NFC INTEGRATION IN REAL-TIME AND NON-REAL-TIME OPERATING SYSTEMS

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SECURE CONNECTIONS
FOR A SMARTER WORLD

AGENDA

- NFC readers software development design-in support
- NFC Frontend integration in Linux
- NFC Reader Library integration in Linux
- Host interface access on Linux systems
- Latency analysis: Linux vs bare metal
- Overcoming Linux higher latency for time-sensitive applications

01.

NFC readers software development design-in support

We make NFC easy

NFC implementation process

We reduce complexity, streamline tasks, and add flexibility at every point in development, so you can deliver a competitive advantage in record time.

Decide the functionality | **Select IC** | **Evaluate features** | **Hardware design** | **Software development** | **Test & debug** | **Get certified**

We know each step in the NFC implementation process

Our support package simplifies the process and reduces time to market

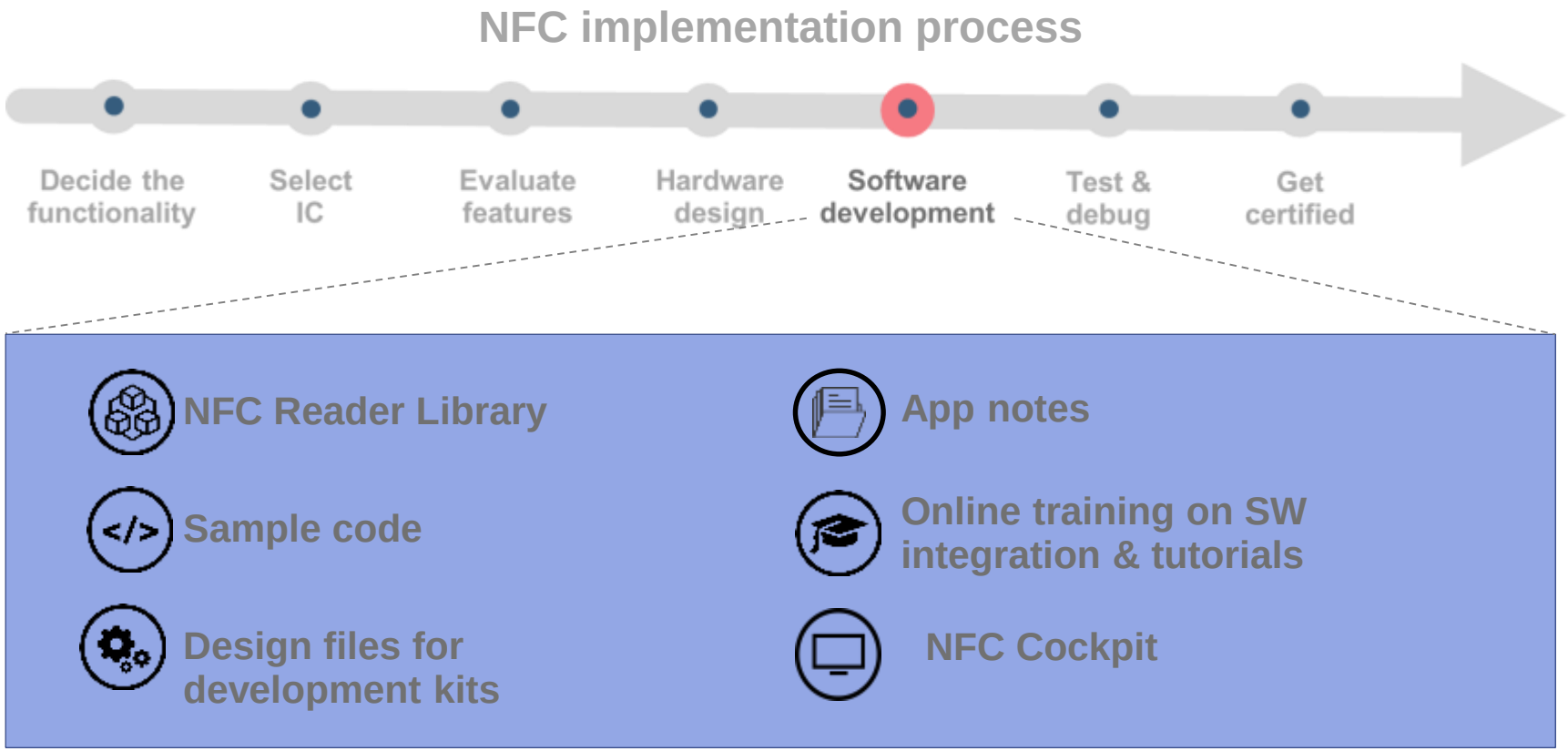
We have the right material for each design step

Full range of development kits, design files, sample code, app notes, online training, tutorials

Directly find answers to your questions

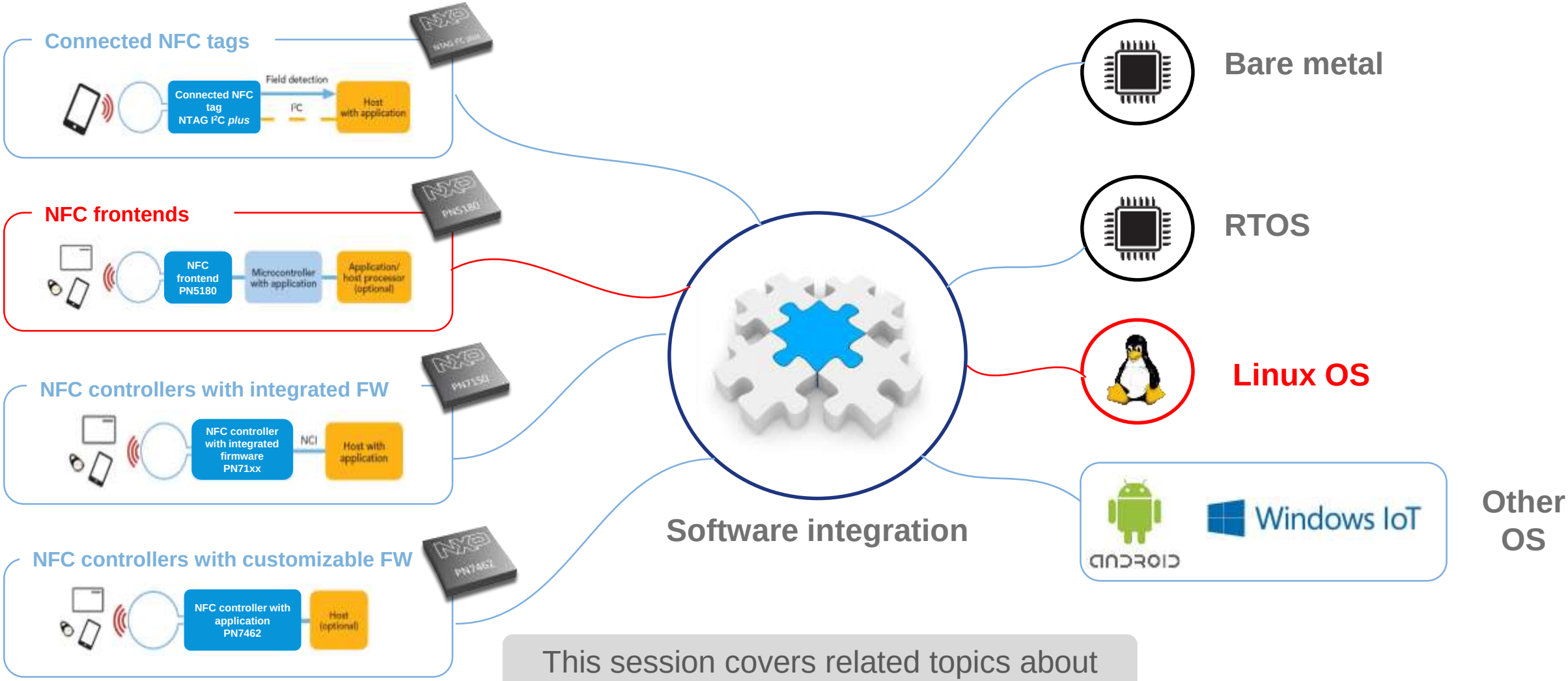
Through our technical NFC community and NXP certified Independent Design Houses (IDHs)

NXP’s software development support



You can re-use design of NXP development boards and sample code examples to speed up your SW development tasks.

NXP software support for integration into any platform



This session covers related topics about NFC frontend software integration in Linux

An increasing number of devices running Linux

Payment terminals

IoT gateways.

Audio devices

Healthcare
and medical devices

Access control &
Ticketing readers

Set top boxes

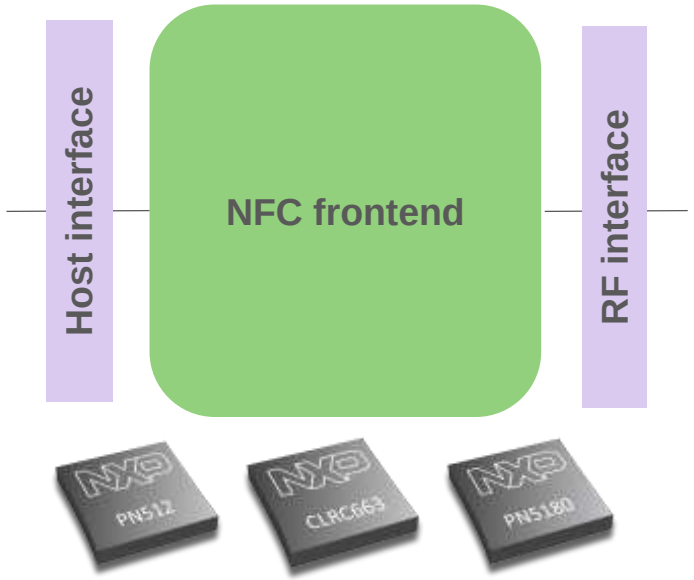
02.

NFC Frontend integration in Linux

NFC frontend expose a host interface and a contactless interface

Host interface

- This register interface is a low level access to the contactless interface providing full access to this IP.
- This could be a direct CLIF-mapped interface (CLRC663, PN512) or a software emulated register interface (PN5180).
- The host controller uses the register access to the contactless interface for:
  - to configure RF framing and signaling .
  - to finally transfer the RF digital protocol based blocks to/from a counterpart.



RF interface

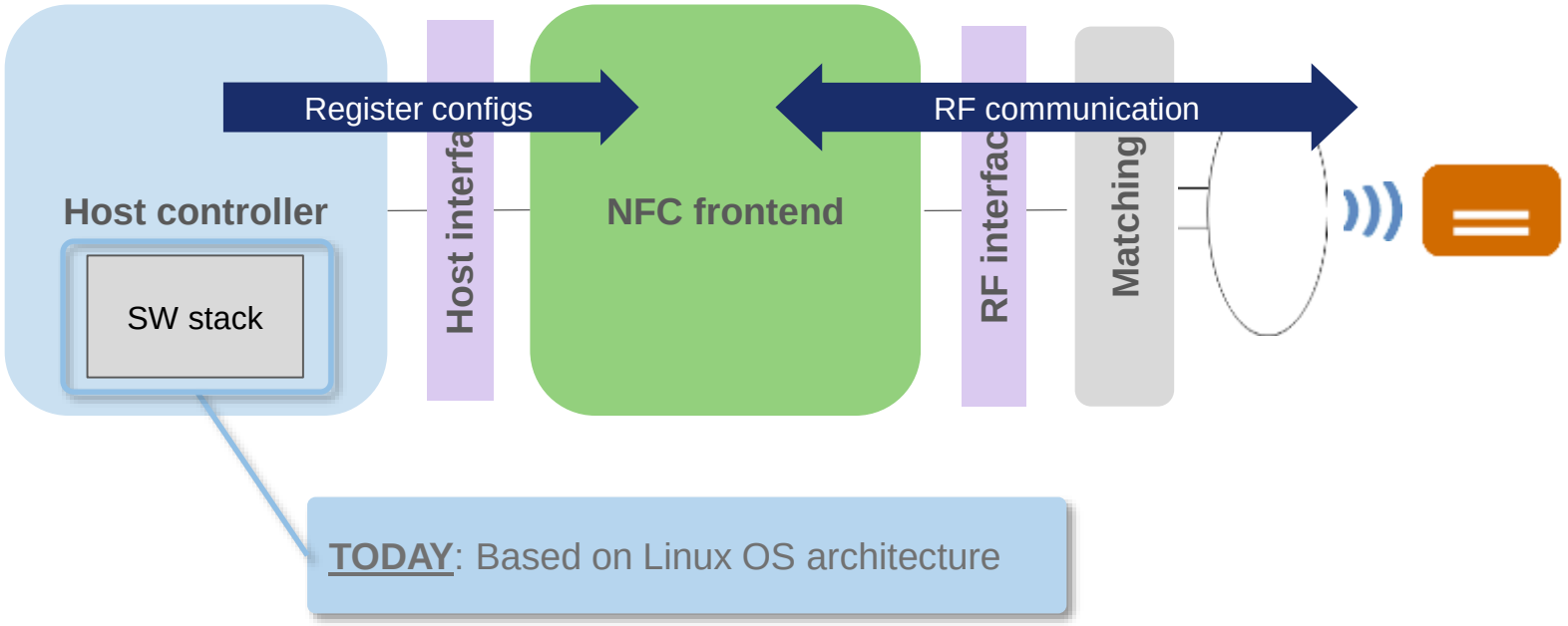
- An NFC frontend is an RF transceiver enabling the contactless communication.
- It deals with the signal modulation and handles the data transmission through the RF interface.
- The NFC frontend needs to be selected according to application requirements:
  - RF performance
  - RF protocols
  - NFC modes of operation
  - Host interfaces
  - Power consumption
  - Device to interact with
  - Others…

NFC frontends expose a ‘register interface’ towards the host controller through the host interface

NFC frontend is controlled by the external host controller SW

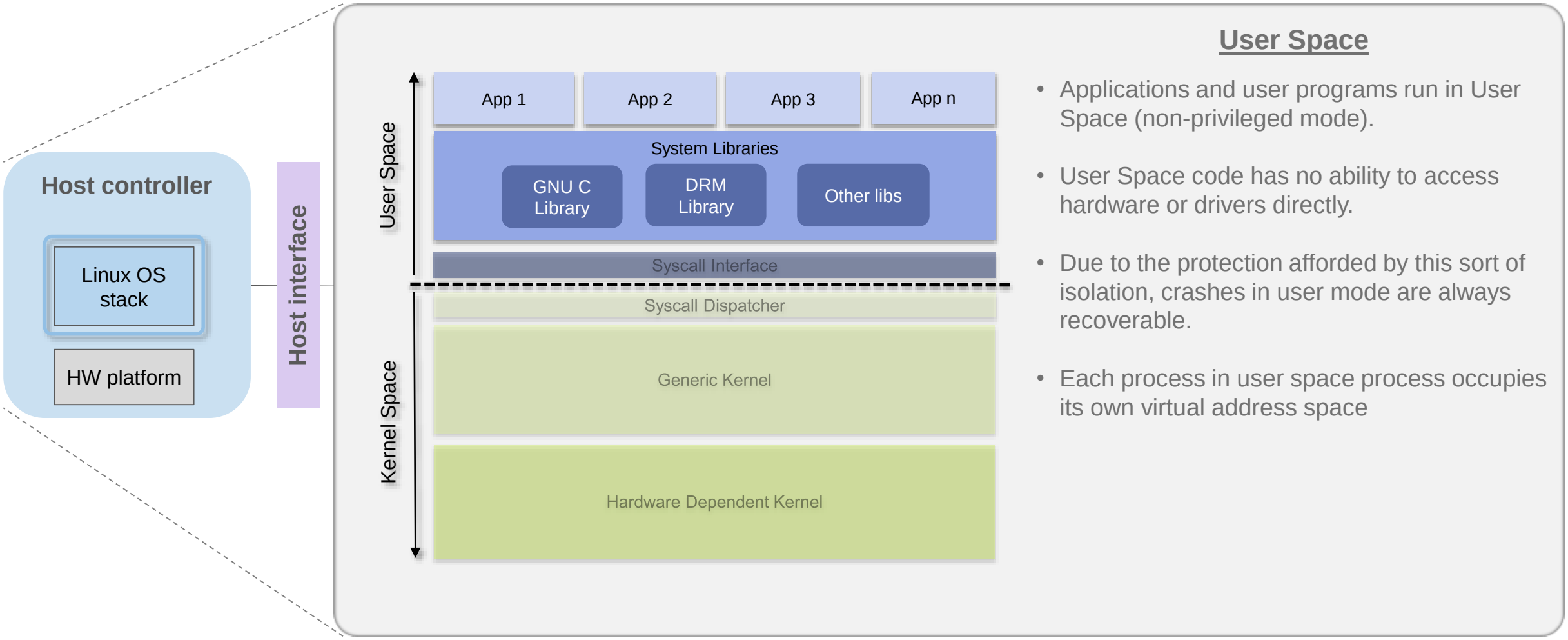
Host controller

- Contains the software implementing the application logic
- The RF digital protocols are implemented on the host controller
- The host controller platform needs to be selected according to system requirements:
  - Memory requirements
  - Clock frequency
  - MCU architecture
  - Host interfaces
  - Power consumption
  - GPIOs and other peripherals



The host controller drives and controls the NFC frontend according to register settings configuration

Host controller SW: Linux OS architecture - User space



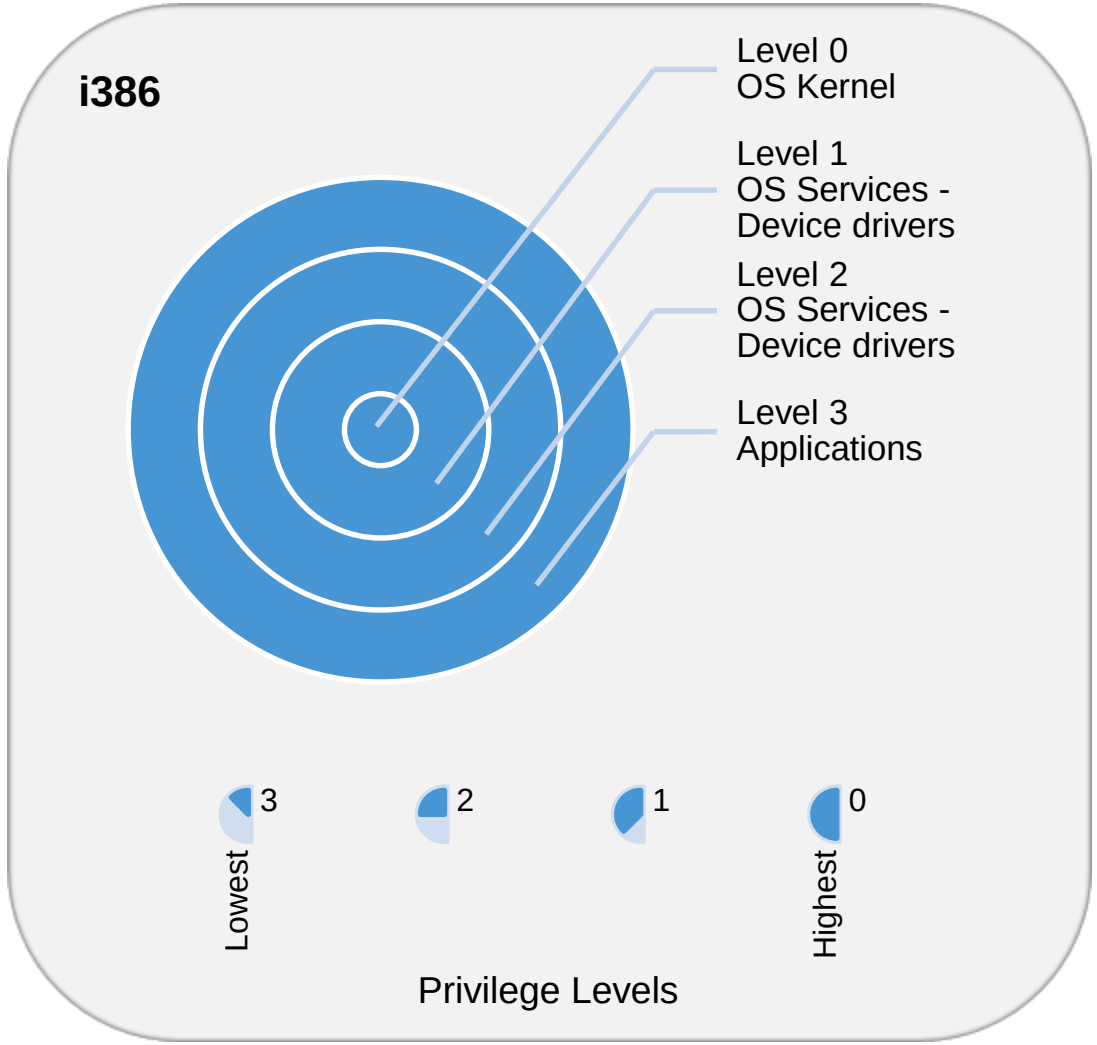
User Space

- Applications and user programs run in User Space (non-privileged mode).
- User Space code has no ability to access hardware or drivers directly.
- Due to the protection afforded by this sort of isolation, crashes in user mode are always recoverable.
- Each process in user space process occupies its own virtual address space

Privilege separation: i386 and ARM architecture

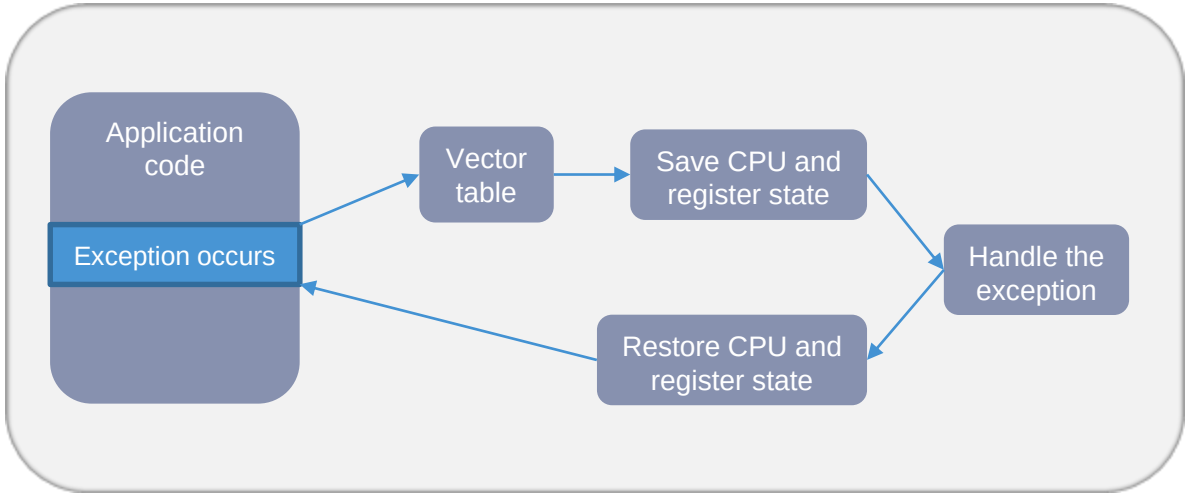
- Most processors define so called privilege levels.
- i386 knows 4.
- ARM v7 knows 3.

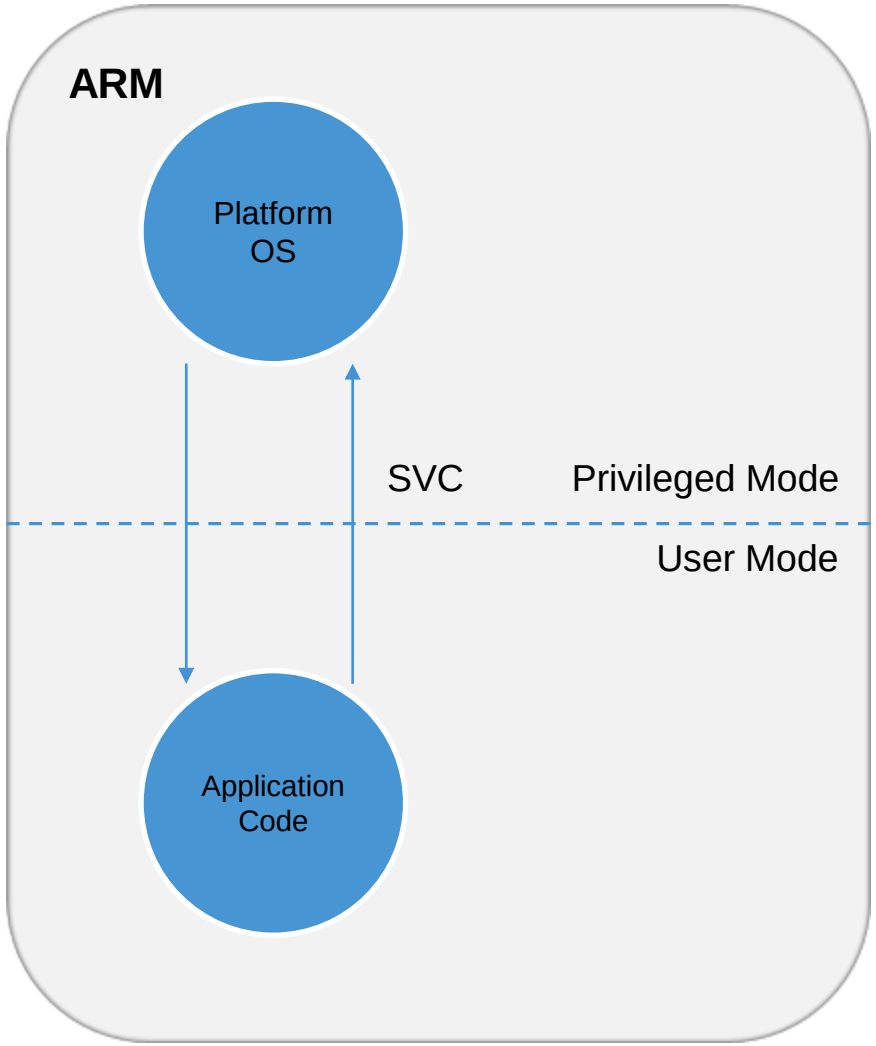
- ARM v7
- PL0 – Unprivileged level for user applications. User mode
- PL1 – Privileged level for operating system.
- PL2 – Hypervisor mode. Can switch between guest OS that execute in PL0.



Privilege separation: switching the level

- Switching the privilege level must be controlled
- On ARM a super visor call (SVC) is used to enable user mode code to access OS functions
- SVC provides a well defined handler to switch the processor mode.
- The SVC triggers a processor exception.



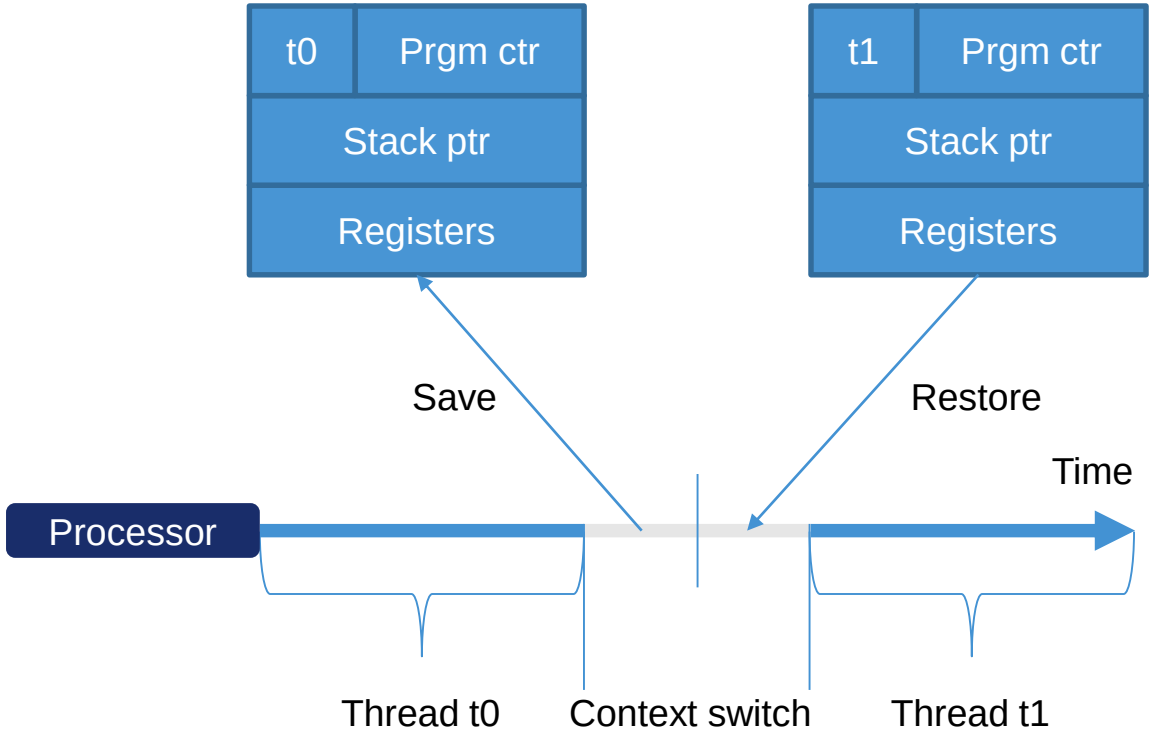


Privilege separation: context switch

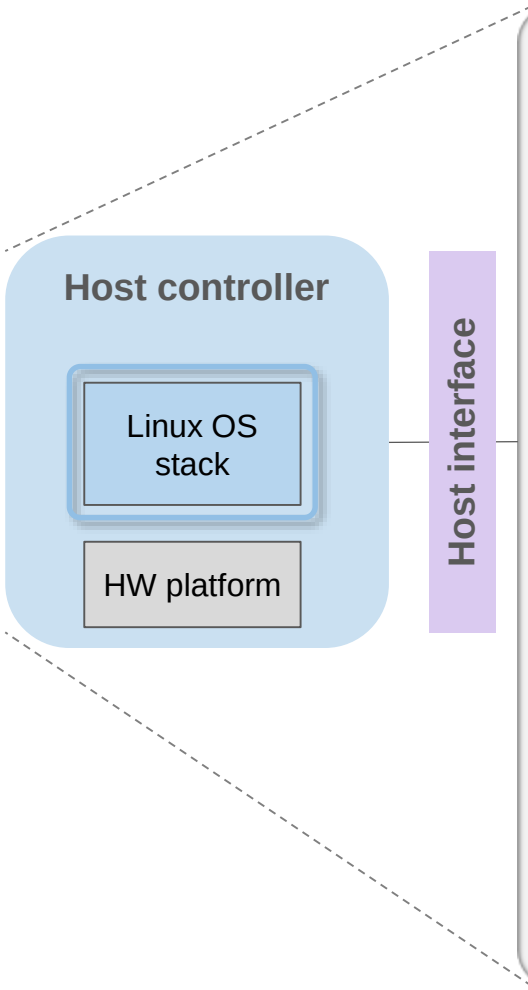
- Changing privilege level on an OS always comes with a context switch.

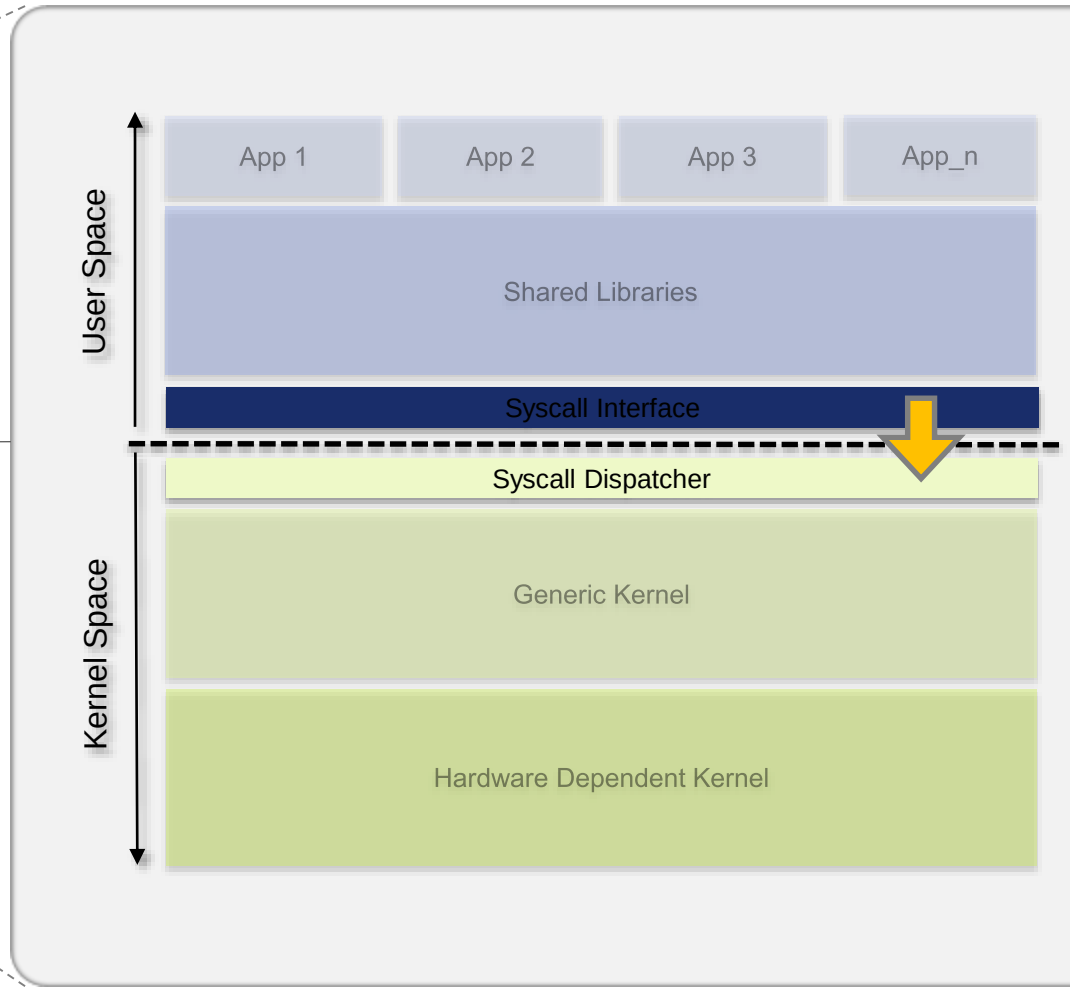
What is a context switch?

- Storing current processor state and restoring another.
- The interrupt handler manages the context switch.
- The interrupt handler has to:
  - Switch to privileged mode
  - Save defined registers to the process stack.
  - Save current task's Process Stack Pointer (PSP) to memory.
  - Load next tasks stack pointer and assign to PSP.
  - Load registers from process stack.
  - Switch back to unprivileged mode.



Host controller SW: Linux OS architecture – System call interface

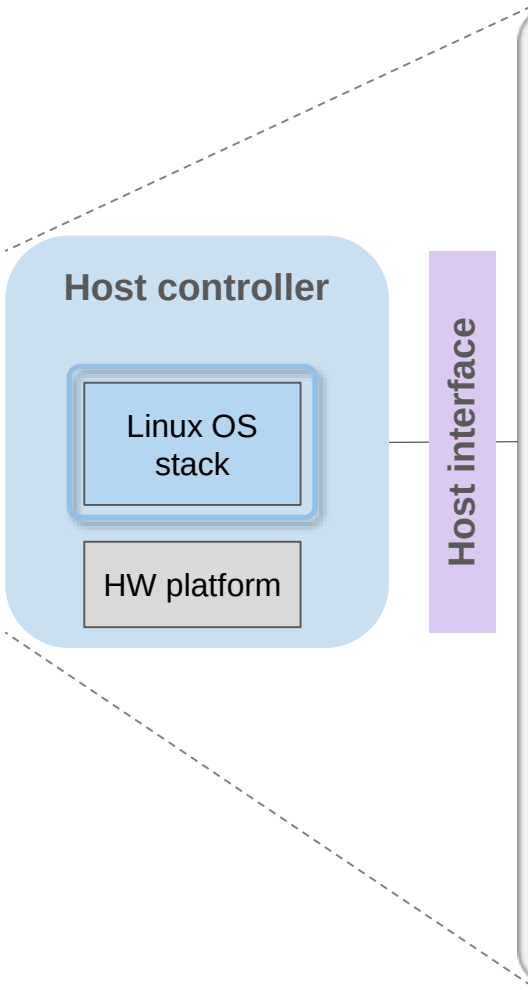


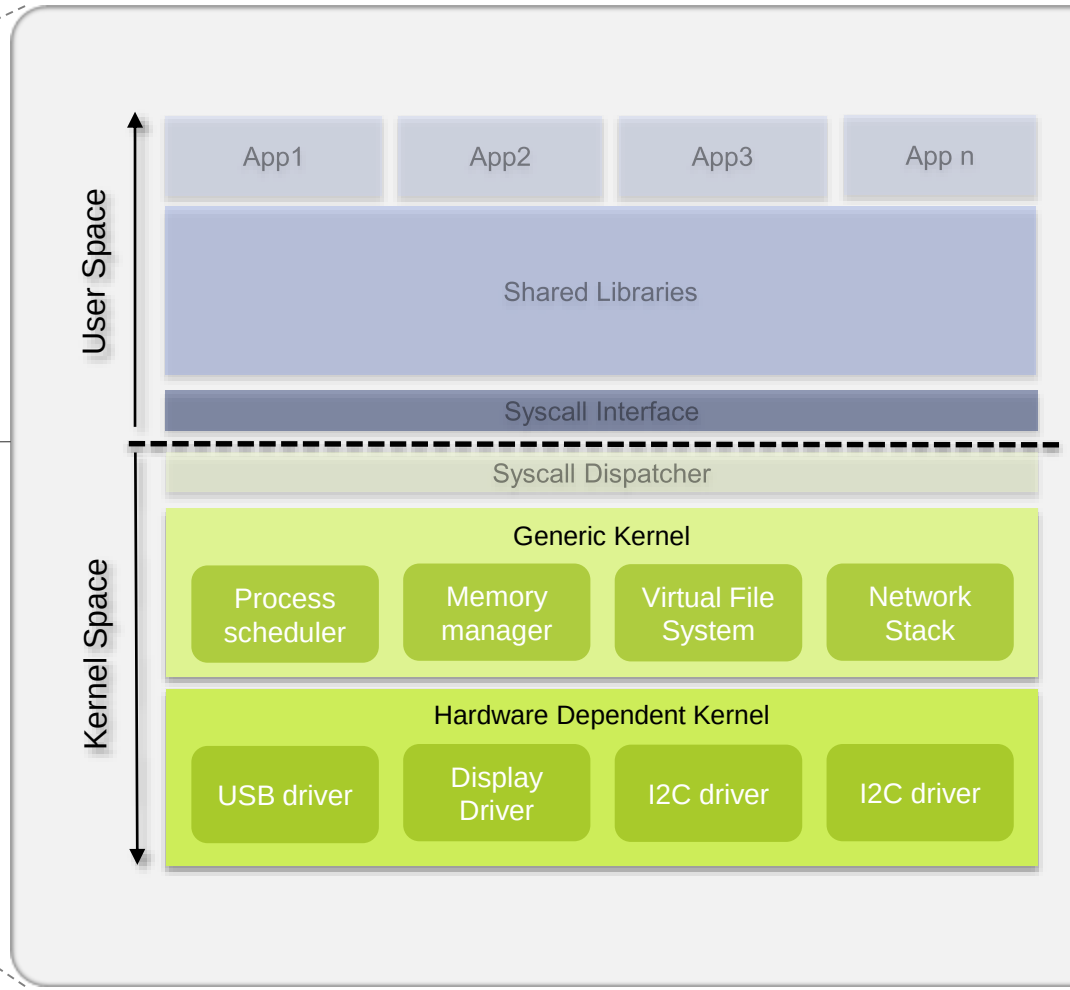


System call interface

- Provides the means to perform function calls from user space into the kernel space
- Code running in user mode must delegate to system call APIs to access hardware or memory.
- Most operations interacting with the system require permissions not available to a user level process (e.g. Input / Output operations)
- Input/output (I/O) is any program, operation or device that transfers data to or from the CPU and to or from a peripheral device

Host controller SW: Linux OS architecture - Kernel space





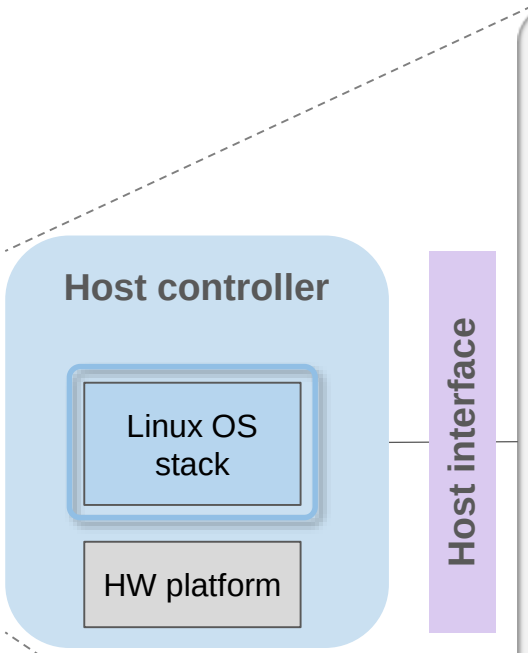
Kernel Space

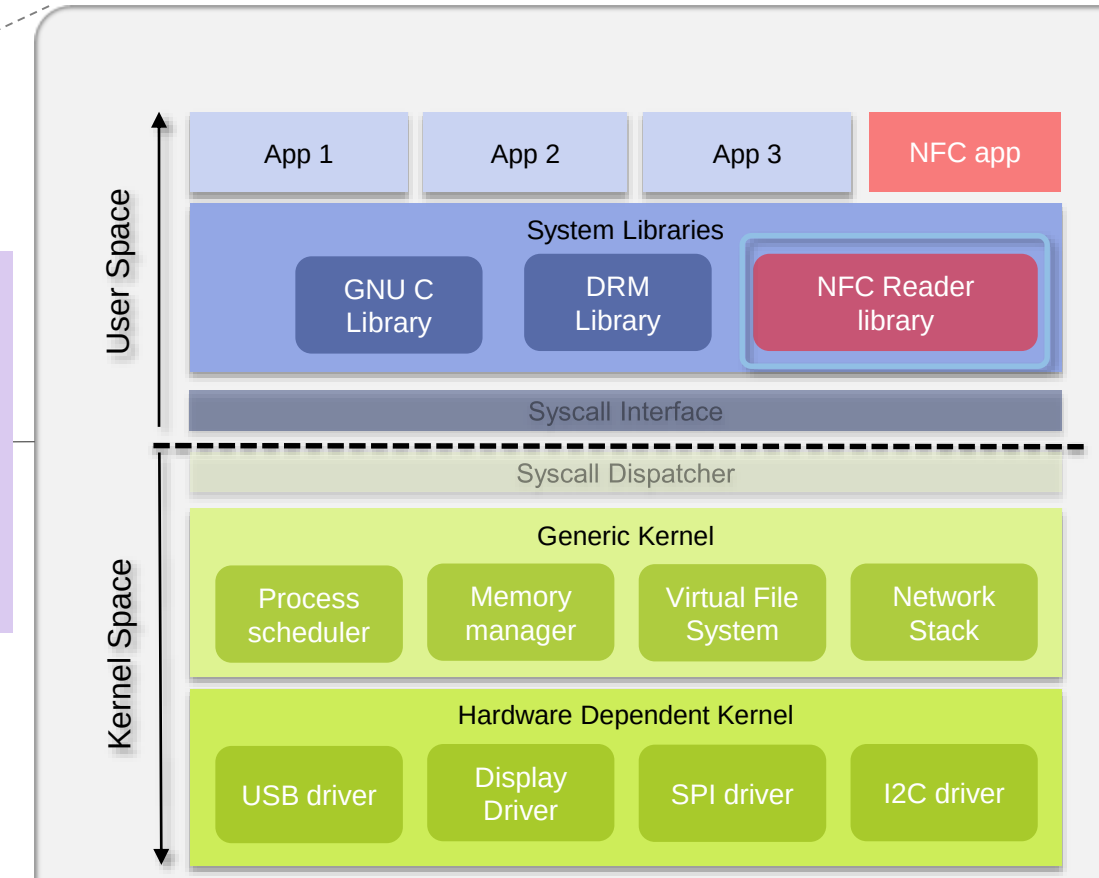
- The kernel connects the application software to the hardware platform.
- The executing code has complete and unrestricted access to the underlying hardware.
- Kernel mode is generally reserved for the lowest-level, most trusted functions of the operating system
- Kernel Mode "prevents" User Mode applications from damaging the system or its features → Crashes in kernel mode are catastrophic.
- Kernel space runs on the single address space.

03.

Integrating the NFC Reader Library in Linux

NFC Reader Library: The SW stack to develop NFC applications





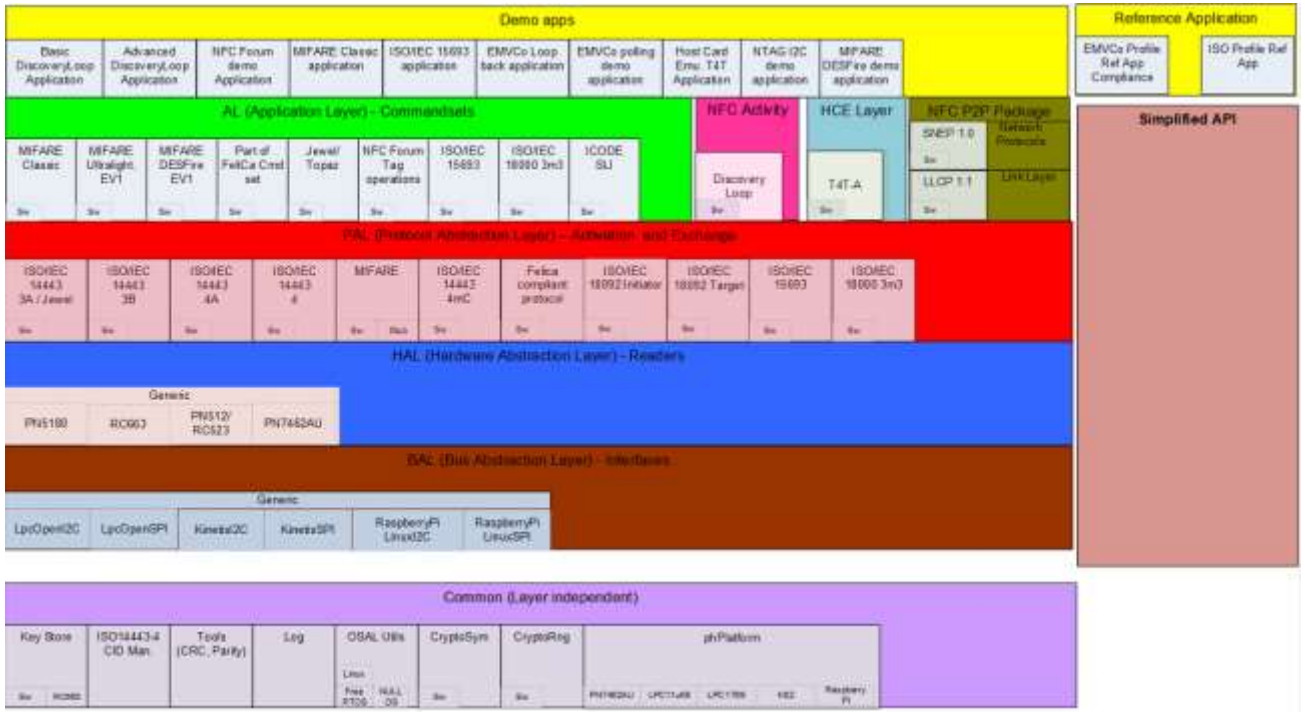
NFC Reader Library SW integration

- The NFC Reader Library provides an API including everything you need to deploy for NFC applications:
  - Host platform drivers
  - RF digital protocols
  - Full feature set according to NFC Forum
  - NXP NFC frontends hardware drivers
  - MIFARE cards and NFC Forum tag operation
- The NFC Reader Library runs within the **User Space.**
- The customer NFC app is built on top of the NFC Reader Library, taking advantage of the offered API

The NFC Reader Library is the NXP software stack to develop NFC applications and there is an existing version for Linux OS architecture!

NFC Reader Library & available resources

NFC Reader Library



Features: Modular, multi-layered, ANSI-C language, portable to multiple platforms and free download

Don't start from scratch, available software examples to test and re-use

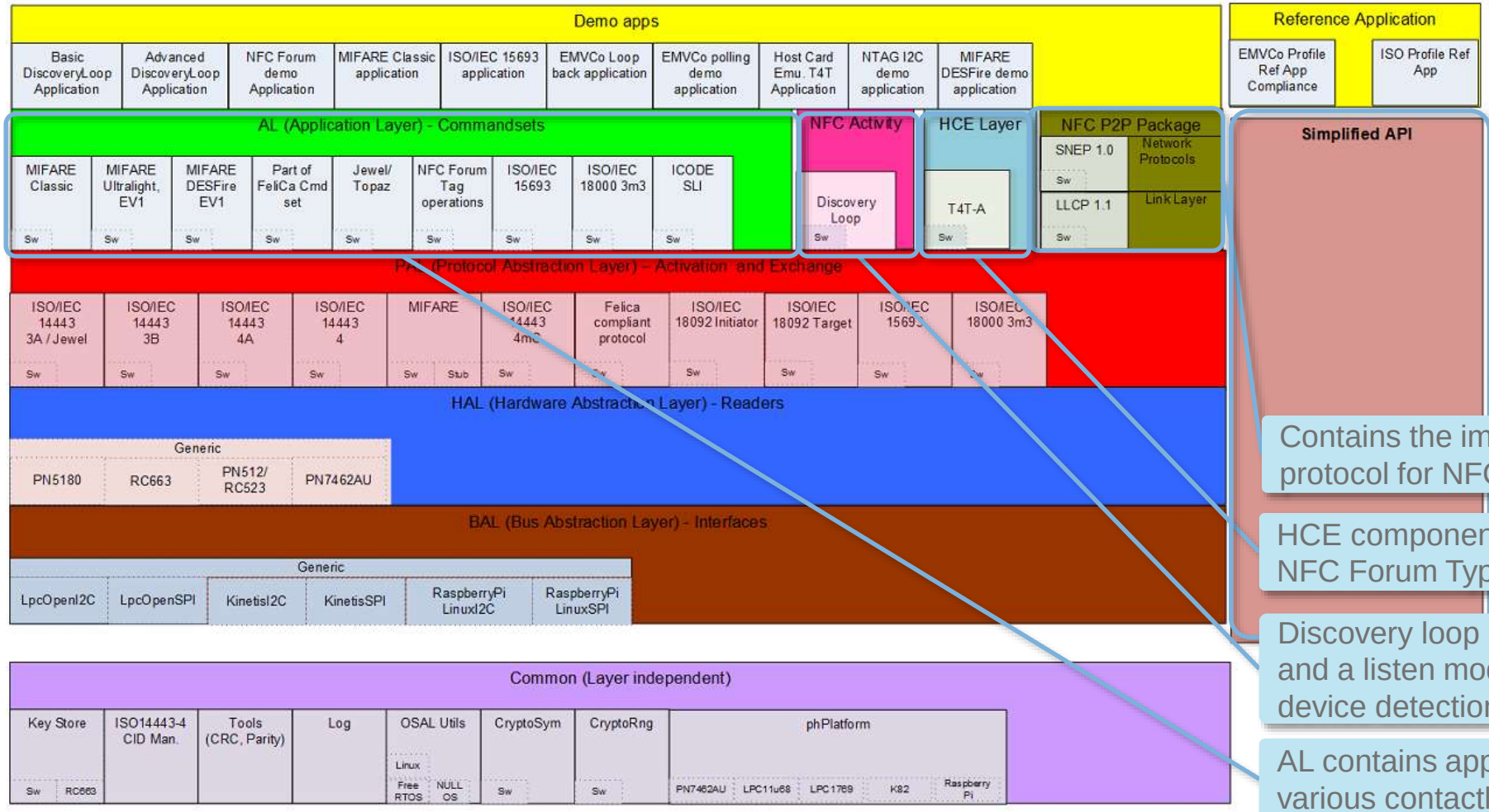
Software examples

Example 1: BasicDiscoveryLoop
Example 2: AdvancedDiscoveryLoop
Example 3: NFCForum
Example 4: MIFARE Classic
Example 5: ISO15693
Example 6: EMVCo Loopback
Example 7: EMVCo Polling
Example 8: HCE T4T
Example 9: NTAG I2C
Example 10: SimplifiedAPI_EMVCo
Example 11: SimplifiedAPI_ISO

For additional information and source code, please visit: www.nxp.com/pages/:NFC-READER-LIBRARY

The **NFC Reader Library** is everything you need to create your own software stack and application for a contactless reader

NFC Reader Library architecture



High level abstraction of the NFC Reader Library. Two profiles for: EMVCo and ISO

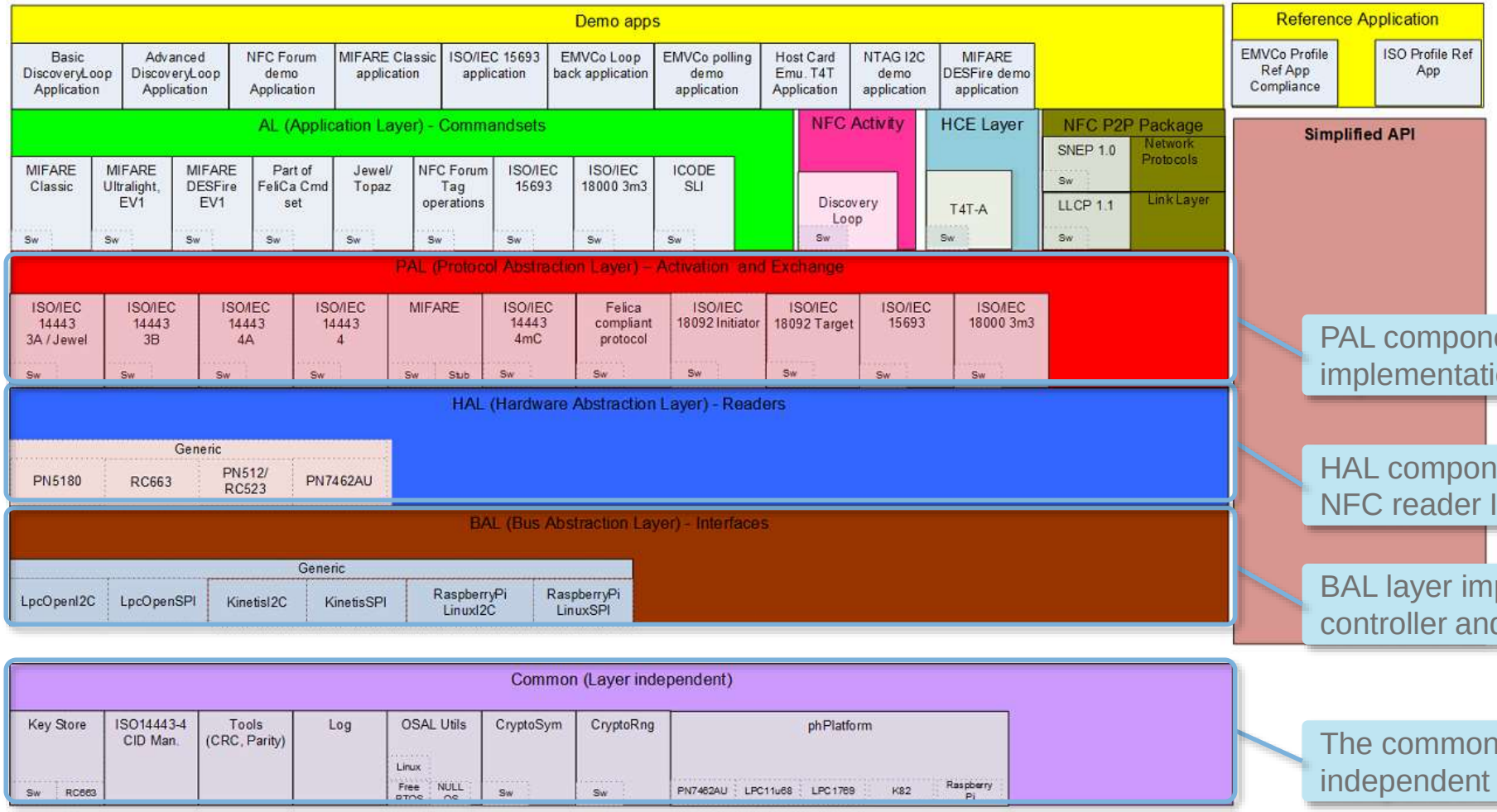
Contains the implementation of LLPC and SNEP protocol for NFC P2P mode

HCE component implements the card emulation of NFC Forum Type 4A tag

Discovery loop component implements a poll mode* and a listen mode** for contactless card and NFC device detection

AL contains application-specific implementations for various contactless cards (card command sets)

NFC Reader Library architecture (II)



PAL components contain hardware-independent implementations of contactless protocols

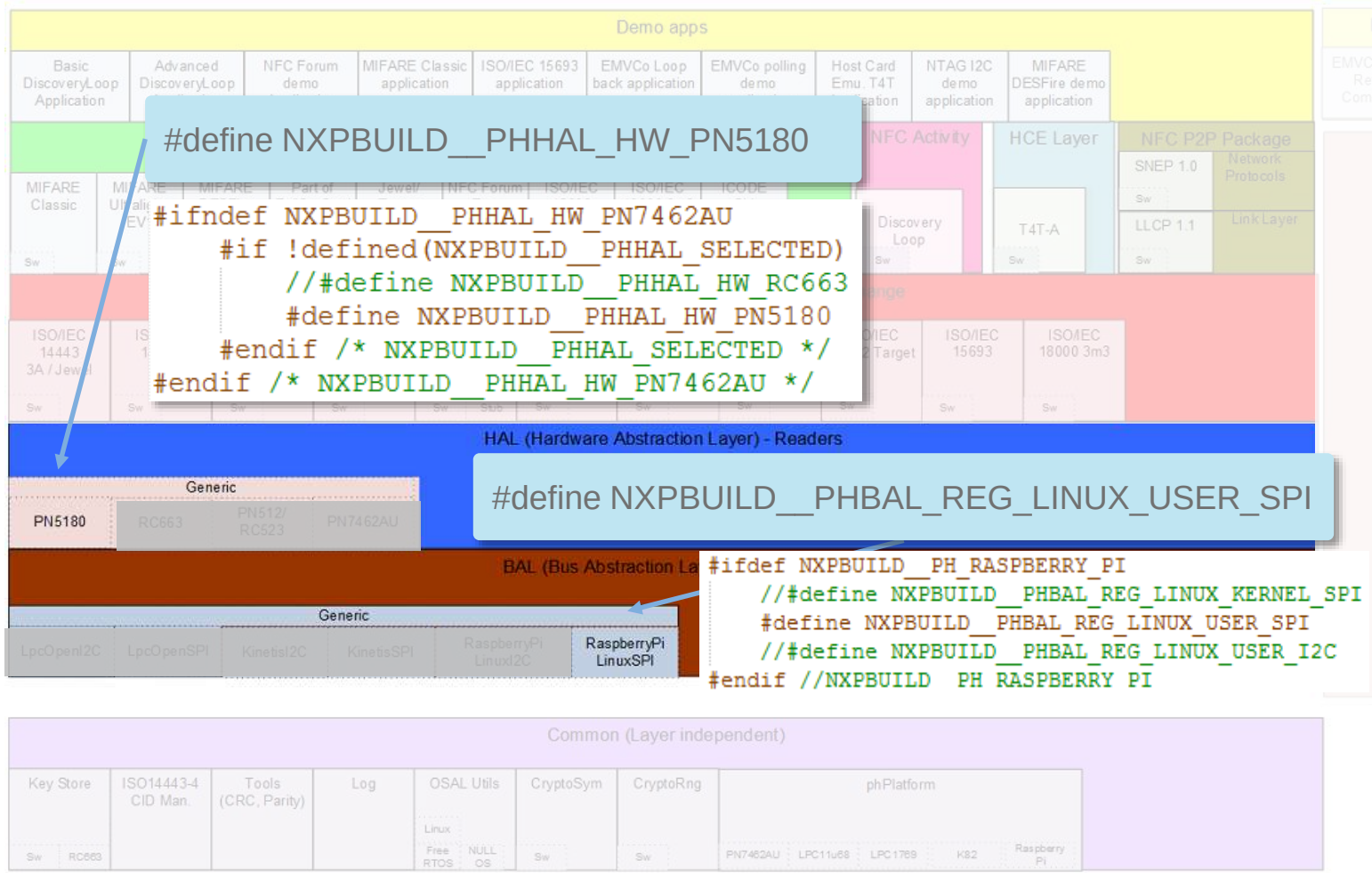
HAL components abstract the functionality of the NFC reader IC to a generic interface

BAL layer implement the interface between host controller and the NFC reader IC

The common layer implements a set of utilities independent of any card and hardware

Raspberry Pi is used as reference platform for Linux version of the NFC Reader Library

NFC Reader Library – building the SW stack



- The build setup and functionality is set in the file: **../intfs/ph_NxpBuild.h.**
- This file defines the modules to be **included** into the build setup or to be **excluded** from the build setup .
- There is a specific **macro** defined for including / excluding each SW component
- Components can be included / excluded depending on the application requirements or to optimize memory footprint.

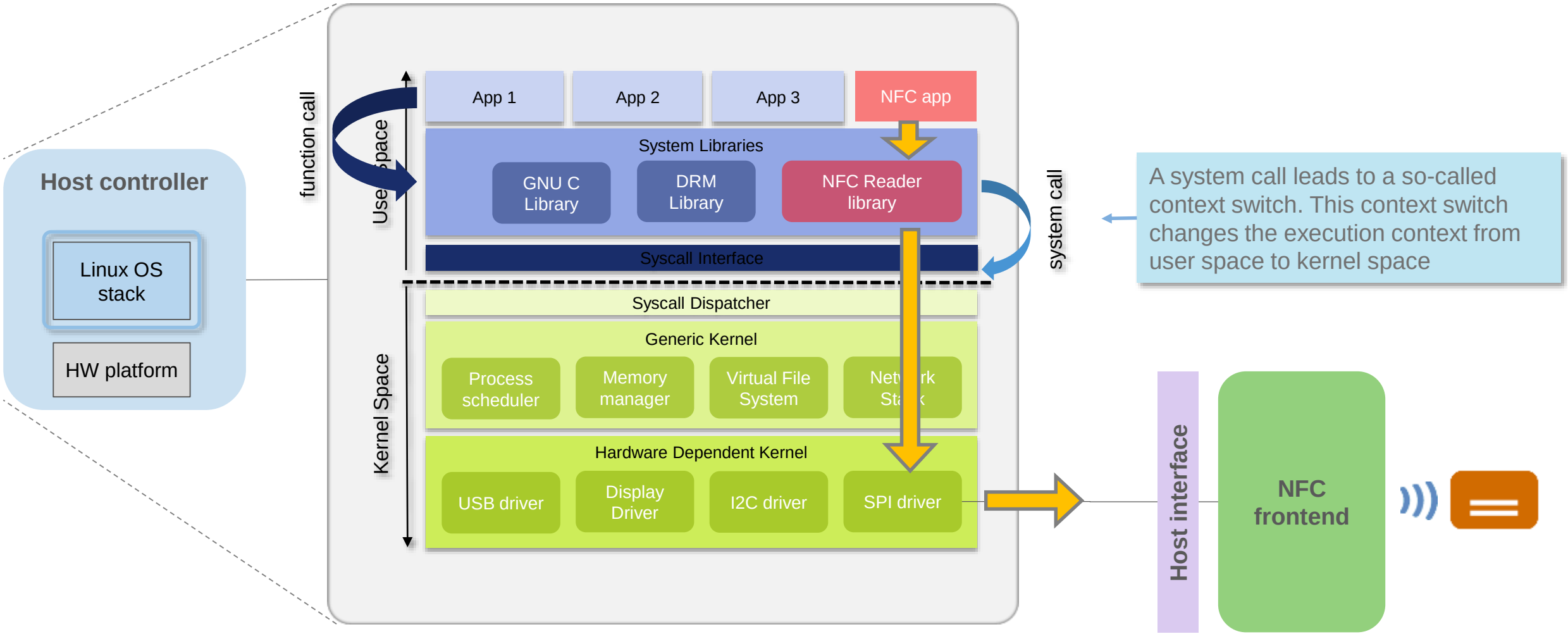
Components not included in the project build

Modules can be enabled / disabled to optimize code size and memory footprint

04.

Host interface access on Linux systems

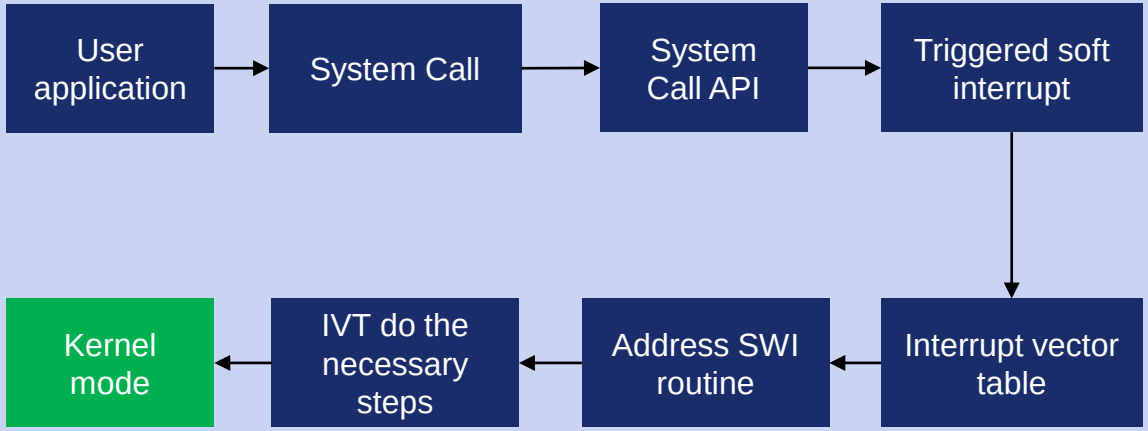
Linux based application: System call interface



The NFC application needs to switch from User Space to Kernel Space for every SPI interface access

Transition between User mode and Kernel mode

Switching from User mode to Kernel mode



- User application initiate switching to kernel mode making a system call (e.g. open, read, write, etc)
- A software interrupt (SWI) is triggered
- The interrupt vector table launch the handler routine which performs all the required steps to switch the user application to kernel mode
- Start execution of kernel instructions on behalf of the user process.

Advantage:

- Well defined interface.
- Horizontal separation: Avoids that a crashing application crashes the whole system and protects system resources.

Disadvantage:

- Performance degradation: A syscall is much **slower** than a direct function call

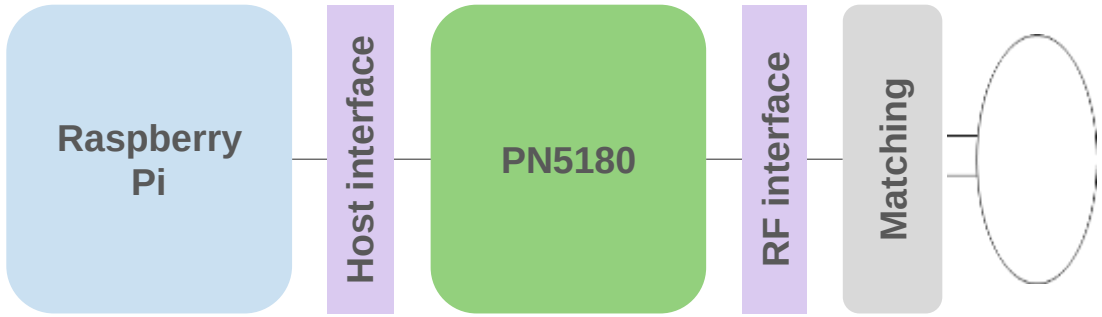
Could challenge the design of time-critical NFC applications

05.

Latency analysis: Linux vs bare metal

Hardware setup

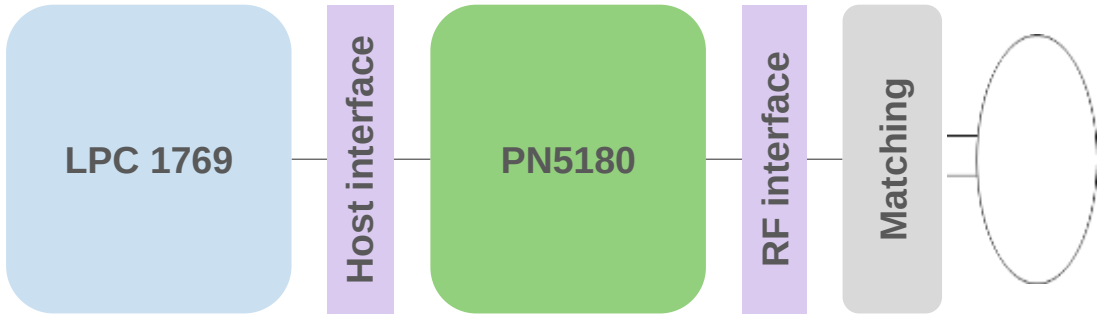
Linux setup



Linux hardware platform

- Raspberry Pi 3 Model B
  - 1.2 GHz 64-bit quad-core ARMv8 CPU
    - Limited to 1 Core @ 100 MHz (3 cores disabled)
  - 1 GB RAM
- PNEV5180B (with LPC bypassed)
  - SPI host interface

Bare metal setup

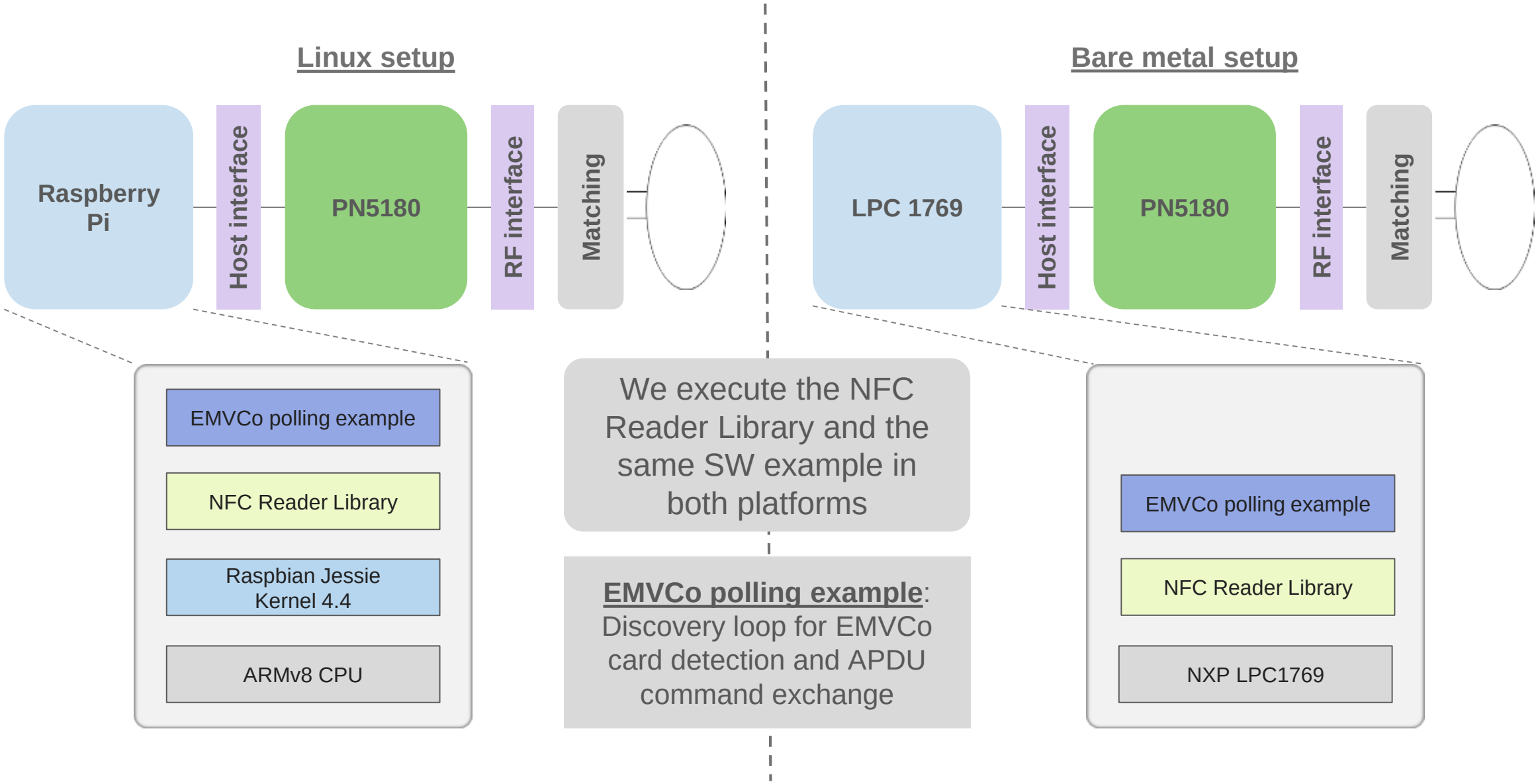


Bare metal hardware platform

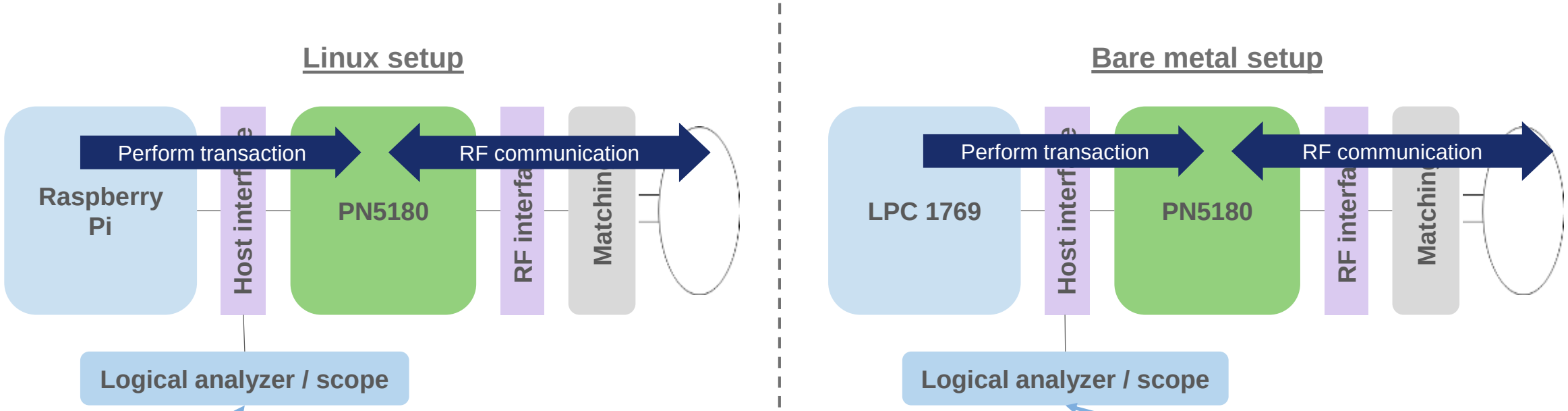
- NXP LPC1769 uC
  - ARM 1 core @ 96 MHz
- LPC-Link2 connected for debugging
- PNEV5180B
  - SPI host interface

We limited Raspberry Pi clock and MCU cores to achieve a comparable setup with LPC1769

Software setup



Measurement setup



We use a logical analyzer / scope connected in the SPI interface between the Host controller & PN5180

Measurements conducted

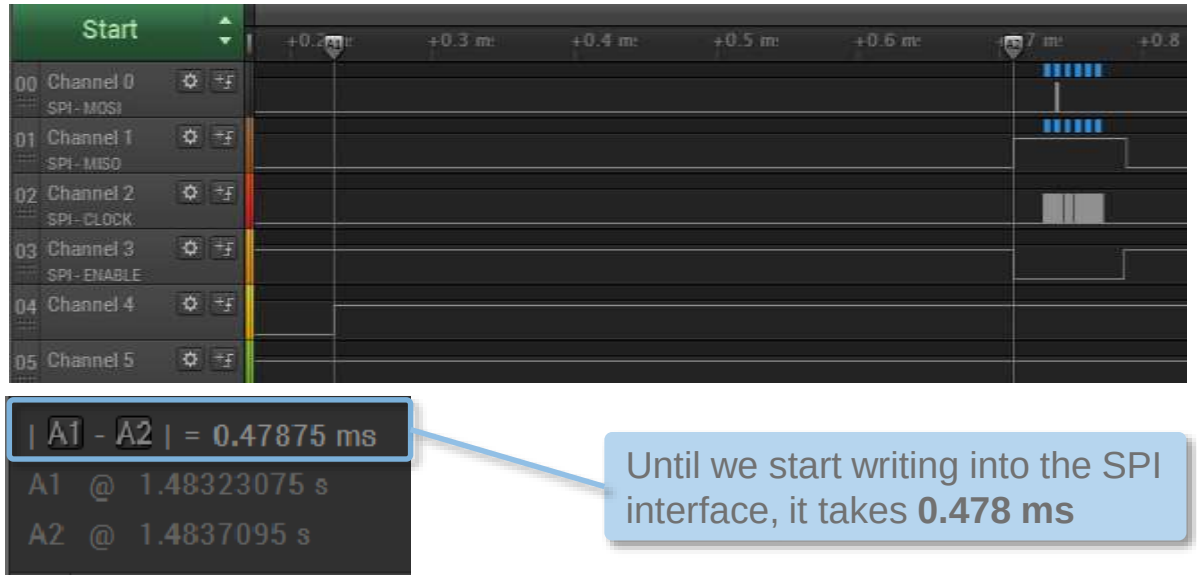
- Time from GPIO toggle to SPI transfer
- Time between two SPI accesses
- Time for EMVCo polling initialization
- Time for EMVCo loopback transaction

We use a logical analyzer / scope connected in the SPI interface between the Host controller & PN5180

We compared the results in the next slides

Measured time from GPIO toggle to SPI transfer

Linux setup

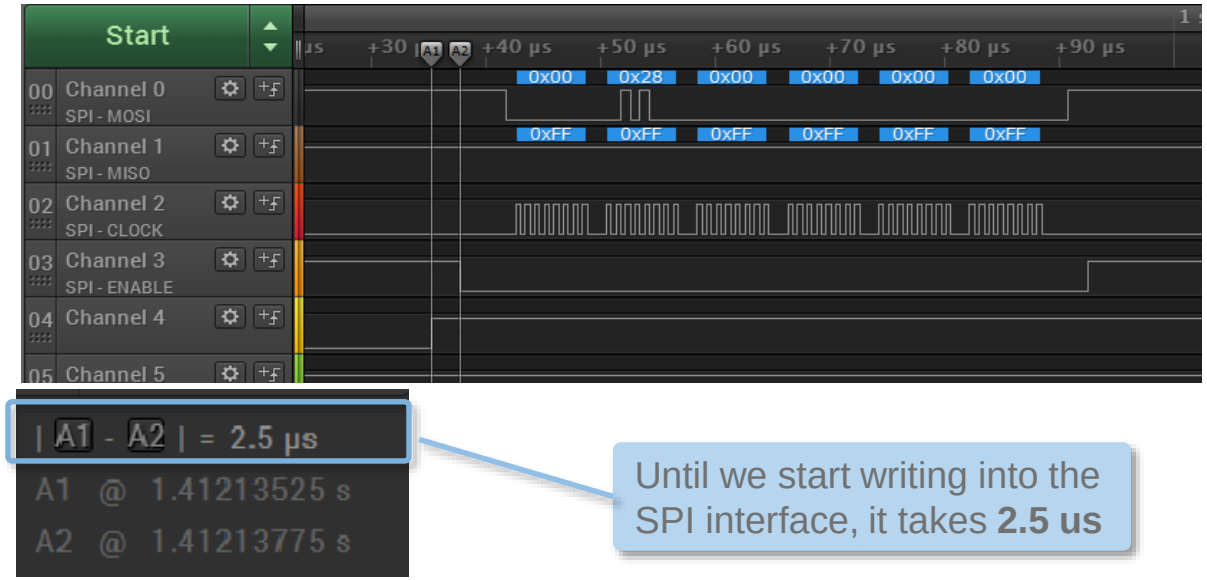


Until we start writing into the SPI interface, it takes **0.478 ms**

```
1. Set_GPIO(High)*;
2. phhalHw_PN5180_WriteRegister(…);
3. Set_GPIO(Low);
```

* Pseudo-code extracted from the real EMVCo polling source code example from the NFC Reader Library
* GPIO toggling execution takes less than 350us

Bare metal setup



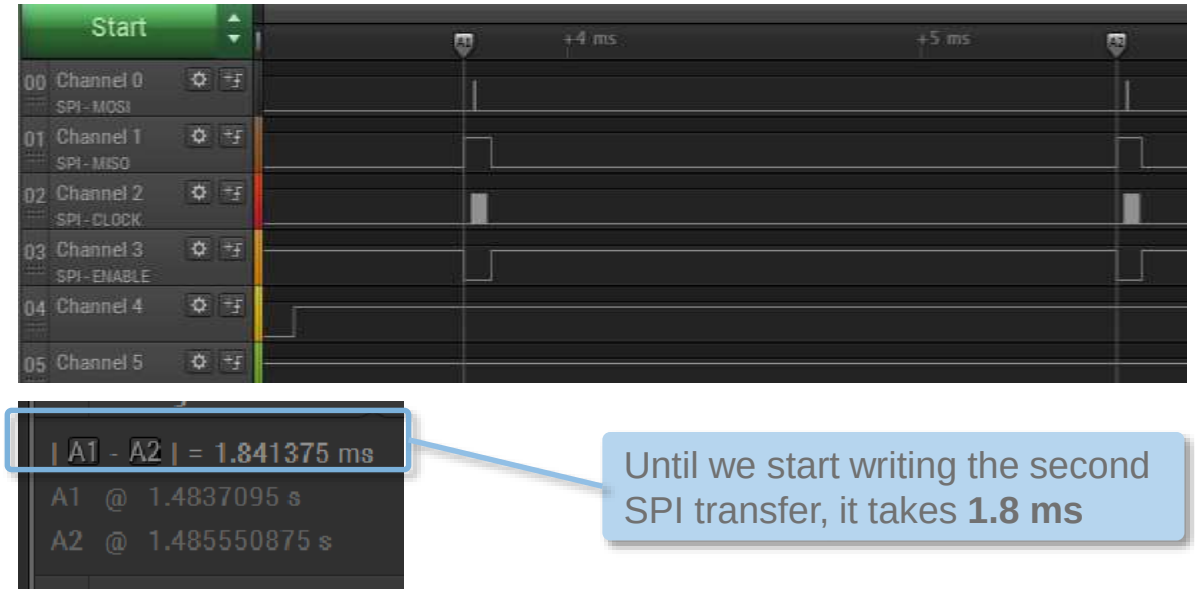
Until we start writing into the SPI interface, it takes **2.5 us**

```
1. Set_GPIO(High)*;
2. phhalHw_PN5180_WriteRegister(…);
3. Set_GPIO(Low);
```

* GPIO toggling execution takes less than 3us

Measured time between two SPI accesses

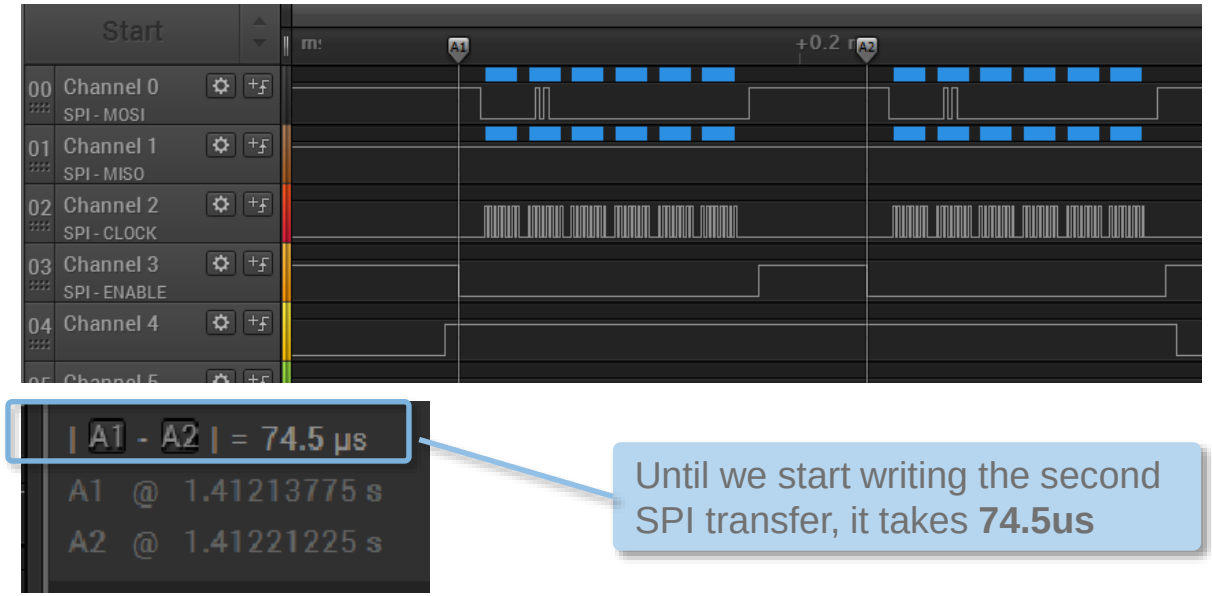
Linux setup



Until we start writing the second SPI transfer, it takes **1.8 ms**

```
1. Set_GPIO(High)*;
2. phhalHw_PN5180_WriteRegister(…);
3. phhalHw_PN5180_WriteRegister(…);
4. Set_GPIO(Low);
```

Bare metal setup



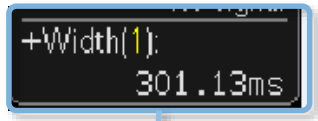
Until we start writing the second SPI transfer, it takes **74.5us**

```
1. Set_GPIO(High)*;
2. phhalHw_PN5180_WriteRegister(…);
3. phhalHw_PN5180_WriteRegister(…);
4. Set_GPIO(Low);
```

* Pseudo-code extracted from the real EMVCo polling source code example from the NFC Reader Library

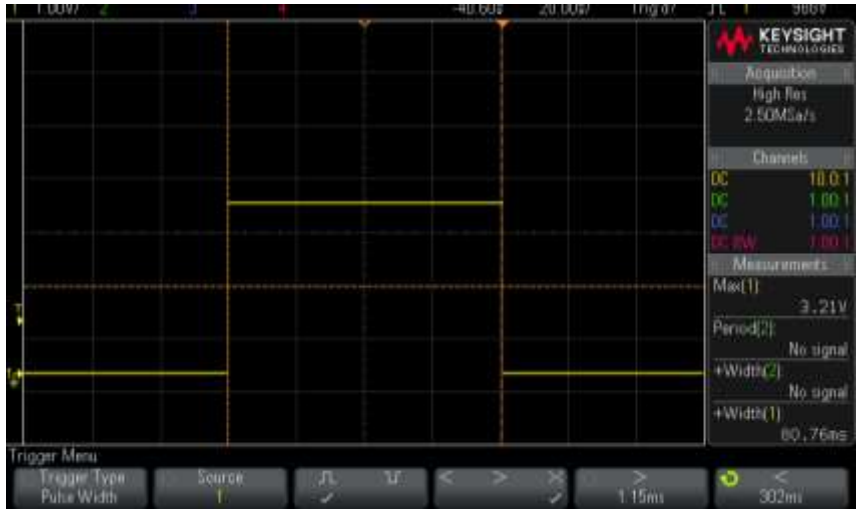
Measured time for EMVCo polling initialization

Linux setup



Measured time for 10 EMVCo polling inits.
1 init ~30.1ms

Bare metal setup



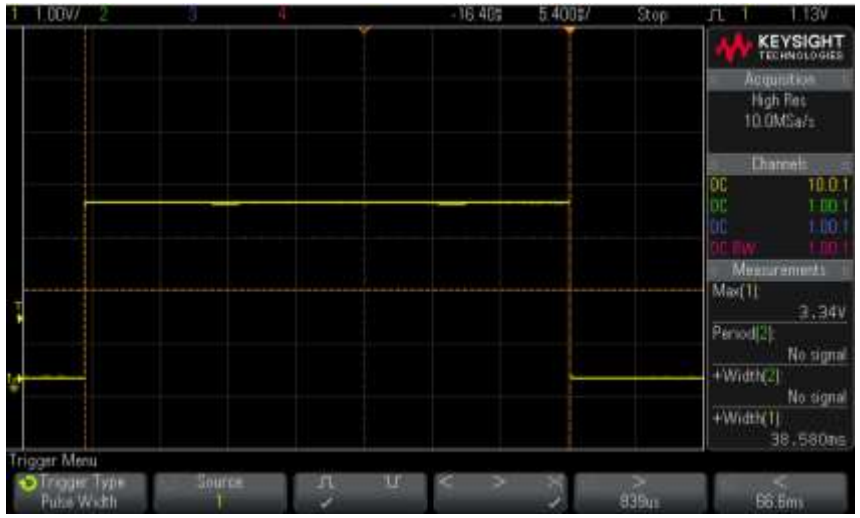
Measured time for 10 EMVCo polling inits.
1 init ~8.07 ms

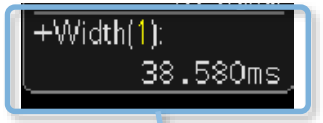
```
void Emvco_Polling(void * pHalParams)
Board_LED_Set(LED_NUM, 1);

for(i=0;i<10;i++)
{
    /* Load Emvco Default setting */
    status = LoadEmvcoSettings();
    CHECK_STATUS(status);

    /* Perform RF Reset */
    status = EmvcoRfReset();
    CHECK_STATUS(status);

    status = phhalHw_SetConfig(pHal, PHHAL_HW_CONFIG_SET_EMD, PH_OFF);
    CHECK_STATUS(status);
}

Board_LED_Set(LED_NUM, 0);
```

* During the initialization, several registers are written.
The process is repeated 10 times to get an average

Measured time for EMVCo loopback

Linux setup





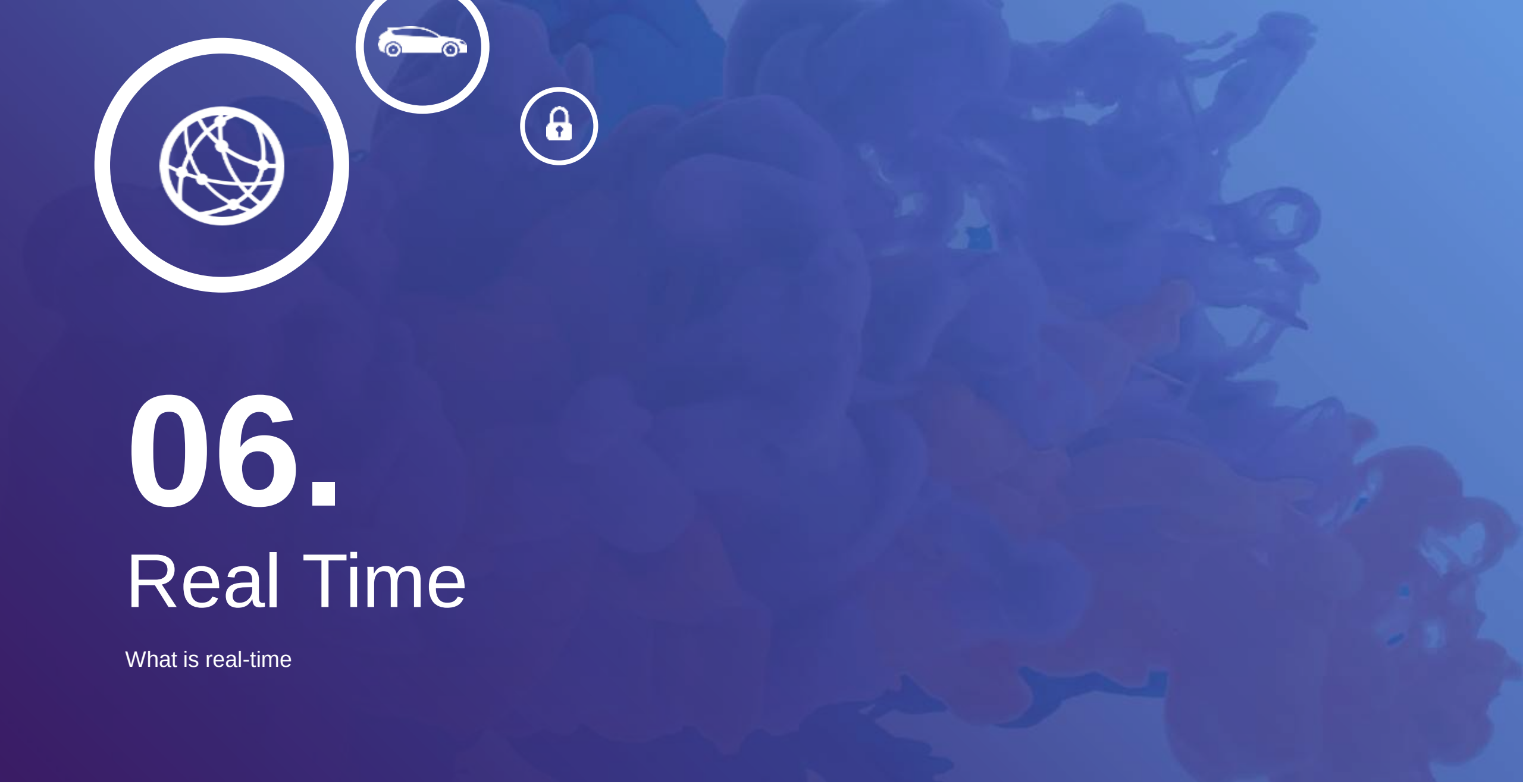
Measured time for a EMVCo loopback transaction takes **33.5ms**

Bare metal setup

Measured time for a EMVCo loopback transaction takes **6.9ms**

```
*phStatus EMVCoDataLoopBack(…){
1. Set_GPIO(High);
2. EMVCoDataExchange(…);
3. phhalHw_PN5180_WriteRegister();
```

* Pseudo-code extracted from the real EMVCo polling source code example from the NFC Reader Library



06.

Real Time

What is real-time

Real Time – Definition

What is Real Time?

- In case a system needs to execute a certain action or task within a given time frame then we are talking about real time
- **Hard real-time** means that exceeding this time frame is not allowed and could lead to malfunction/failure
- In **Soft real-time** there is no hard deadline but rather a typical limit until certain tasks can be finished
- **Firm real-time** also “allows” exceeding the deadline, but the result could be invalid/outdated

Hard real-time - Examples

- During EMVCo L1 certification of a terminal the measured guard time between a WUPA and a WUPB **must** not exceed 10ms
- So, the system must guarantee that the WUPB frame is sent after latest 10ms
- If this is not achieved the device is not EMVCo L1 compliant and fails certification

Soft real-time - Examples

- The same terminal in field operation should not exceed the guard time of 10ms between a WUPA and a WUPB
- If it’s exceeded the system is still working and operable with typically no negative impact

Real Time – Definition

- **What is Real Time?**
  - In case a system needs to execute a certain action or task within a given time frame then we are talking about real time
  - **Hard real-time** means that exceeding this time frame is not allowed and could lead to malfunction/failure
  - In **Soft real-time** there is no hard deadline but rather a typical limit until certain tasks can be finished
  - **Firm real-time** also “allows” exceeding the deadline, but the result could be invalid/outdated

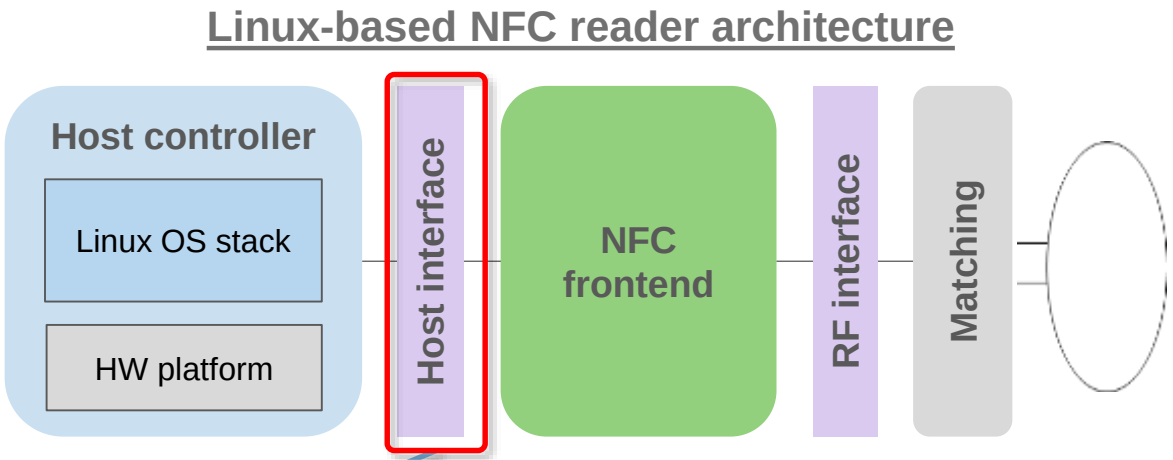
- **Hard real-time - Examples**
  - During EMVCo L1 certification of a terminal the measured guard time between a WUPA and a WUPB **must** not exceed 10ms
  - So, the system must guarantee that the WUPB frame is sent after latest 10ms
  - If this is not achieved the device is not EMVCo L1 compliant and fails certification

- **Soft real-time - Examples**
  - The same terminal in field operation should not exceed the guard time of 10ms between a WUPA and a WUPB
  - If it’s exceeded the system is still working and operable with typically no negative impact

07.

Overcoming Linux higher latency for time-sensitive applications

Recommendations to reduce Linux latency



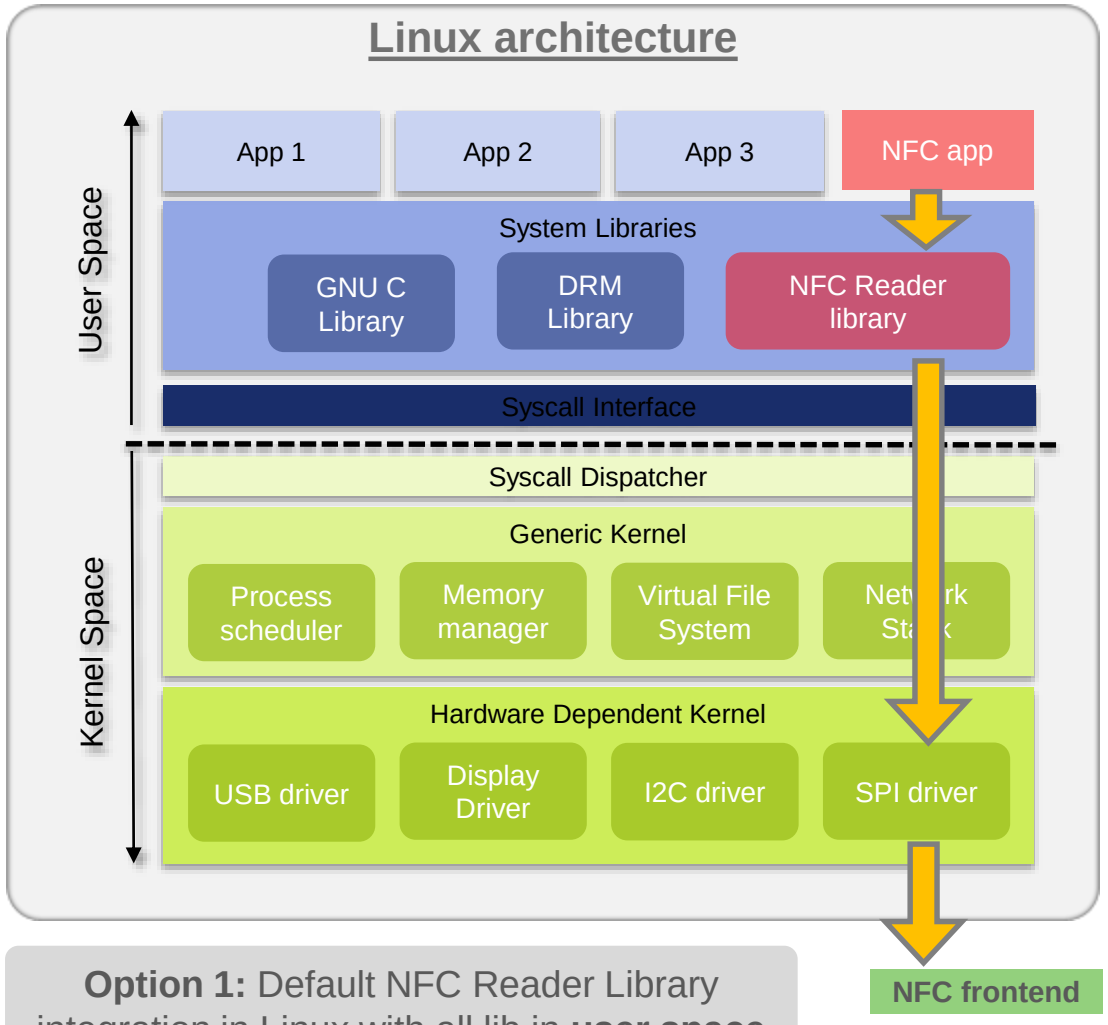
The major parameter influencing the Linux latency is the large time required to access the host interface from the host controller due to the Linux SW stack architecture

Solutions

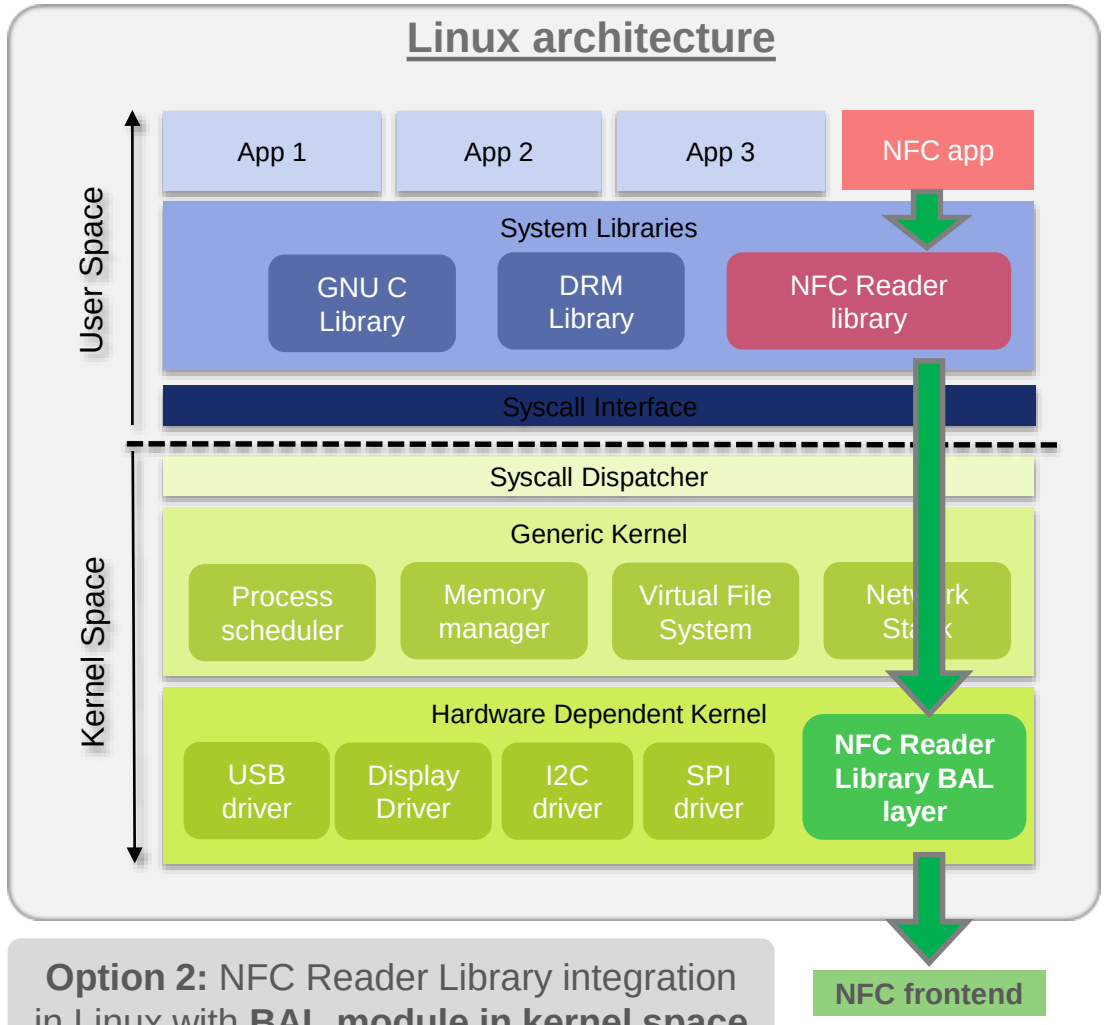
- Increase CPU/SPI clock as much as the MCU can process.
- Reduce SPI / host interface interactions as much as possible: Linux driver are optimized for few long transactions rather than lots of short ones
- **Move NFC Reader Library BAL module to Kernel space**

The most effective solution !!

NFC Reader Library support of BAL module in Kernel space

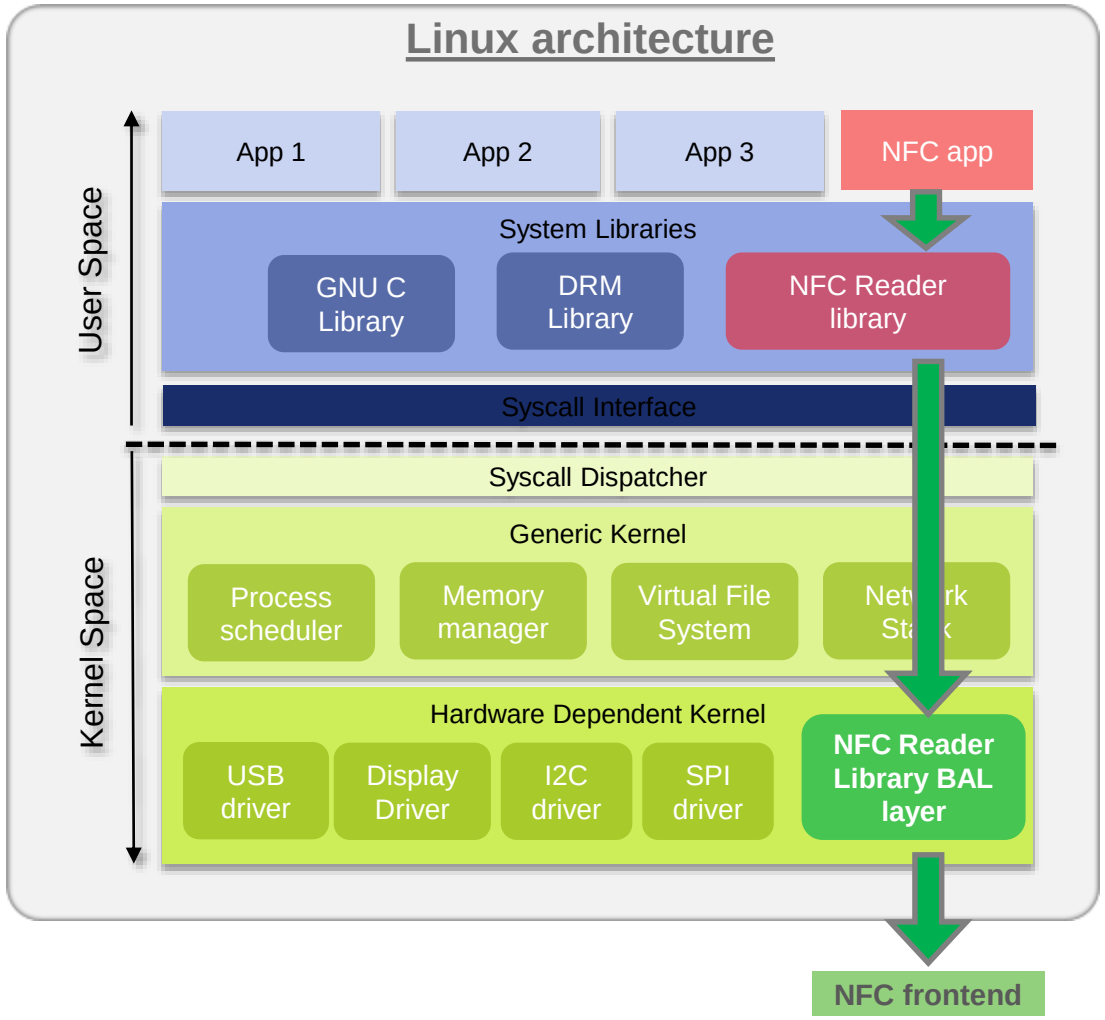


Option 1: Default NFC Reader Library integration in Linux with all lib in **user space**



Option 2: NFC Reader Library integration in Linux with **BAL module in kernel space**

NFC Reader Library BAL module: User Space vs Kernel space



BAL layer in User Space

1. Read GPIO to wait for BUSY line from previous command going low.
2. Setup and start first SPI transfer.
3. Read GPIO to wait for BUSY going low.
4. Setup and start second SPI transfer.
5. ....

Plenty of system calls and context switching operations

BAL layer in Kernel Space

1. System call read() leading to a context switch
2. Access BAL kernel module with direct access to the SPI and GPIO frameworks.

ONLY ONE SYSTEM CALL → Much more efficient instead of having individual access from user space

NFC Reader Library BAL module: User Space vs Kernel space

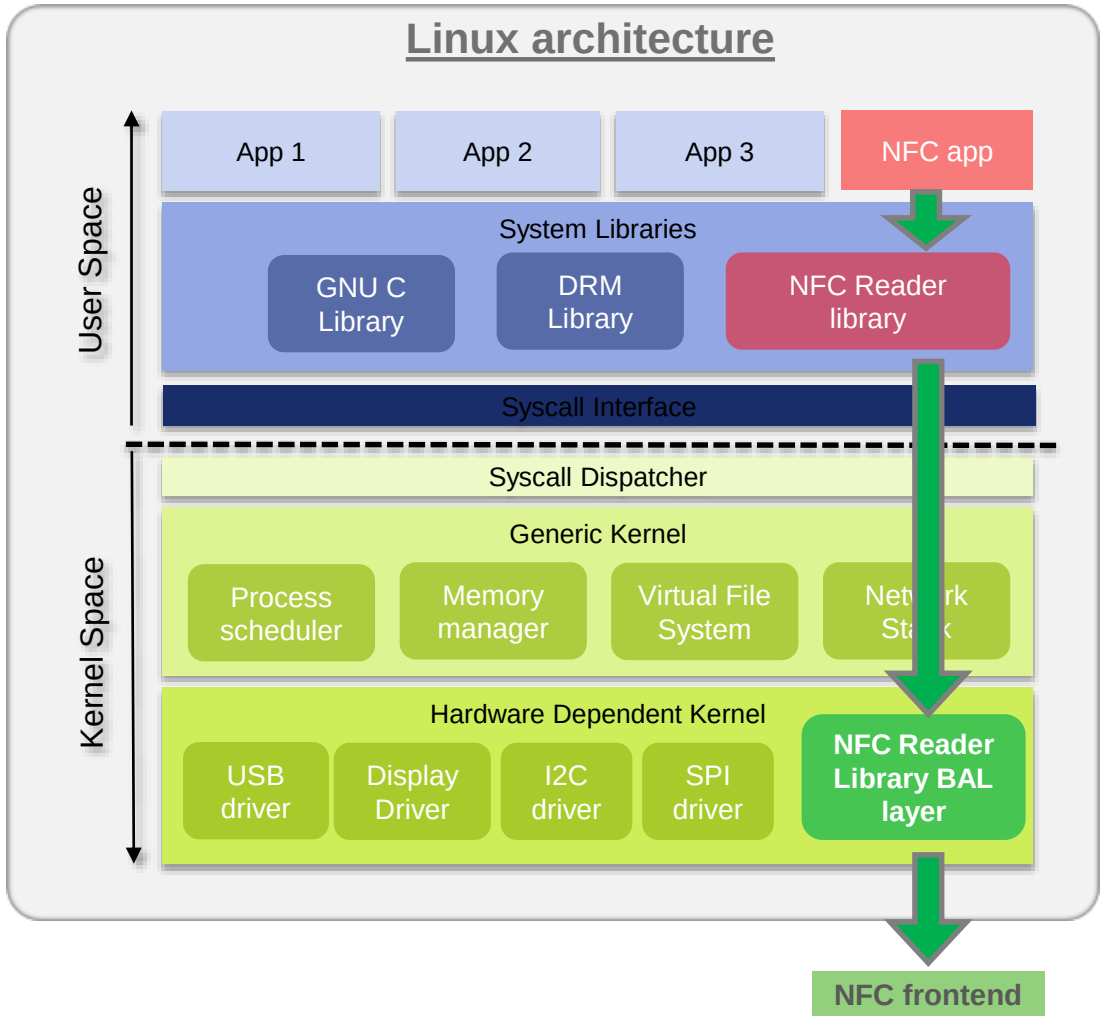
BAL layer in User Space: Measured time between two SPI transfers (Raspberry Pi 2 running Linux OS)

Until we start writing into the SPI interface, it takes **86us**

BAL layer in Kernel Space: Measured time between two SPI transfers (Raspberry Pi 2 running Linux OS)

Until we start writing into the SPI interface, it takes **2us**

NFC Reader Library BAL module in Kernel space: Resources



[1] GitHub repo with:

- Information about building, configuring and
- An example the integration on Raspberry Pi is given.

[2] App note with:

- Explanation of how the NFC Reader Library needs to be changed in order to call the kernel module instead of using the default BAL module running in user-space.

[1] https://github.com/NXPNFCLinux/nxprdlib-kernel-bal

[2] http://www.nxp.com/documents/application_note/AN11802.pdf

Further considerations

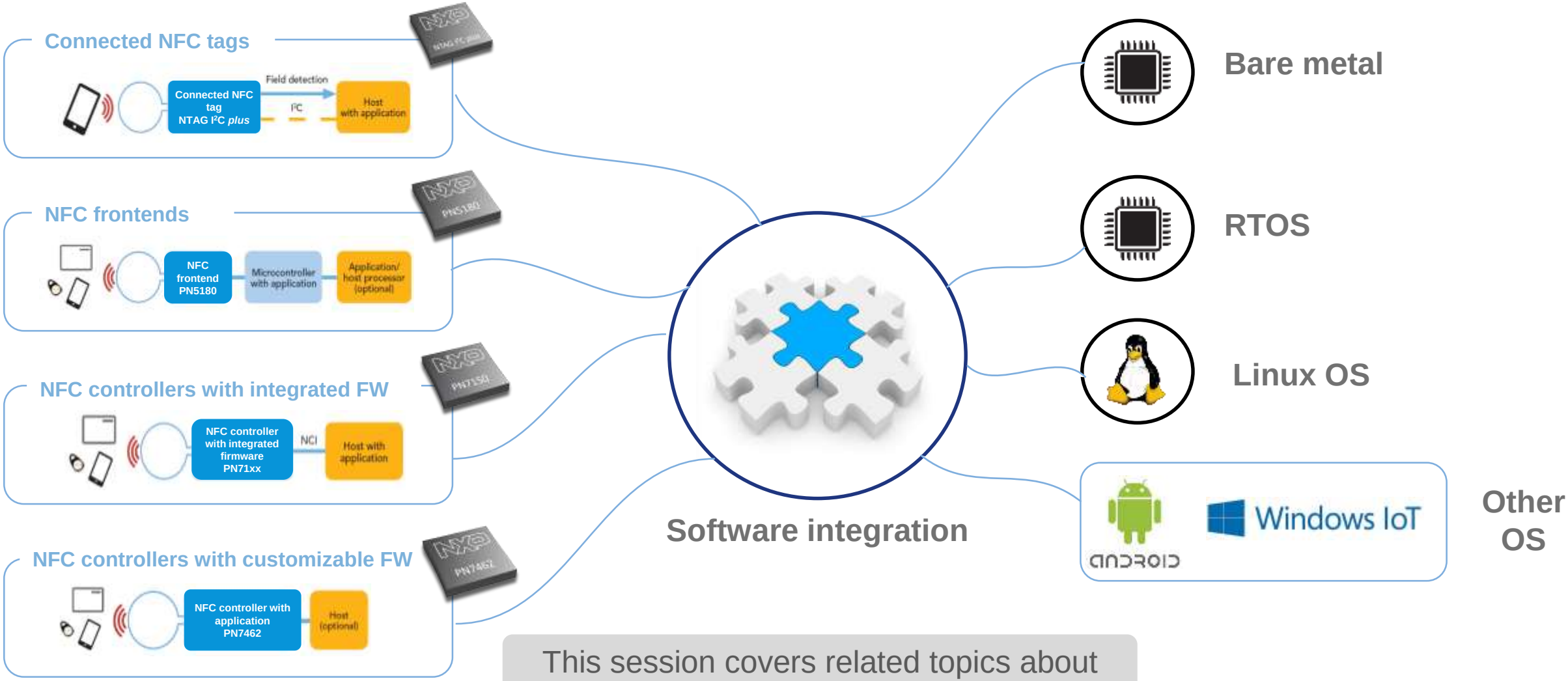
- Changing the scheduling policy.
  - FIFO and RT.
- RT-Preempt Linux Kernel patch [1].
  - Not part of Linux mainline. Needs to be applied manually.
- Dedicated MCU for timing sensitive parts.
  - E.g. i.MX6 CPU with dedicated Cortex-M4 core.

[1] https://rt.wiki.kernel.org/index.php/Main_Page

08.

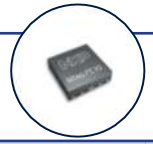
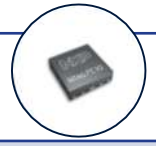
Selecting the right product

NXP software support for integration into any platform



This session covers related topics about NFC frontend software integration in Linux

Latest non-mobile NFC products

	PN5180 	CLRC663 *plus* 	NTAG I²C *plus* 	PN7462 & derivates 	PN7150 
Commercial tagline	*The best full NFC frontend in the market*	*Best performance at lowest power consumption*	*Simplest and lowest BoM NFC solution*	*All-in-one full NFC solutions*	*Best plug'n play, high-performance full NFC solution - Easy integration into any OS environment*
Positioning	Building on NXP's trusted leadership in the core NFC markets	NXP next-gen multi-protocol NFC frontend	Easy and reliable entry to the world of NFC, incl. password protection	The true innovation: The all-in-one product	Following the success of PN7120, PN7150 brings the same plug 'n play experience with higher performance
Target markets	Payment Access	Access Payment Gaming Industrial	IoT Mass market	Access Gaming Home banking	IoT Consumer Mass market
Required NFC know-how, targeted applications	› NFC experts who want to further optimize and/or customize their implementation	› NFC intermediates › High performance with low power requirements for the most demanding applications	› NFC beginners › Simple applications, where no reader functionality needed › Applications requiring simple protection of data	› Applications requiring multiple functionalities (NFC, CT, USB) › Freely programmable	› NFC integration into Linux and Android › Small and medium sized enterprises (SMEs)

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