

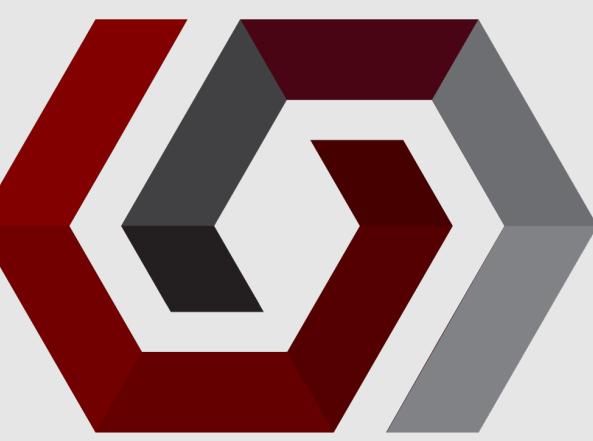
# ZEPHYR AND OPEN AMP

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Mohammed Billoo

MAB Labs Embedded Solutions

Zephyr Dev Summit 2024

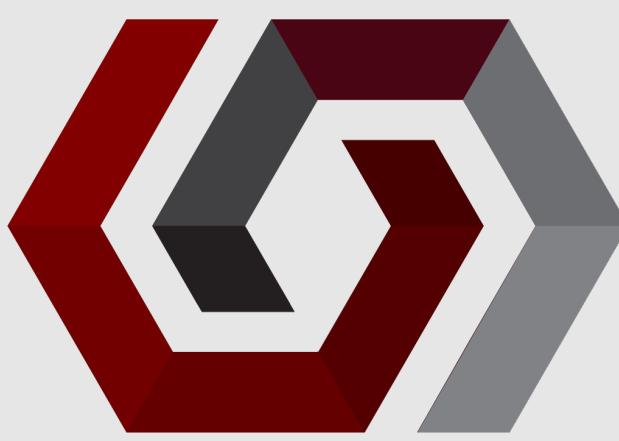


# AGENDA

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- Motivation
- OpenAmp in Zephyr
- System Architecture
- Development Process (**WARNING: Yocto ahead!**)
- Common Issues and Resolutions
- Next steps

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# THE SPEAKER

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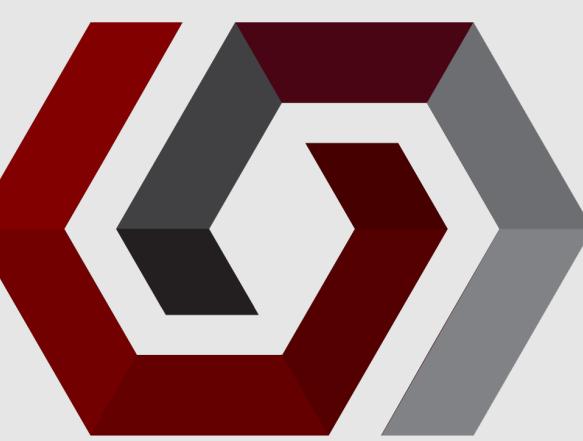


/mab-embedded



@mabembedded

- Embedded Software Consultant
- Design Work
  - Medical Devices
  - Scientific Instruments
  - LIDAR
  - Custom ASICs
- Experience/Expertise
  - Zephyr RTOS
  - Embedded Linux
  - GUI-based applications

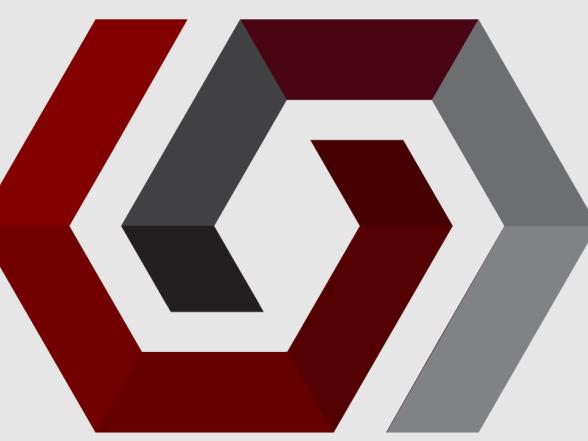


# BIOS FOOD NEWSLETTER

Training/Workshops



[www.mab-labs.com](http://www.mab-labs.com)



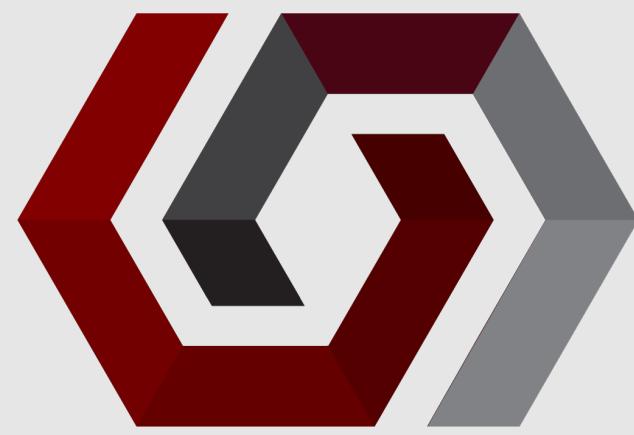
# MOTIVATION

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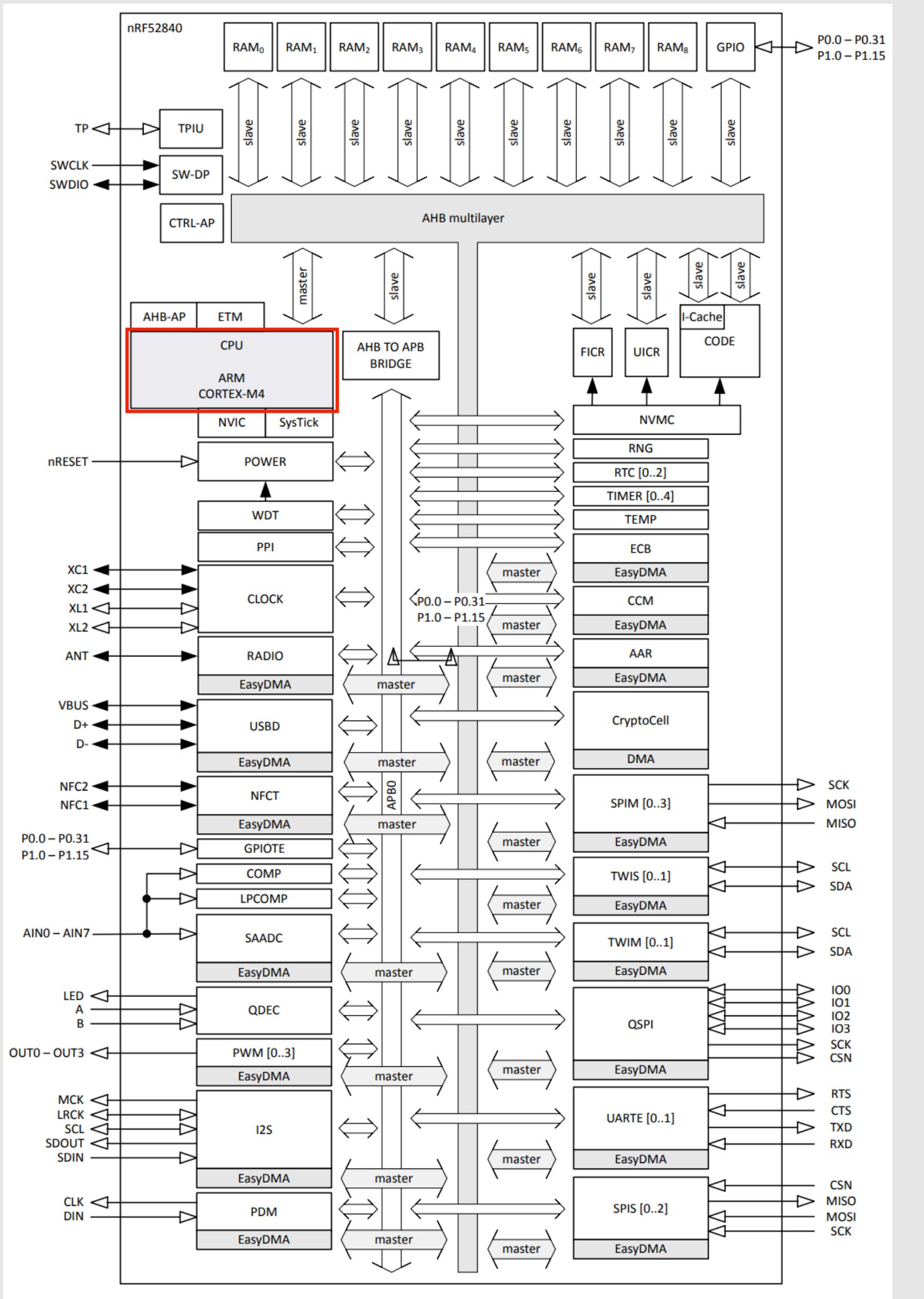


<https://www.electronicproducts.com>

- Heterogenous multi-processor systems
- Traditionally on distinct silicon dice
  - Communication using traditional busses
    - CAN
    - UART
    - SPI
  - Each MCU responsible for a safety-critical component
  - MPU responsible for non-critical components



# MOTIVATION



- Silicon density has exploded
- Single silicon die no longer just a single controller
- Entire **hardware** stacks now present on System-on-Chips (SoC)
  - Radio
  - USB
  - Peripherals
  - Etc
- Actual CPU itself occupies ~3% of silicon

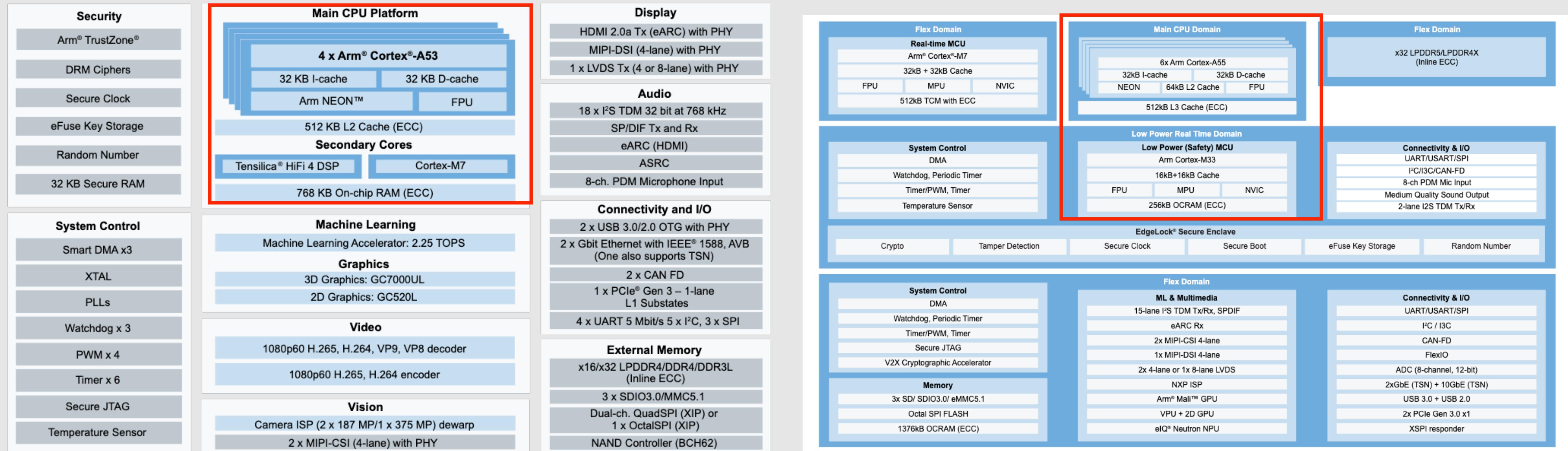
[https://infocenter.nordicsemi.com/pdf/nRF52840\\_PS\\_v1.0.pdf](https://infocenter.nordicsemi.com/pdf/nRF52840_PS_v1.0.pdf)



# MOTIVATION

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- Add multiple microcontrollers and microprocessors to single die
- Can distribute the workload
  - MCU responsible for realtime operations
  - MPU responsible for non-realtime operations
- Robotics
  - MCU responsible for actuation
  - MPU responsible for GUI/display, communications, etc..



NXP iMX95



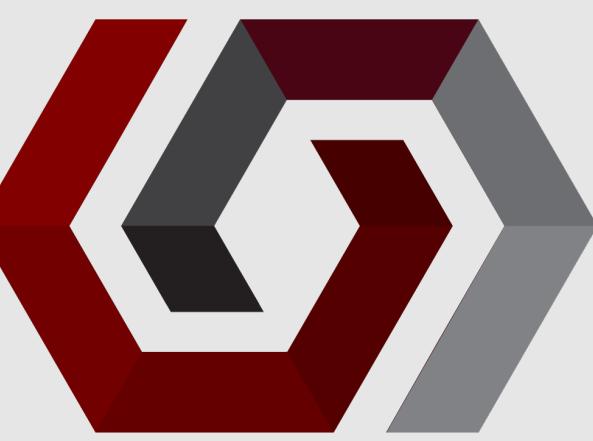
# MOTIVATION

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<https://www.toradex.com/videos/taq-the-balancing-robot>

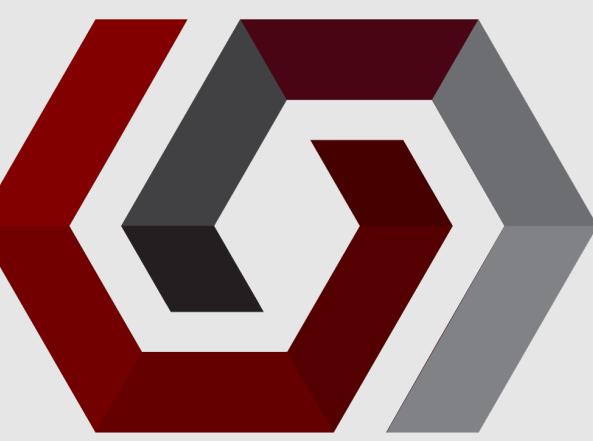
 **Toradex**  
Swiss. Embedded. Computing.



# ADVANTAGES

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- Increased speed and reduced latency
  - Massive!
  - On-chip interconnects >> traditional protocols
- OTA simplified
  - MCU firmware resident on MPU filesystem
  - MCU OTA can be part of overall OTA



# OPENAMP IN ZEPHYR

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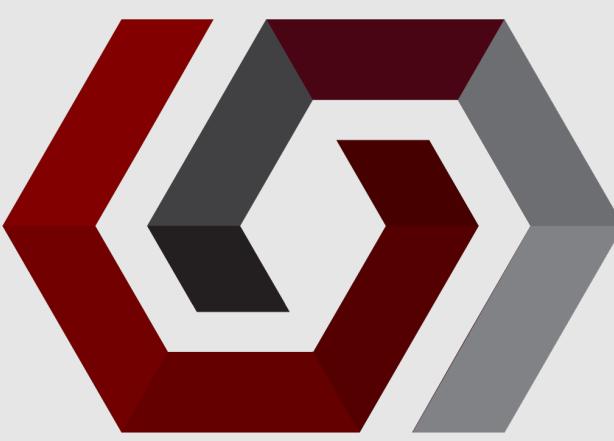
- OpenAMP (<https://github.com/OpenAMP>) **framework**
  - Multiple components
  - OpenAMP library
- Remoteproc and RPMsg
  - Core building blocks of library



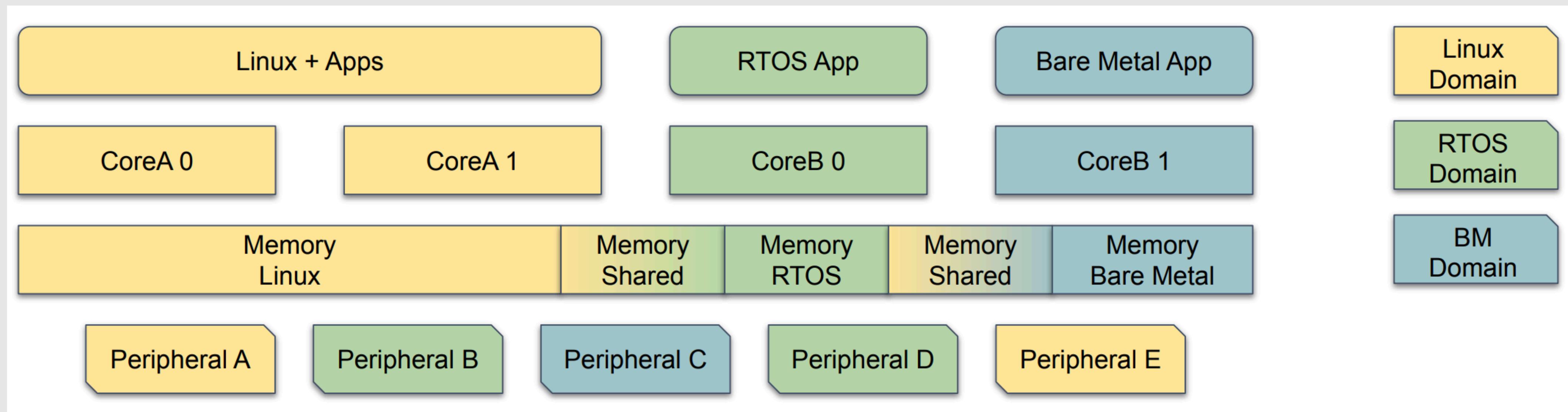
# OPENAMP IN ZEPHYR

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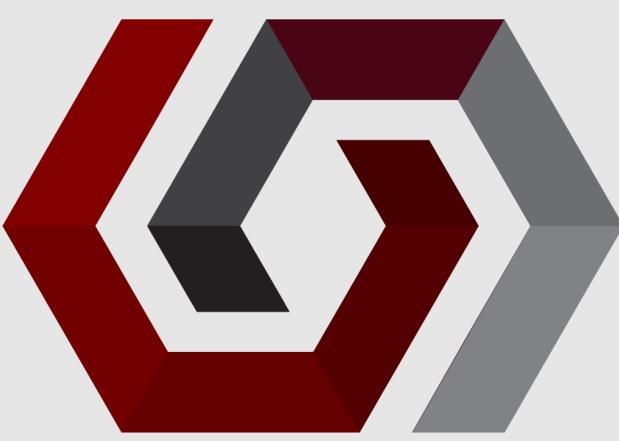
- Remoteproc/RPMsg originally committed to Linux kernel by TI
  - Linux <→ SYS/BIOS (i.e. TI/RTOS)
- Picked up by OpenAMP
  - Expanded beyond just Remoteproc/RPMsg into a complete framework
- “OpenAMP Project”
  - [openampproject.org](http://openampproject.org)



# OPENAMP IN ZEPHYR



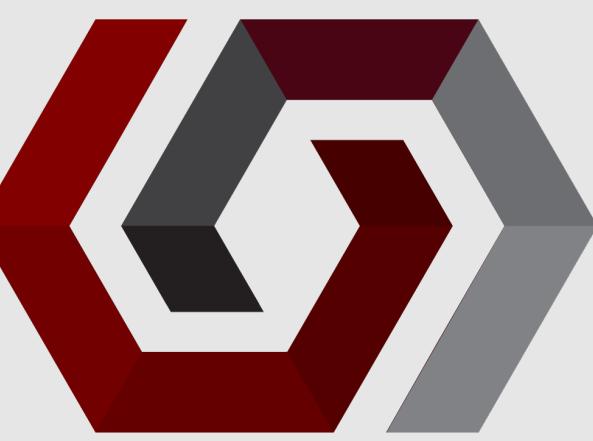
<https://www.openampproject.org/docs/presentations/OpenAMP-Elevator-Pitch-2024-Q1.pdf>



# OPENAMP IN ZEPHYR

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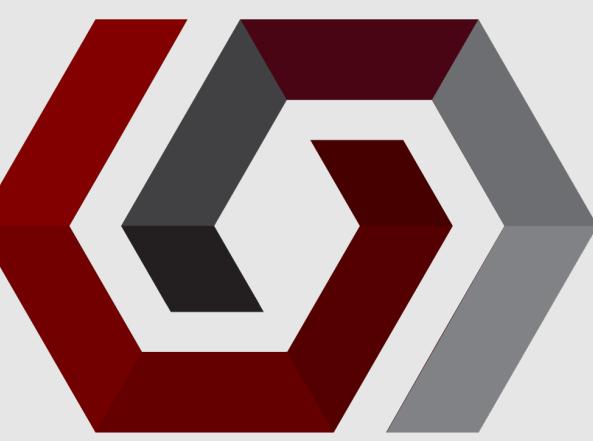
- Remoteproc
  - Parses ELF file
    - Ensure that it has appropriate memory segments to be loaded (**important later**)
  - Loads remote processor firmware
  - Starts the remote firmware



# OPENAMP IN ZEPHYR

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- RPMsg
  - IPC communication mechanism
  - Defines message format
  - RPMsg header
    - Defines source, destination, payload size



# OPENAMP IN ZEPHYR

---

- VirtIO
  - Abstract out IPC
  - Use shared memory region between processors
- Metal
  - Abstraction between OpenAmp and underlying OS
  - Locks, interrupts, DMA, memory, sleep, etc...



# OPENAMP IN ZEPHYR

- OpenAmp In Zephyr

```
[zephyrproject]$ ls -l modules/lib/open-amp/open-amp/
total 172
drwxrwxr-x 4 mab mab 4096 Jan  9 13:50 cmake
-rw-rw-r-- 1 mab mab   819 Jan  9 13:50 CMakeLists.txt
drwxrwxr-x 5 mab mab 4096 Jan  9 13:50 doc
-rw-rw-r-- 1 mab mab 122997 Jan  9 13:50 Doxyfile
drwxrwxr-x 8 mab mab 4096 Jan  9 13:50 lib
-rw-rw-r-- 1 mab mab 4696 Jan  9 13:50 LICENSE.md
-rw-rw-r-- 1 mab mab   524 Jan  9 13:50 MAINTAINERS.md
-rw-rw-r-- 1 mab mab 14983 Jan  9 13:50 README.md
-rw-rw-r-- 1 mab mab    54 Jan  9 13:50 VERSION
```

```
[zephyrproject]$ ls zephyr/lib/open-amp/
CMakeLists.txt  Kconfig  resource_table.c  resource_table.h
```

```
[zephyrproject]$ ls -l zephyr/samples/subsys/ipc/openamp_rsc_table/
total 24
drwxrwxr-x 2 mab mab 4096 Jan  9 13:50 boards
-rw-rw-r-- 1 mab mab   691 Jan  9 13:50 CMakeLists.txt
-rw-rw-r-- 1 mab mab   248 Jan  9 13:50 prj.conf
-rw-rw-r-- 1 mab mab 2272 Jan  9 13:50 README.rst
-rw-rw-r-- 1 mab mab   401 Jan  9 13:50 sample.yaml
drwxrwxr-x 2 mab mab 4096 Apr 17 12:46 src
```

Zephyr OpenAMP sample using resource table



# OPENAMP IN ZEPHYR

---

- Relevant Kconfig options

```
CONFIG_IPM=y
CONFIG_OPENAMP=y
CONFIG_OPENAMP_RSC_TABLE_NUM_RPMSG_BUFF=8
CONFIG_OPENAMP_RSC_TABLE=y
CONFIG_OPENAMP_MASTER=n
```

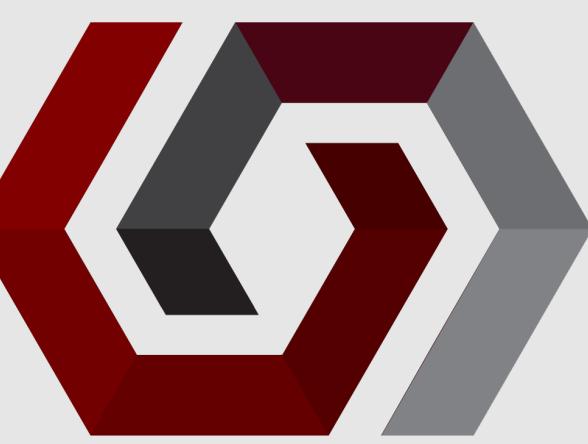


# OPENAMP IN ZEPHYR

- Devicetree configuration

```
1 /*
2  * Copyright (c) 2020, STMICROELECTRONICS
3  *
4  * SPDX-License-Identifier: Apache-2.0
5  */
6
7 / {
8     chosen {
9         /*
10          * shared memory reserved for the inter-processor communication
11          */
12         zephyr,ipc_shm = &mcusram3;
13         zephyr,ipc = &mailbox;
14     };
15
16     mcusram3: memory1@10040000 {
17         compatible = "mmio-sram";
18         reg = <0x10040000 DT_SIZE_K(64)>;
19     };
20 };
21
22 &mcusram {
23     reg = <0x10000000 DT_SIZE_K(256)>;
24 };
```

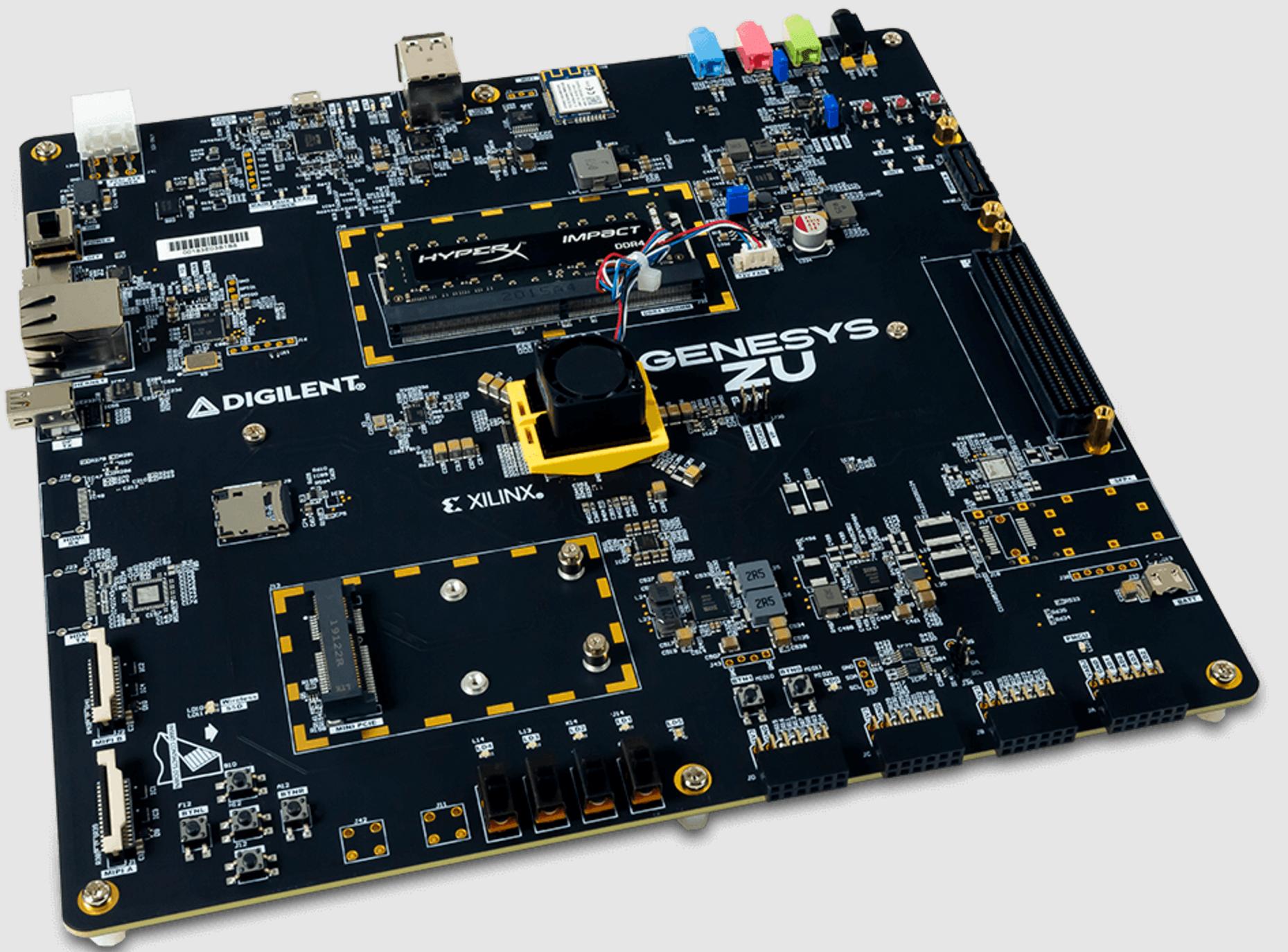
STM32MP157C\_DK2

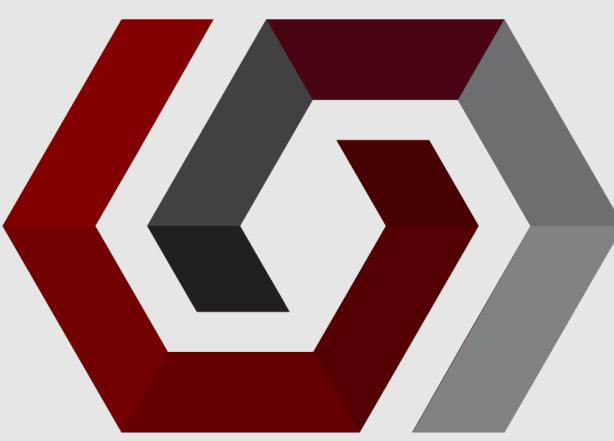


# SYSTEM ARCHITECTURE

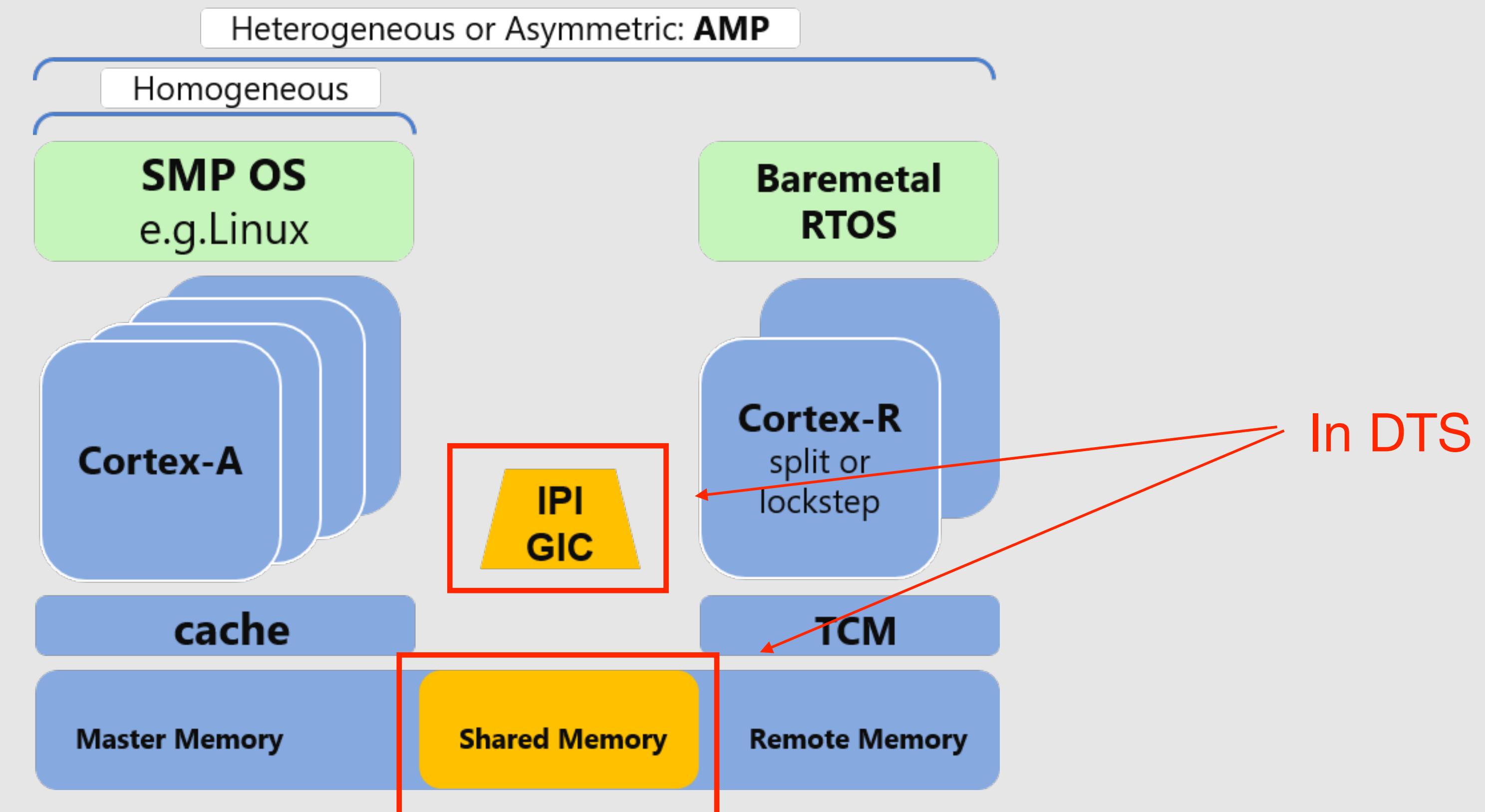
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- Digilent Genesys ZU
- Zynq MPSoC
  - Quad-core ARM Cortex A53
  - Dual-core ARM Cortex R5

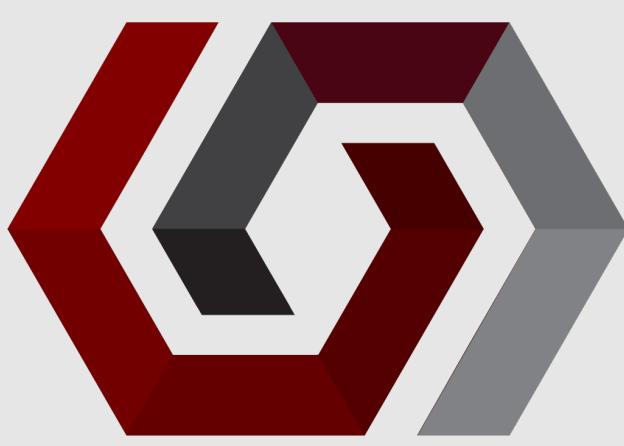




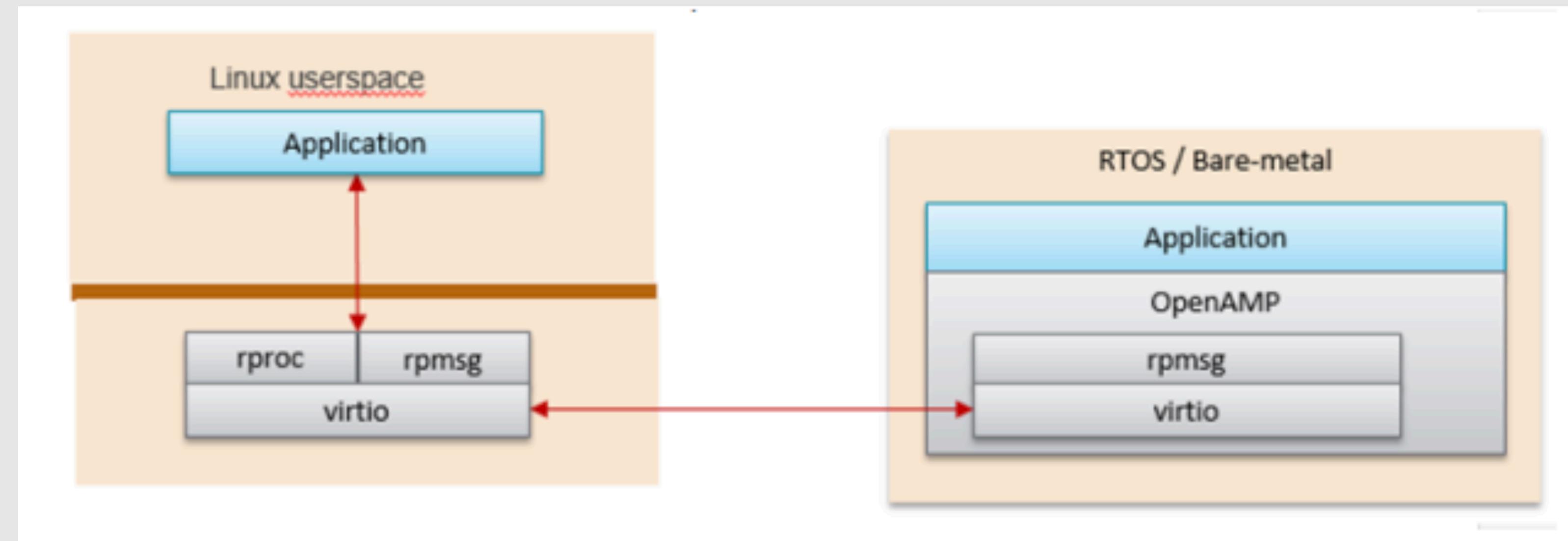
# SYSTEM ARCHITECTURE

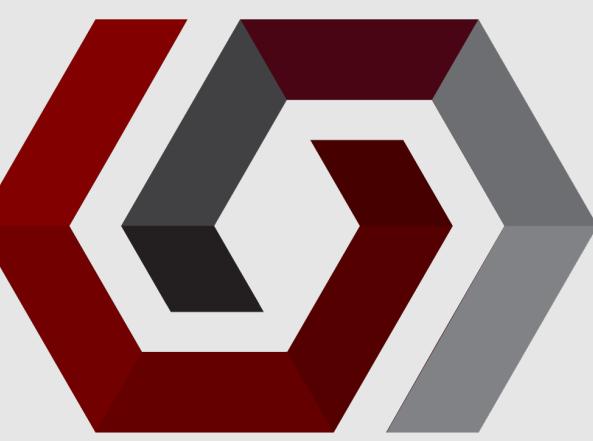


<https://xilinx-wiki.atlassian.net/wiki/spaces/A/pages/18841718/OpenAMP>



# SYSTEM ARCHITECTURE

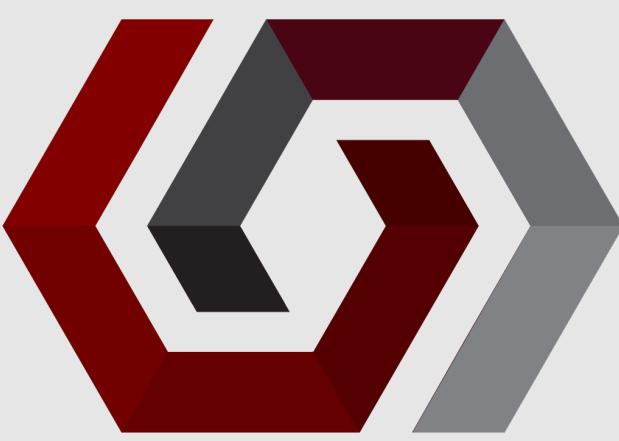




# SYSTEM ARCHITECTURE

---

- Goal
  - Zephyr firmware for R5 on A53 root filesystem
  - Load Zephyr firmware from (Peta) Linux
  - “Start” Zephyr firmware from Linux
  - Send message from Linux to Zephyr
    - Echo back to Linux



# DEVELOPMENT PROCESS

---

- Use KV260 R5 board in Zephyr as starting point
- Get blinky working
  - Confirm that clock configuration and pinout modifications are correct
  - Use Xilinx tools (i.e. Vitis) to load firmware
  - Use o-scope to confirm blinky frequency
- Test!



# DEVELOPMENT PROCESS

---

- Add remoteproc drivers in Peta Linux

```
Device Drivers --->

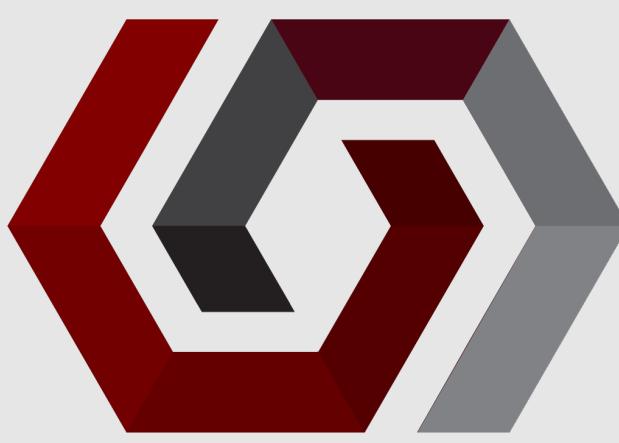
Remoteproc drivers --->

# for R5:

<M> ZynqMP_r5 remoteproc support

# for Zynq A9

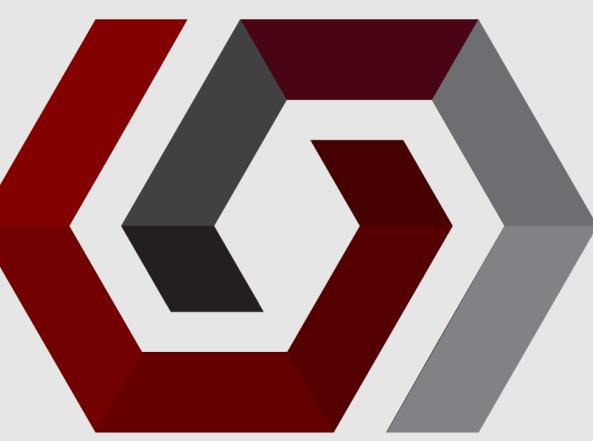
<M> Support ZYNQ remoteproc
```



# DEVELOPMENT PROCESS

- Create recipe to add Zephyr binary to RFS

```
1 #
2 # This file is the openamp-test recipe.
3 #
4
5 SUMMARY = "Simple openamp-test application"
6 SECTION = "PETALINUX/apps"
7 LICENSE = "MIT"
8 LIC_FILES_CHKSUM = "file://${COMMON_LICENSE_DIR}/MIT;md5=0835ade698e0bcf8506ecda2f7b4f302"
9
10 SRC_URI = "file://zephyr.elf \
11         "
12
13 S = "${WORKDIR}"
14
15 INSANE_SKIP_${PN} = "arch"
16
17 RDEPENDS_${PN} = " \
18     libmetal \
19 "
20 ■
21 do_install() {
22     install -d ${D}/lib/firmware
23     install -m 0644 ${S}/zephyr.elf ${D}/lib/firmware/zephyr.elf
24 }
25
26 FILES_${PN} = "/lib/firmware/zephyr.elf"
```



# DEVELOPMENT PROCESS

---

- Use Vitis as a debugger
  - Copy over source files
  - Inform Vitis how to reconcile final binary with source files
    - Many-step process
    - Not focus of this talk (maybe another)
  - **Have step through debugging!**



# DEVELOPMENT PROCESS

---

- After boot, instruct Peta Linux to load Zephyr firmware and start

```
echo zephyr > /sys/class/remoteproc/remoteproc0/firmware
```

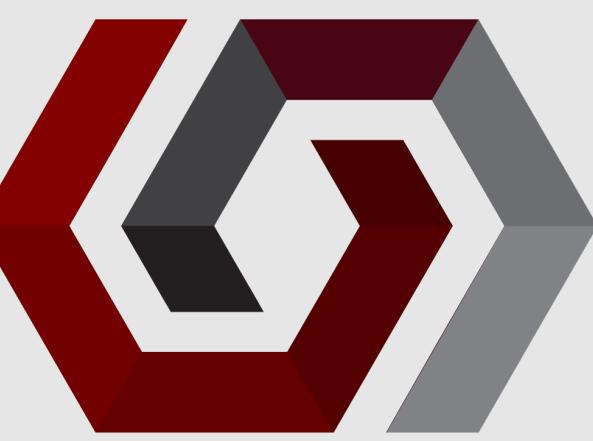
```
echo start > /sys/class/remoteproc/remoteproc0/state
```



# COMMON ISSUES AND RESOLUTIONS

---

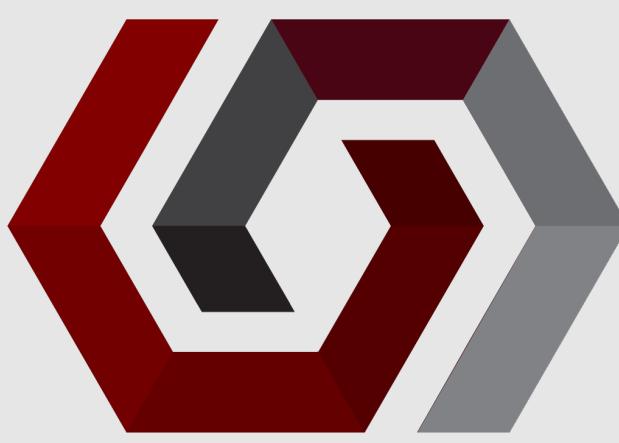
- Issue when loading and starting firmware
  - **CONFIG\_OPENAMP\_RSC\_TABLE=y**
    - Adds resource table section in final ELF
    - Checked by Linux kernel module



# COMMON ISSUES AND RESOLUTIONS

---

- Segfault when sending commands from Linux to Zephyr
  - Zephyr IPC connected to mailbox in DTS?
  - Zephyr SRAM updated to reflect new value?
  - Zephyr SHM node connected to SRAM?



# COMMON ISSUES AND RESOLUTIONS

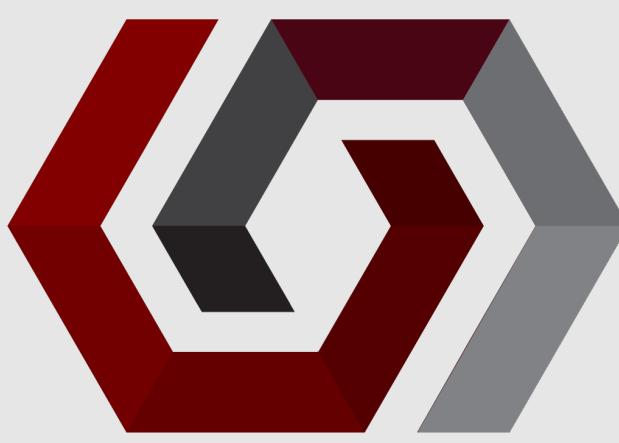
```
rpu0_ipi: zynqmp-ipi@ff310000 {
    status = "disabled";
    compatible = "xlnx,zynqmp-ipi-mailbox";
    #address-cells = <1>;
    #size-cells = <1>

    reg = <0xff310000 0x10000>;
    reg-names = "host_ipi_reg";
    interrupts = <GIC_SPI 33 IRQ_TYPE_LEVEL
                  IRQ_DEFAULT_PRIORITY>;
    local-ipi-id = <1>;

rpu0_apu_mailbox: mailbox@ff990200 {
    remote-ipi-id = <0>;
    reg = <0xff990200 0x20>,
          <0xff990220 0x20>,
          <0xff990040 0x20>,
          <0xff990060 0x20>;
    reg-names = "local_request_region",
                "local_response_region",
                "remote_request_region",
                "remote_response_region";
};
```

```
&rpu0_ipi {
    status = "okay";
};
```

```
zephyr,ipc = &rpu0_apu_mailbox;
```

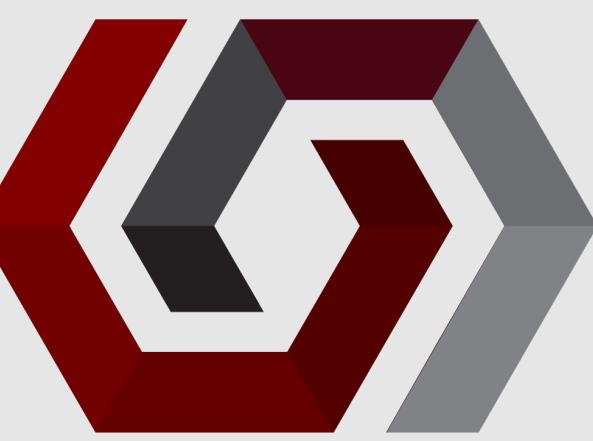


# COMMON ISSUES AND RESOLUTIONS

```
1 #ifndef SHARED_MEM_PA
2 #if XPAR_CPU_ID == 0
3 #define SHARED_MEM_PA 0x3ED40000UL
4 #else
5 #define SHARED_MEM_PA 0x3EF40000UL
6 #endif /* XPAR_CPU_ID */
7 #endif /* !SHARED_MEM_PA */
8
9 #ifndef SHARED_MEM_ST7F
10 #define SHARED_MEM_SIZE 0x100000UL
11 #endif /* !SHARED_MEM_SIZE */
12
13 #ifndef SHARED_BUF_OFFSET
14 #define SHARED_BUF_OFFSET 0x8000UL
15 #endif /* !SHARED_BUF_OFFSET */
```

```
&sram0 {
    reg = <0x3ed40000 0x100000>;
};
```

- zephyr,ipc\_shm = &sram0;



# NEXT STEPS

---

- Upstream!
  - Add Digilent board to Zephyr
  - Add necessary board overlay to IPC sample
- Document steps to debug Zephyr in Vitis



# THANK YOU!

Mohammed Billoo

MAB Labs Embedded Solutions

Zephyr Dev Summit 2024