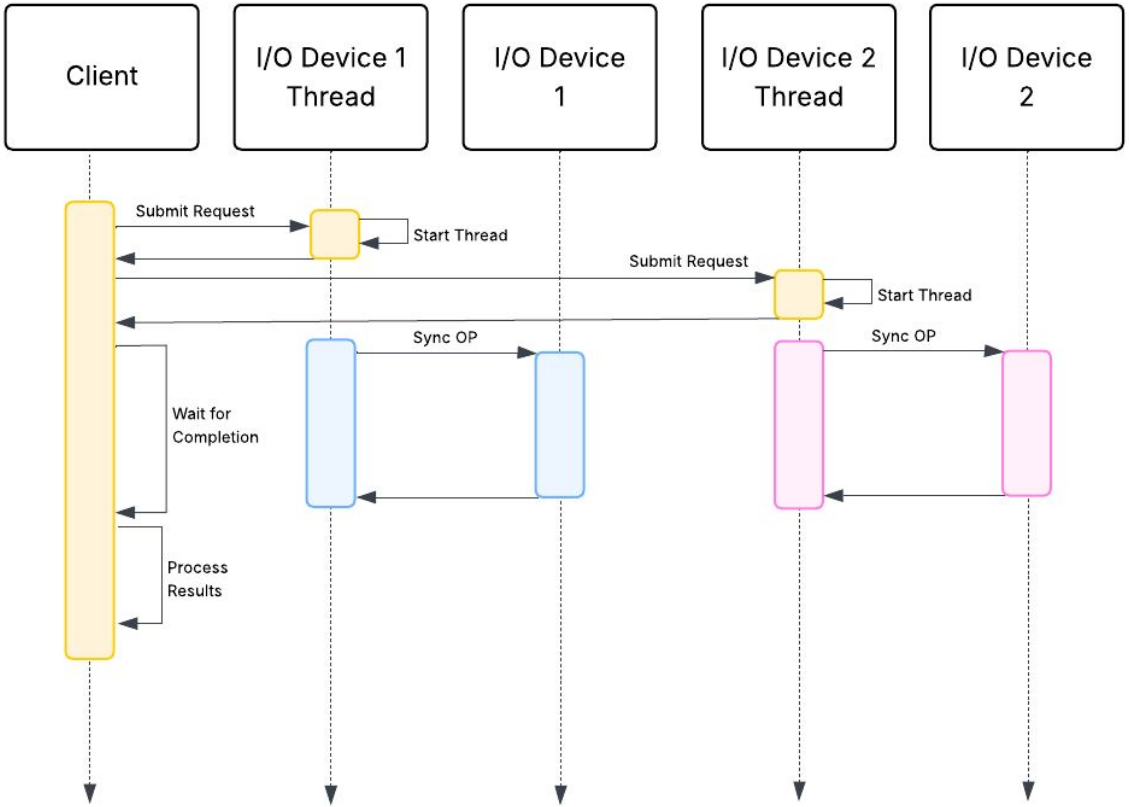
RTIO: the Async paradigm

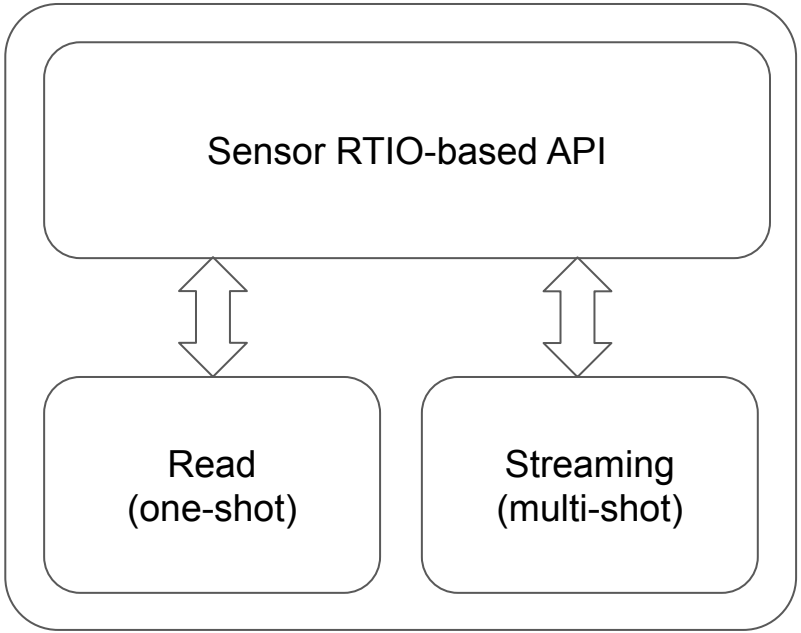


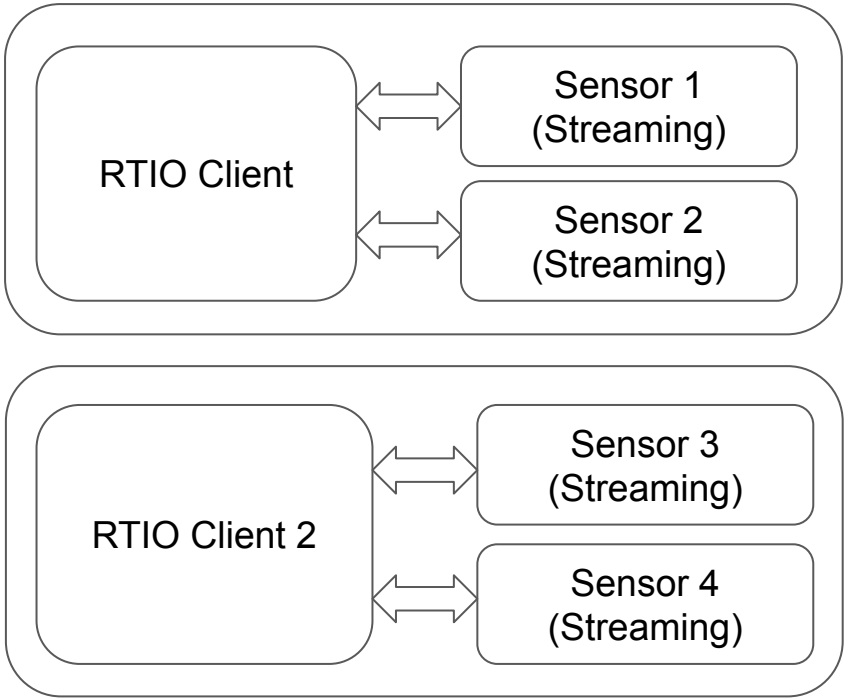
Thread-based paradigm



Sensor RTIO-based API

Sensor RTIO-based API





RTIO and Real Time

Real-Time in RTIO

Real-Time Constraints

Perform actions with guaranteed minimum constraints

- Maximum Allowed Latency
  - Reaction Time
  - Bus Latency
  - Jitter
- CPU Cycles to perform all the required actions
  - Data Collection
  - Data Processing/Transport
- Conditions validated under worst case scenario(s)

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Real-Time in RTIO

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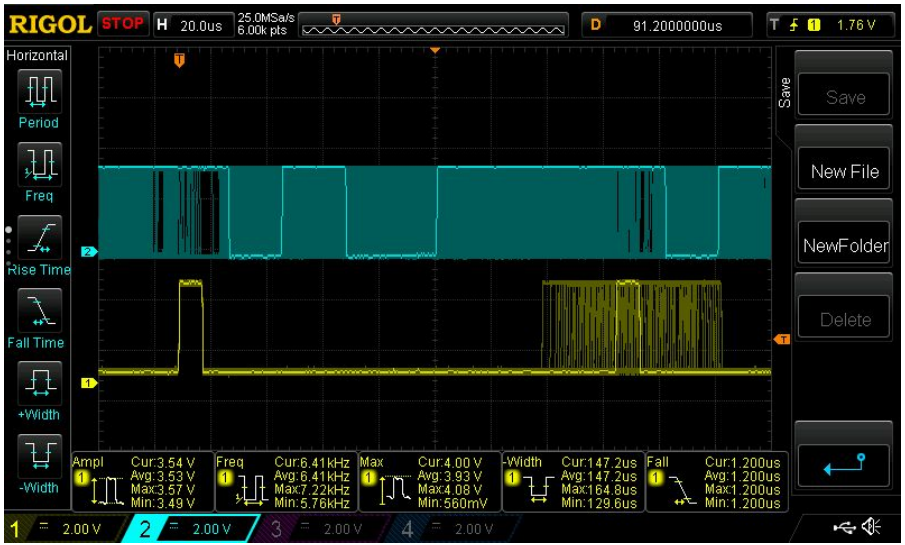
Real-Time in RTIO



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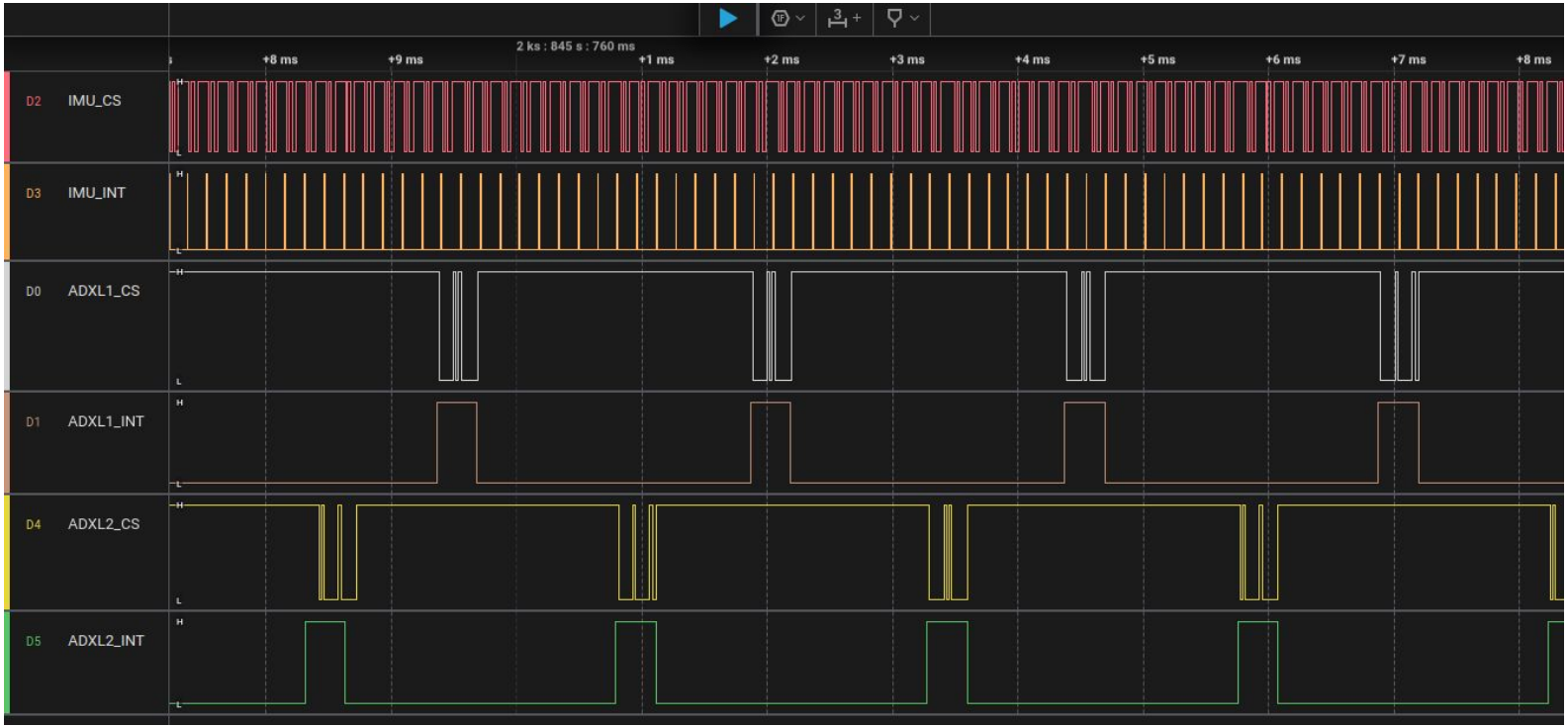
Real-Time in RTIO



RTIO in Real-Time

- Minimize Overhead
  - Memory Copying
  - Data conversions
  - Context Swapping
- Designed for Real Time
  - Take advantage of Hardware features (e.g: FIFO, DMA)
  - Ease to set up simultaneous streams of data (Async paradigm)
  - Guarantees decoupling of data-acquisition and processing
- Optimized Results
  - Latency
  - Jitter
  - CPU Load

Sensor Performance Benchmarks

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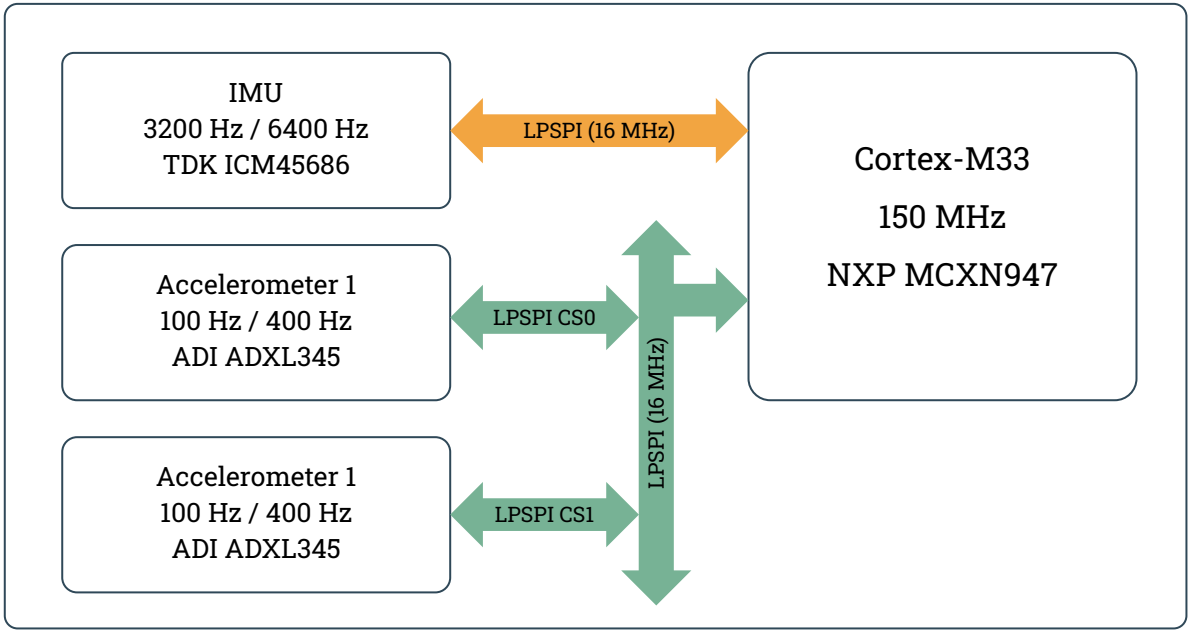
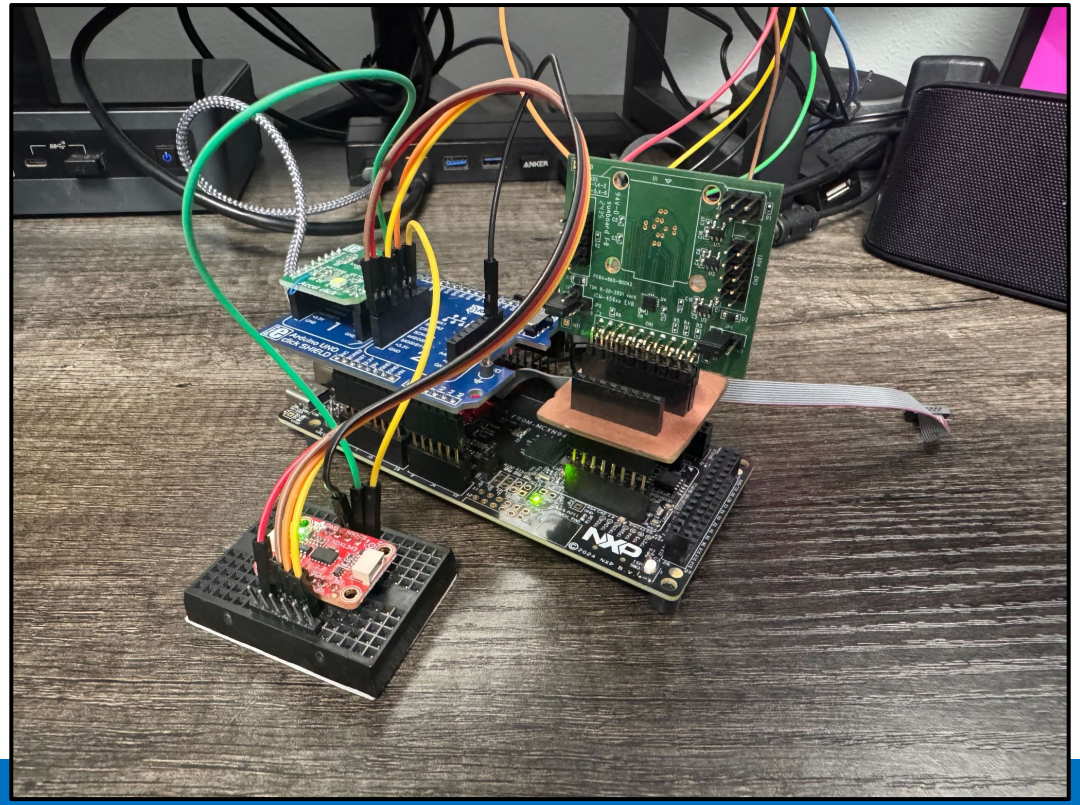
Setup: Device Under Test



Setup: Device Under Test



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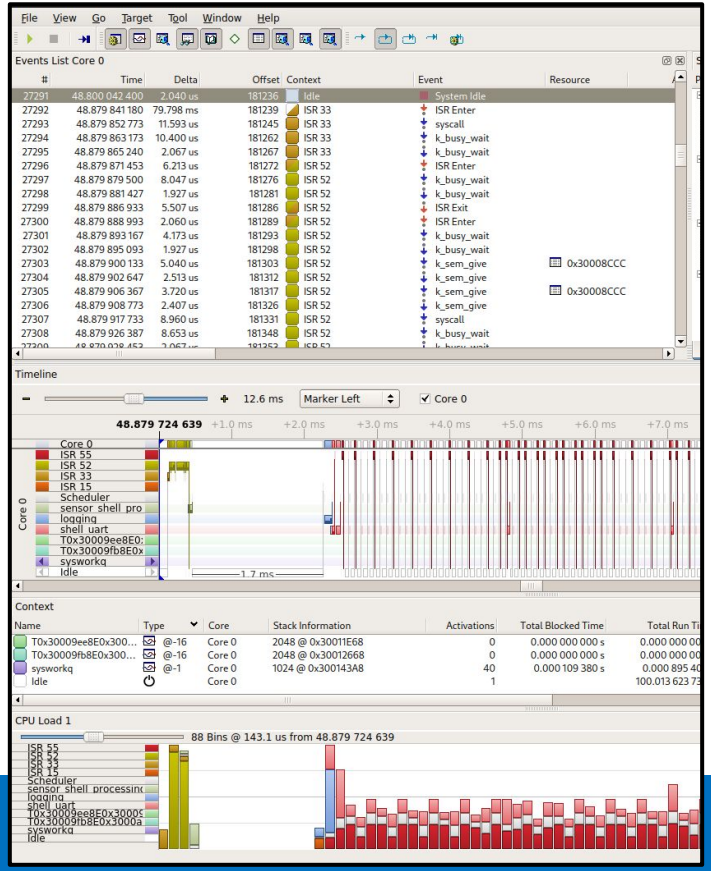
Setup: Measuring CPU Load




```
# Overlay Configuration
CONFIG_CPU_LOAD=y
CONFIG_CPU_LOAD_LOG_PERIODICALLY=5000
```

```
[00:16:10.015,000] <inf> cpu_load: Load:47.003%
[00:16:15.015,000] <inf> cpu_load: Load:47.003%
[00:16:20.015,000] <inf> cpu_load: Load:47.003%
[00:16:25.015,000] <inf> cpu_load: Load:47.003%
[00:16:30.015,000] <inf> cpu_load: Load:47.002%
[00:16:35.015,000] <inf> cpu_load: Load:47.003%
[00:16:40.015,000] <inf> cpu_load: Load:47.003%
[00:16:45.015,000] <inf> cpu_load: Load:47.003%
[00:16:50.015,000] <inf> cpu_load: Load:47.003%
[00:16:55.015,000] <inf> cpu_load: Load:47.003%
[00:17:00.015,000] <inf> cpu_load: Load:47.003%
[00:17:05.015,000] <inf> cpu_load: Load:47.003%
[00:17:10.016,000] <inf> cpu_load: Load:47.003%
[00:17:15.016,000] <inf> cpu_load: Load:47.003%
[00:17:20.016,000] <inf> cpu_load: Load:47.003%
uart:~$
  bypass              clear               date
  demo                device              devmem
  dynamic             help                history
  kernel              log                 log_test
  rem                 resize              retval
  section_cmd         sensor              shell
  shell_uart_release  stats               version
uart:~$
```

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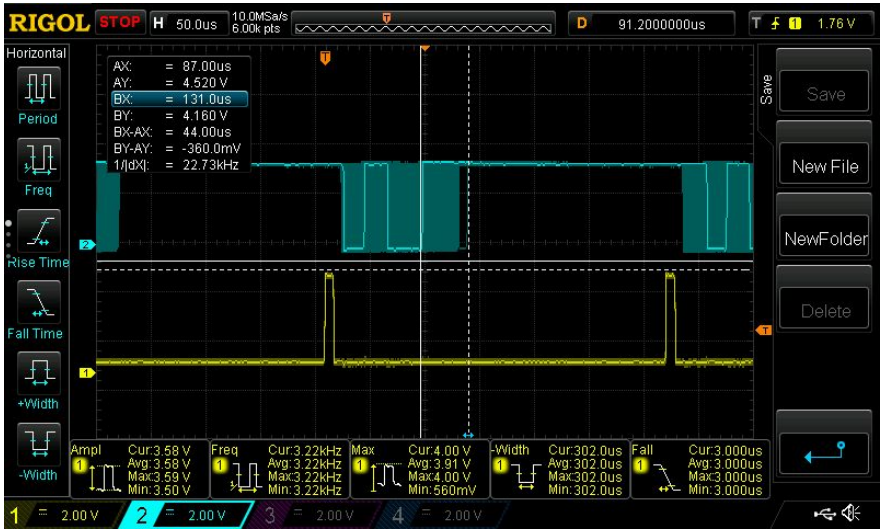
Setup: Measuring Jitter



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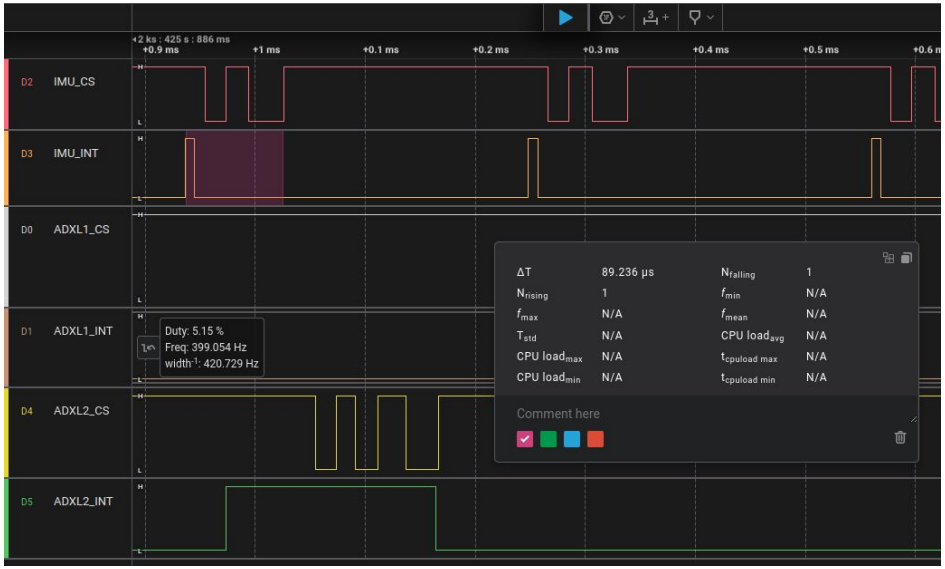
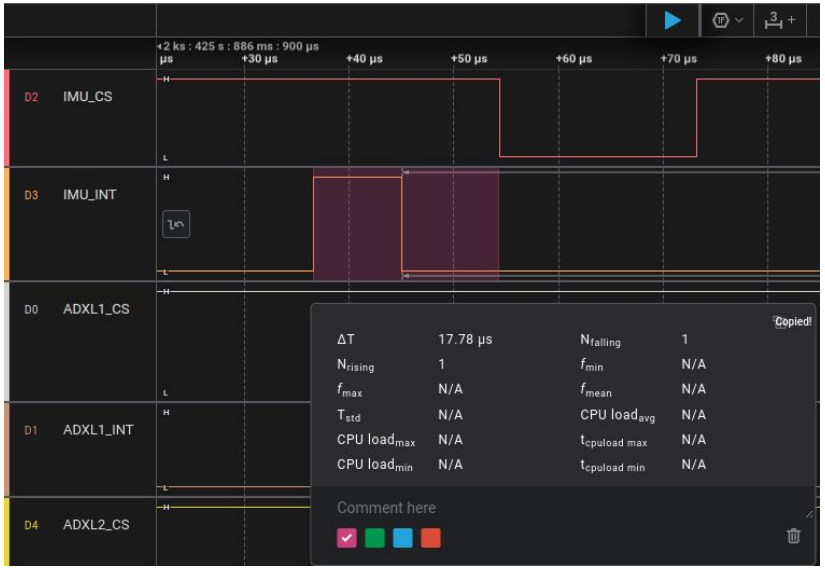
Setup: Measuring Bus Latency





Performance Benchmarks

Settings		CPU Load (%)		Latency (us)		Jitter (us)	
		Thread-based	RTIO-based	Thread-based	RTIO-based	Thread-based	RTIO-based
IMU at 3200Hz ODR	No Simultaneous Stream	42	35	92	90.6	37.2	11.6
	Simult. 1 Accel at 100Hz ODR	43	36	93	89.7	92	32
	Simult. 2 Accels at 100Hz ODR	45	38	92	89.7	116	41.6
	Simult. 1 Accel at 400Hz ODR	48	41	93	91	175	44
	Simult. 2 Accels at 400Hz ODR	55	47	92	90	155	44
IMU at 6400Hz ODR	No Simultaneous Stream	83	72	90	92	63	12.8
	Simult. 1 Accel at 100Hz ODR	Missing events	72	Missing events	93	Missing events	34.4
	Simult. 2 Accels at 100Hz ODR	Missing events	74	Missing events	89	Missing events	44.4
	Simult. 1 Accel at 400Hz ODR	Missing events	76	Missing events	90	Missing events	37.2
	Simult. 2 Accels at 400Hz ODR	Missing events	80	Missing events	91	Missing events	48

Real-Time Sensors in CogniPilot

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Real-Time Sensors in CogniPilot

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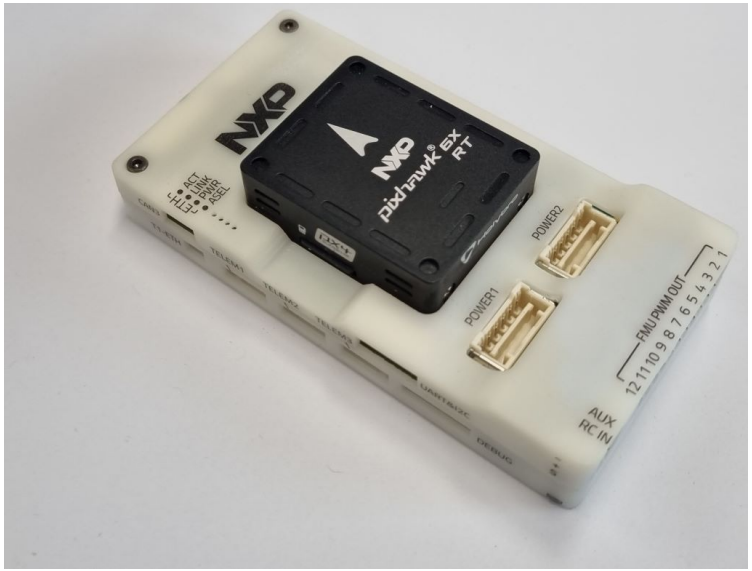

NXP Flight Controller (VMU-RT1170)

NXP Optical Flow Module (MR-MCXN-T1)

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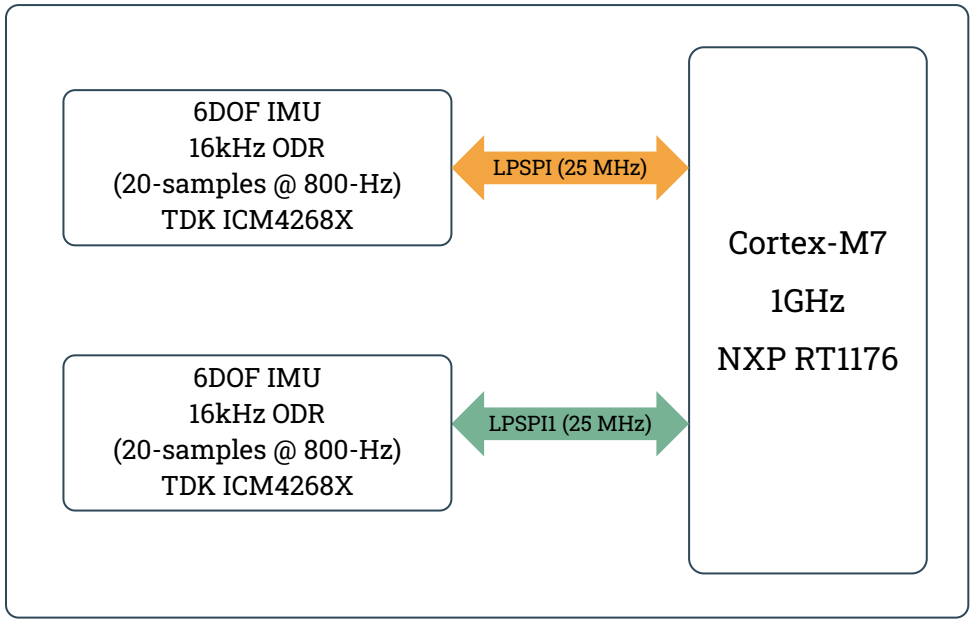
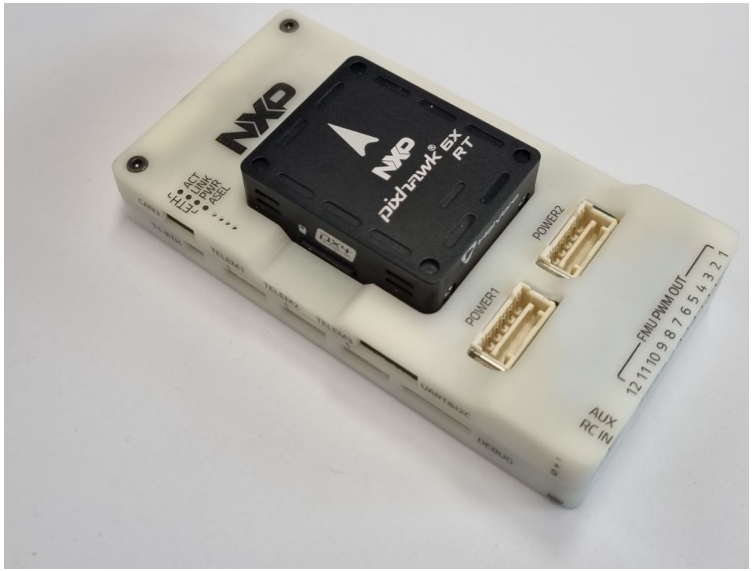
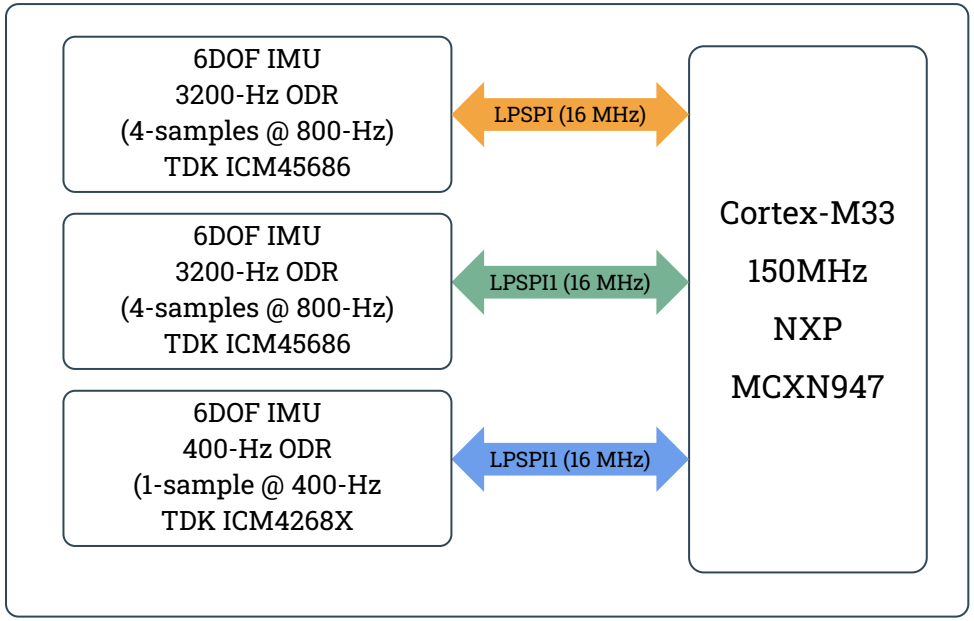
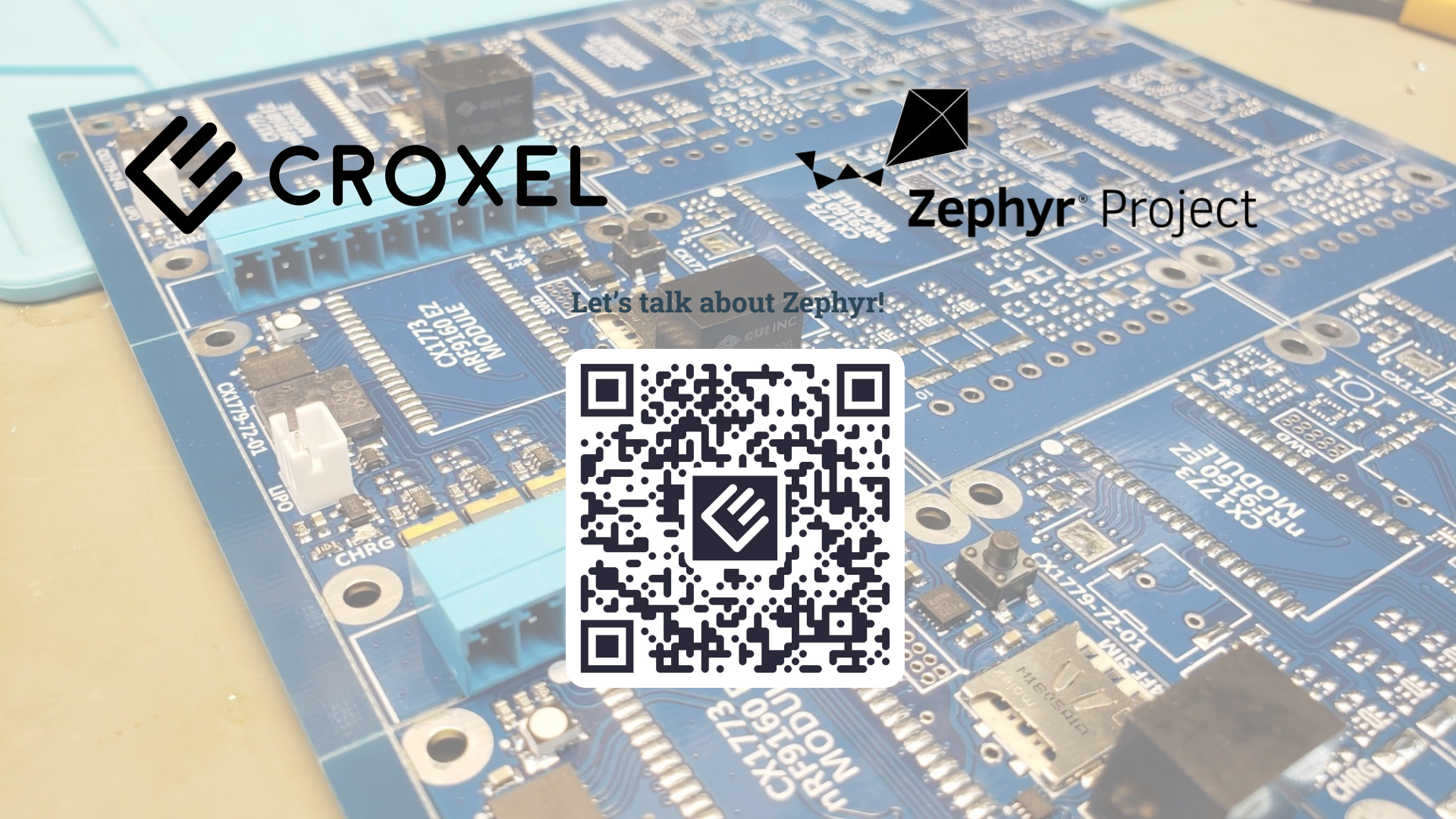
Real-Time Sensors in CogniPilot





Real-Time Sensors in CogniPilot

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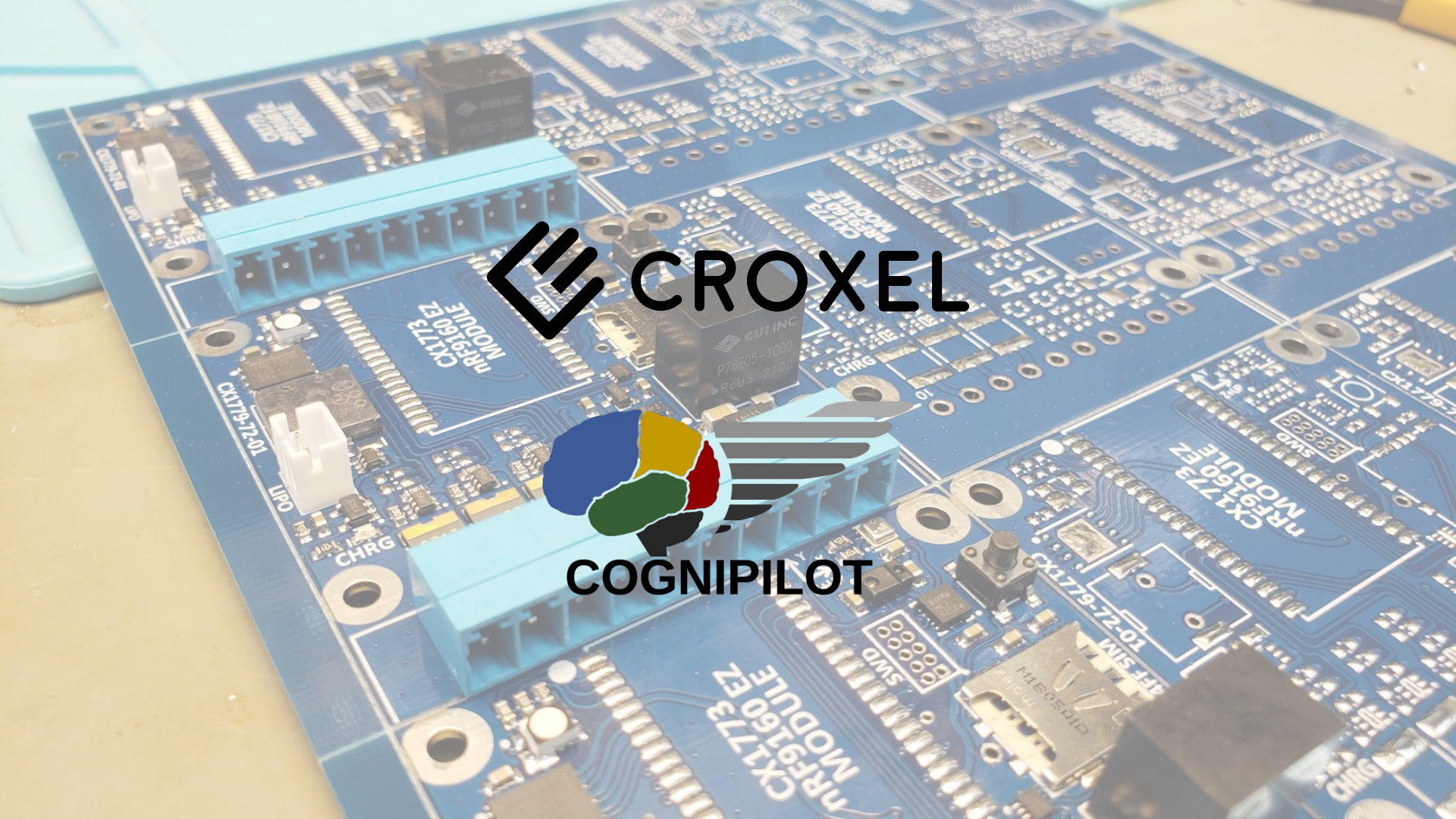
Zephyr® Project
Let's talk about Zephyr!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