Fast DDS (XRCE) Installation on PineTime64 smart watch

Assignment 2

Heterogeneous Computing (COE 504)

Submitted by

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Fast DDS (XRCE)

Fast DDS XRCE (also known **as eProsima Fast DDS-XRCE**) is an implementation of the DDS-XRCE (DDS for Extremely Resource Constrained Environments) protocol, part of the Data Distribution Service (DDS) family of standards maintained by the Object Management Group (OMG) [1]. The aim of the DDS-XRCE protocol is to provide access to the DDS Global-Data-Space from resource-constrained devices. This is achieved thanks to a client-server architecture, where low resource devices, called *XRCE Clients*, are connected to a server, called *XRCE Agent*, which acts on behalf of its clients in the DDS Global-Data-Space.

The eprosima Micro XRCE-DDS library implements a client-server protocol that enables resource-constrained devices (clients) to take part in DDS communications. The eProsima Micro XRCE-DDS Agent (server) acts as a bridge to make this communication possible. It acts on behalf of the Micro XRCE-DDS Clients by enabling them to take part to the DDS Global Data Space as DDS publishers and/or subscribers. It also allows for Remote Procedure Calls, as defined by the DDS-RPC standard, which implement a request/reply communication pattern.

eProsima Micro XRCE-DDS provides both a plug and play eProsima Micro XRCE-DDS Agent and an API layer which allows the user to implement the eProsimaMicro XRCE-DDS Clients.

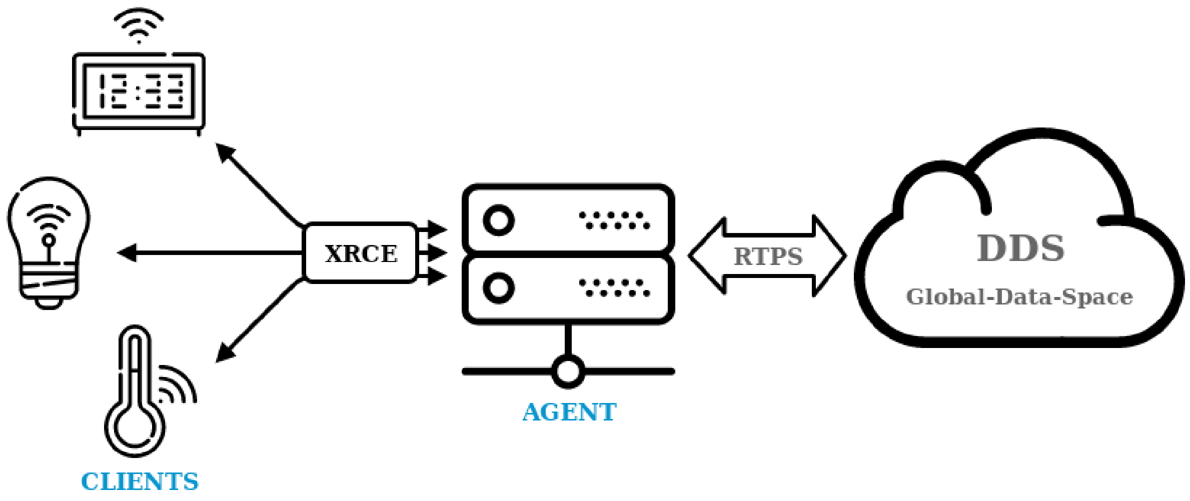


Fig. 1. Micro XRCE-DDS Architecture [1].

It is designed to allow devices with very limited resources, such as IoT sensors, microcontrollers, or embedded systems, to communicate in a DDS network. **Fast DDS-XRCE** serves as a middleware that enables data exchange between highly resource-constrained devices (clients) and full DDS networks (servers or agents), thus making DDS more accessible to a wider range of devices.

Key Features:

1. **Client-Server Architecture**: XRCE is built on a client-server model. The client is a lightweight entity on a resource-constrained device, and the server (or agent) acts as an intermediary between the client and the DDS network.
2. **Interoperability with DDS**: XRCE clients can publish or subscribe to data in a DDS network through an XRCE agent, bridging the gap between DDS-enabled systems and resource-constrained devices.
3. **Small Footprint**: It is optimized for environments with limited computational power, memory, and network bandwidth.
4. **Real-Time Communication**: Like DDS, Fast DDS XRCE supports real-time communication with a focus on low latency and high reliability.
5. **Wide Range of Use Cases**: It can be used in various fields such as industrial automation, robotics, automotive systems, and IoT applications, where small devices need to participate in complex communication networks.
6. **Customization**: Fast DDS-XRCE provides different Quality of Service (QoS) settings and can be tailored to specific use cases in constrained environments.

In essence, Fast DDS XRCE is a lightweight extension of the DDS protocol, enabling constrained devices to become part of larger, real-time data communication systems, maintaining compatibility with the broader DDS ecosystem.

Now, we would like to use XRCE DDS on day to day life IoT device such as PineTime smart watch.

PineTime

The PineTime [2] is a free and open source smartwatch capable of running custom-built open operating systems. Some of the notable features include a heart rate monitor, a week-long battery, and a capacitive touch IPS display that is legible in direct sunlight. It is a fully community driven side-project which anyone can contribute to, allowing you to keep control of your device.

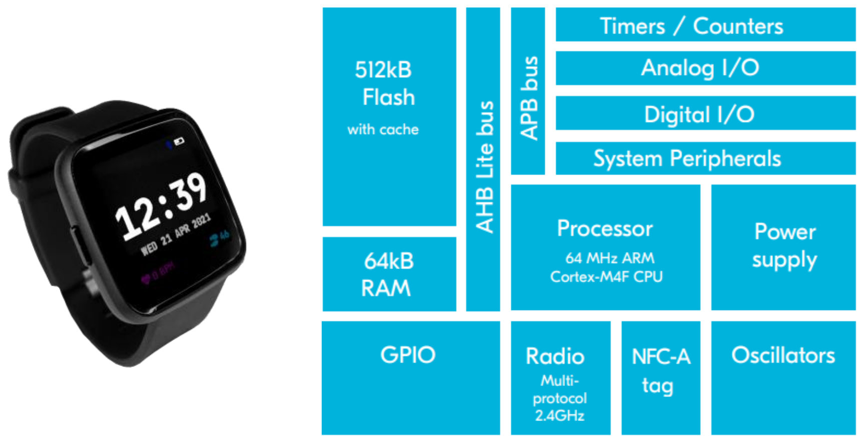


Fig. 2. PineTime64 [2] watch and SoC architecture of nRF52832 [3].

The smart watch is based **nRF52832** chip. That's SoC [3] architecture is shown in Fig.2. The nRF52832 takes Bluetooth Low Energy SoCs to the next level with its support for Bluetooth 5. It has an ARM Cortex M4 CPU at its heart, running at 64 MHz, it is capable of handling demanding application and communication tasks in a short timeframe. This frees up the CPU handle even more tasks, or to return to sleep mode, thus conserving precious battery energy. The nRF52832, and all SoCs in the nRF52 Series family are flash-based SoCs and are ideal for Device Firmware Updates (DFU). DFU brings total flexibility and control to the firmware running in your product. Enabling new security updates, bugfixing and feature additions in the field.

Features and Specification

Display	Square 1.3-inch 240×240 IPS capacitive touch display
SoC	Low-power Nordic Semiconductor nRF52832 64 MHz + Floating Point
Software	Any open-source operating systems built on top of numerous RTOSes
Body	Dimensions: 37.5mm x 40mm x 11mm Weight: 38 grams Made with Zinc Alloy and Plastic Dustproof and water-resistant up to 1m (Rated at IP67)
Health Tracking	Step Counting (with Accelerometer) Heart Rate Detection
Notification features	Notification access Wrist vibration Quick glance via lift-to-wake.
Connectivity	Bluetooth 5 and Bluetooth Low Energy Compatible with almost any device Over-the-air update
Storage	4 MB of User Storage 0.5 MB of OS Storage
Battery	All-week 180 mAh battery 2-pin USB charging dock

IPS touch display

The PineTime includes a color IPS capacitive touch display

Dustproof and Water Resistant

The PineTime comes with a IP67 rating, meaning that it can handle up to one meter of water and is fully dust proof

Bluetooth 5

With Bluetooth 5 and Bluetooth Low Energy, the PineTime can pair to other devices

Heartrate and Step Counting

With a built-in accelerometer and heart-rate sensor, the PineTime can help you keep track of your health

Since this smart watch has been designed as a very resource constrained manner for lightweight power consumption but to perform suitable tasks on a single chip architecture. That's why it's our key interest to implement XRCE DDS on this deice.

Environment Setup

Since the smartwatch contains **nRF52832** chip, we need a programmer to upload the firmware of this chip. To do this task we have chosen ESP32 chip as a programmer with SWD interface from Arduino IDE.

Required Hardware

- ESP32 WROOM S2 chip
- Bread Board
- PineTime64 smartwatch
- USB Cable
- Jumper wires
- Cables
- LED

Required Software

- Arduino IDE https://www.arduino.cc/
- ESP32 core Library https://github.com/espressif/arduino-esp32
- This version of the WifiManager

  https://github.com/tzapu/WiFiManager/tree/feature_asyncwebserver
- AsyncTCP https://github.com/me-no-dev/AsyncTCP
- ESPAsyncWebServer https://github.com/me-no-dev/ESPAsyncWebServer
- ArduinoBufferedStreams https://github.com/paulo-raca/ArduinoBufferedStreams

Arduino IDE Setup and preparation:

We have downloaded the Arduino IDE and complete the installation

- Copy or install the three downloaded libraries (AsyncTCP, ESPAsyncWebServer, WifiManager) into the Arduino > libraries directory
- Arduino > libraries: Rename:
- AsyncTCP-master to AsyncTCP
- ESPAsyncWebServer-master to ESPAsyncWebServer
- WiFiManager-master to WiFiManager

Installing libraries for ESP32 chip:

Now to add the ESP32 Core to Arduino

- File > Additional Boards Manager URLS >

https://raw.githubusercontent.com/espressif/arduino-esp32/gh-pages/package_esp32_index.json

ESP 32 SWD Programmer Interface preparation

We have followed this github (https://github.com/atc1441/ESP32_nRF52_SWD) tutorial for this preparation. We downloaded the repository and open the "ESP32_SWD_WIFI.ino" file with Arduino and select the "DOIT ESP32 DEVKIT V1" (Tools > Board: > DOIT ESP32 DEVKIT V1)

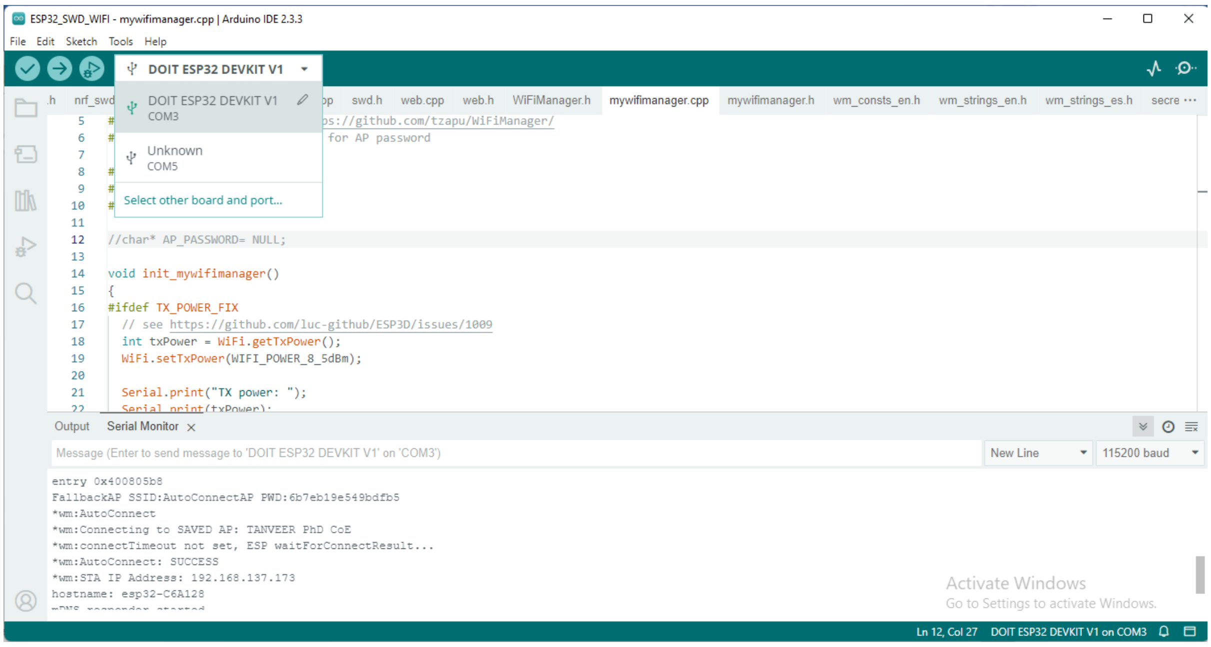
While compiling the sketch in IDE there were several issues found in the program that we had to fix. We had to define the pins for the ESP32 module perform as a programmer.

```
#define LED 2
#define GLITCHER 5
#define NRF_POWER 22

#define OSCI_PIN 34

#define swd_clock_pin 21
#define swd_data_pin 19
```

The repository didn't include the `WiFiManager.h` header file rather it used `wifimanager.h` and `wifimanager.cpp` files which made the ambiguity so that it was causing compilation error. We downloaded the `WiFiManager.h` and `WiFiManager.cpp` corresponding files from the git (`https://github.com/tzapu/WiFiManager/`) repository and added them to the project.

Firmware upload to the ESP32 chip

Our chip is connected to the COM3 Port in the computer


ESP32_SWD_WIFI - mywifimanager.cpp | Arduino IDE 2.3.3
File Edit Sketch Tools Help
DOIT ESP32 DEVKIT V1
DOIT ESP32 DEVKIT V1 COM3
Unknown COM5
Select other board and port...
.h nrf_swd swd.h web.cpp web.h WiFiManager.h mywifimanager.cpp mywifimanager.h wm_consts_en.h wm_strings_en.h wm_strings_es.h secre
Output Serial Monitor
New Line
115200 baud
Ln 12, Col 27 DOIT ESP32 DEVKIT V1 on COM3

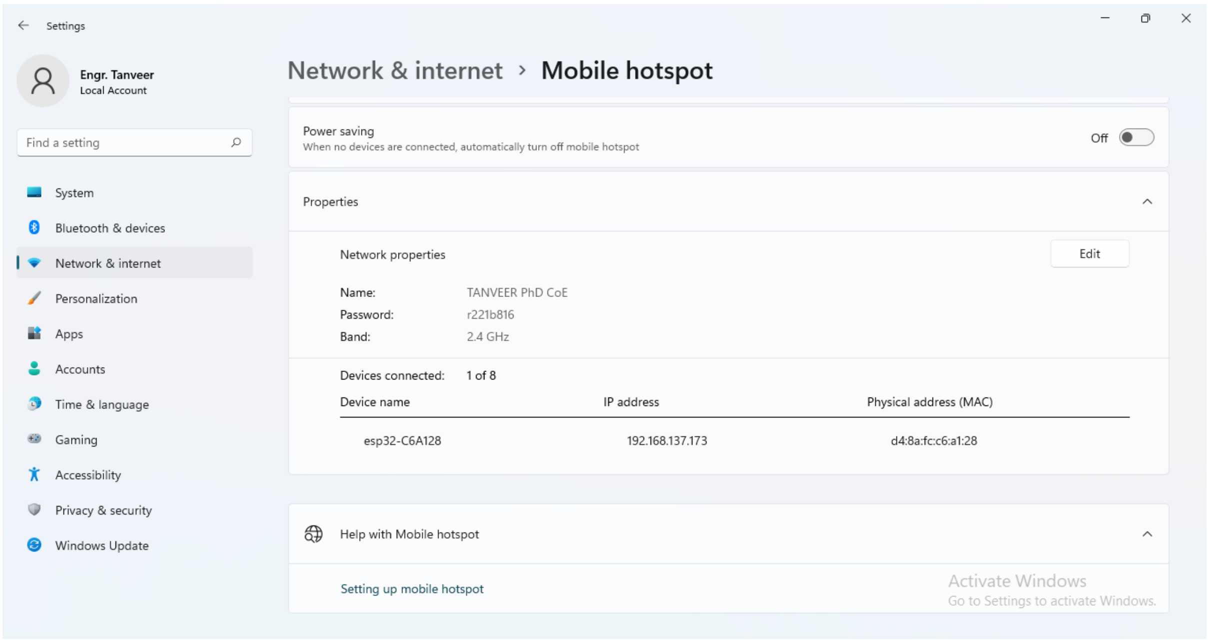
```
#                                   ps://github.com/tzapu/WiFiManager/
#                                    for AP password

#
#
#

//char* AP_PASSWORD= NULL;

void init_mywifimanager()
{
#ifdef TX_POWER_FIX
  // see https://github.com/luc-github/ESP3D/issues/1009
  int txPower = WiFi.getTxPower();
  WiFi.setTxPower(WIFI_POWER_8_5dBm);

  Serial.print("TX power: ");
  Serial.print(txPower);
```

Message (Enter to send message to 'DOIT ESP32 DEVKIT V1' on 'COM3')

```
entry 0x400805b8
FallbackAP SSID:AutoConnectAP PWD:6b7eb19e549bdfb5
*wm:AutoConnect
*wm:Connecting to SAVED AP: TANVEER PhD CoE
*wm:connectTimeout not set, ESP waitForConnectResult...
*wm:AutoConnect: SUCCESS
*wm:STA IP Address: 192.168.137.173
hostname: esp32-C6A128
```

Fig. 3. Arduino IDE connection with ESP32.

After successful upload the ESP32 is start working as SWD programmer over the air (OTA). That’s why the chip has been connected to our computer hotspot via WiFi obtaining the IP Address **192.168.137.173**



Power saving
When no devices are connected, automatically turn off mobile hotspot
Off

Network properties

Name:	TANVEER PhD CoE
Password:	r221b816
Band:	2.4 GHz

Devices connected: 1 of 8

Device name	IP address	Physical address (MAC)
esp32-C6A128	192.168.137.173	d4:8a:fc:c6:a1:28

Fig. 4. ESP32 connected to the host PC through mobile hotspot WiFi.

The Arduino Serial monitor is reading at 115200 baud rate with the ESP32 chip.

```
wm:AutoConnect
*wm:Connecting to SAVED AP: TANVEER PhD CoE
*wm:connectTimeout not set, ESP waitForConnectResult...
*wm:AutoConnect: SUCCESS
```

```
*wm:STA IP Address: 192.168.137.173
hostname: esp32-C6A128
mDNS responder started
DP Write reg: 0x00 : 0x0000001e
DP Write reg: 0x04 : 0x50000000
SWD Id: 0x00000000
```

Connecting the pinetime64 to ESP32 chip

The SWD pinout for the PineTime watch is shown below

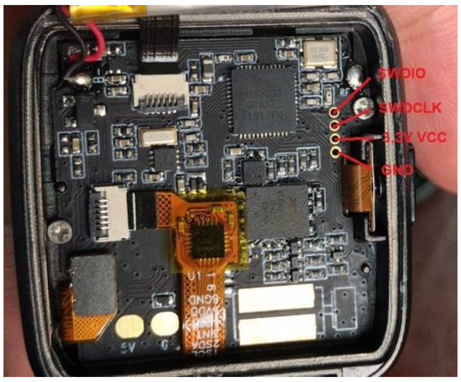


Fig. 5. SWD pinout of the PineTime64 smartwatch [4]

To flash an nRF52 connect the following:

- nRF52 **SWDCLK** to ESP32 **GPIO 21**
- nRF52 **SWDIO** to ESP32 **GPIO 19**
- nRF52 **GND** to ESP32 **GND**
- Then power the nRF52 as needed

According to this we have connected the watch as per figure

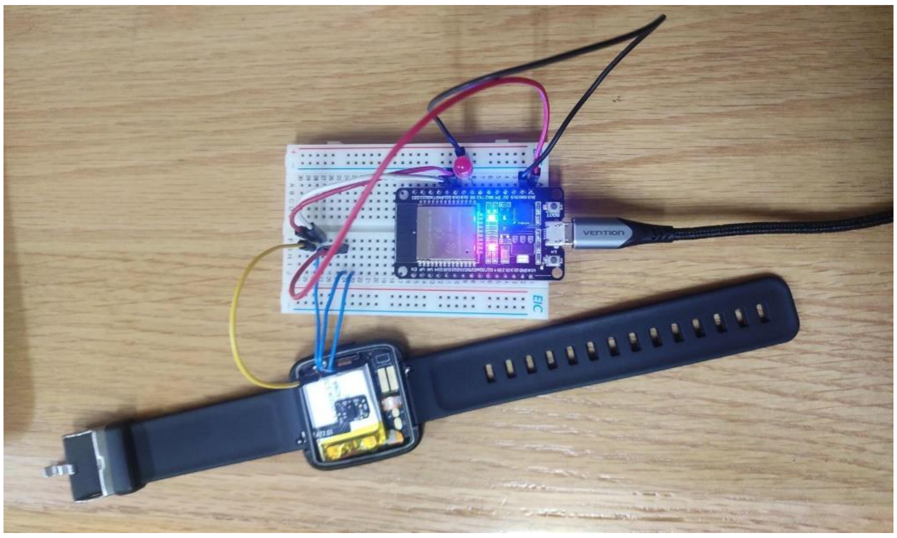
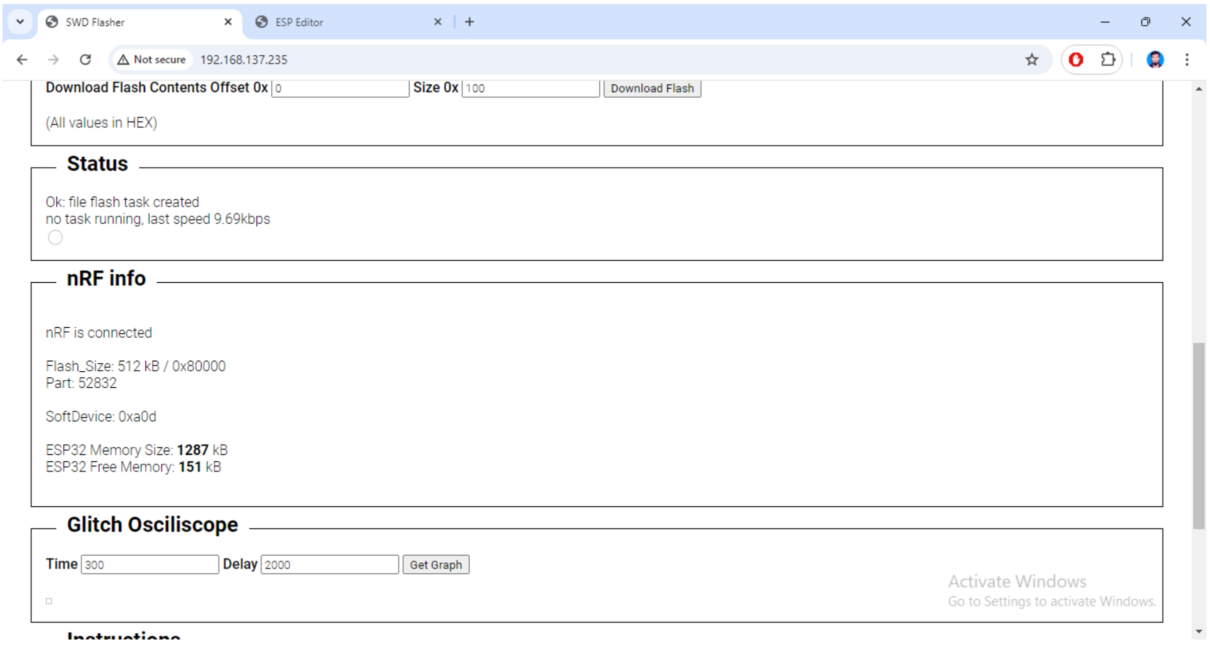


Fig. 6. PineTime64 smart watch SWD pin connection to ESP32 chip.

Firmware update to PineTime smart watch

- Once fully connected enter: "http://swd.local" in our internet browser and it showed a first page from the ESP32
- login with admin:admin: "http://swd.local/edit"
- We Choose File and browse for the "data/index.htm" file and clicked Upload
- Went to: "http://swd.local" again, the ESP32 SWD Flasher page was displayed
- We connected the nRF52 via SWD. Click the button "Init SWD" and wait for the response in the info page or look in the Arduino UART terminal if something doesn't work. The nRF chip should be detected and it will display a notification about whether or not the nRF52 is locked



Download Flash Contents Offset 0x 0 Size 0x 100 Download Flash

(All values in HEX)

Status

Ok: file flash task created
no task running, last speed 9.69kbps

nRF info

nRF is connected

Flash_Size: 512 kB / 0x80000
Part: 52832

SoftDevice: 0xa0d

ESP32 Memory Size: **1287** kB
ESP32 Free Memory: **151** kB

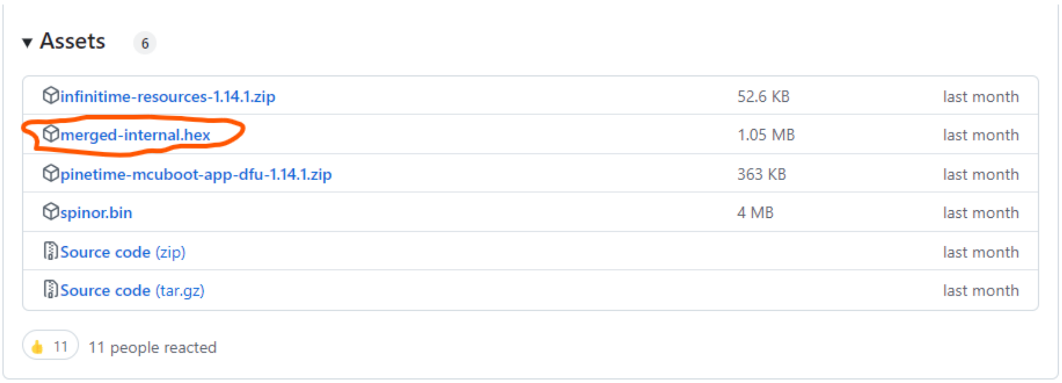
Glitch Osciliscope

Time 300 Delay 2000 Get Graph

Activate Windows
Go to Settings to activate Windows.

Fig. 7. PineTime64 smart watch chip nRF connected to the ESP32.

Now downloaded the PineTime64 latest firmware hex file from github repository https://github.com/InfiniTimeOrg/InfiniTime/releases the **merged-internal.hex**



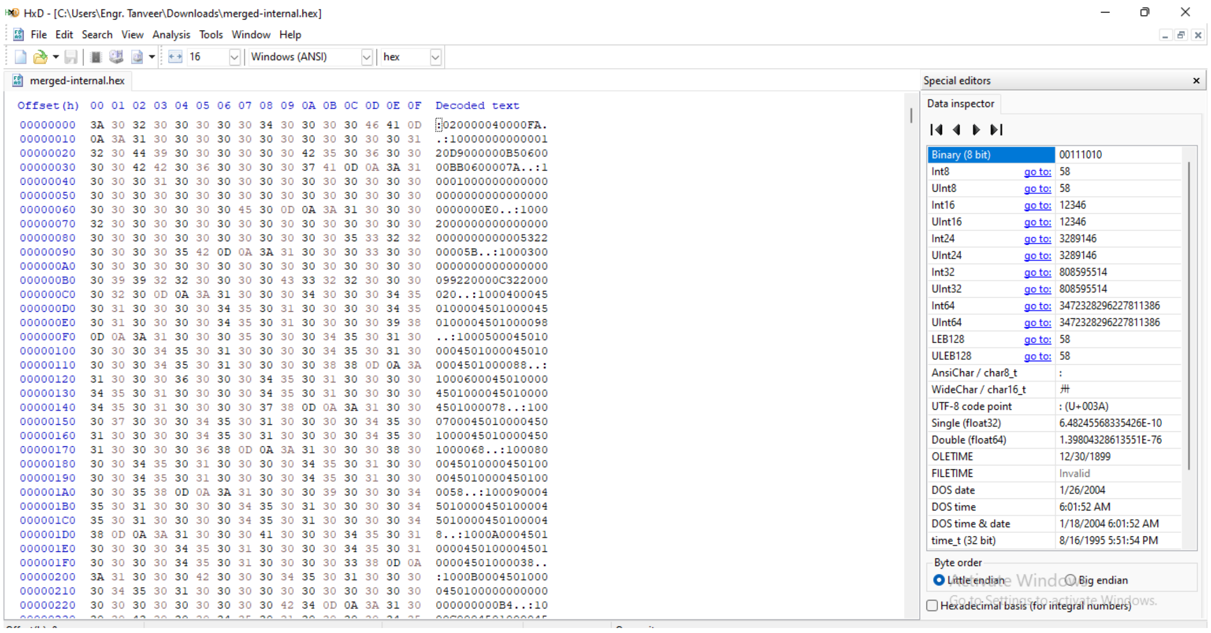
▾ Assets 6

infinitime-resources-1.14.1.zip	52.6 KB	last month
merged-internal.hex	1.05 MB	last month
pinetime-mcuboot-app-dfu-1.14.1.zip	363 KB	last month
spinor.bin	4 MB	last month
Source code (zip)		last month
Source code (tar.gz)		last month

👍 11 11 people reacted

Fig. 8. PineTime64 smartwatch firmware hex file

Now we opened the .hex file in HxD to save it as infinitime.bin file.


HxD - [C:\Users\Engr. Tanveer\Downloads\merged-internal.hex]
File Edit Search View Analysis Tools Window Help
16
Windows (ANSI)
hex
merged-internal.hex
Special editors
Data inspector

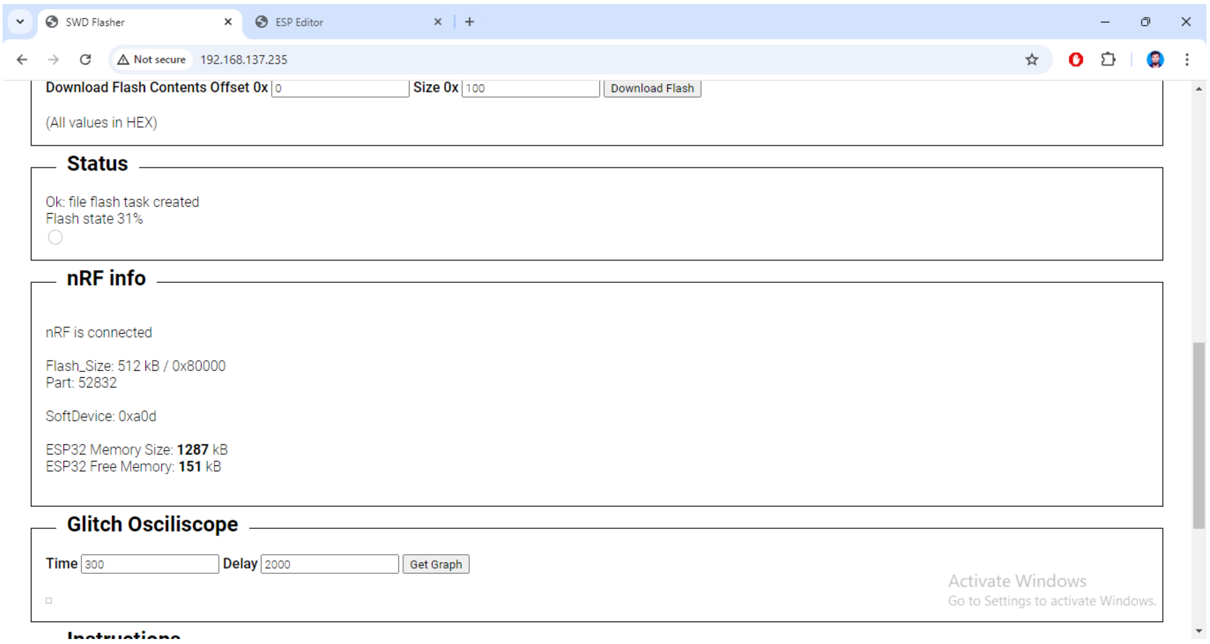
```
Offset(h) 00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F  Decoded text
00000000  3A 30 32 30 30 30 30 30 34 30 30 30 30 46 41 0D  :020000040000FA.
00000010  0A 3A 31 30 30 30 30 30 30 30 30 30 30 30 30 31  .:10000000000001
00000020  32 30 44 39 30 30 30 30 30 30 42 35 30 36 30 30  20D9000000B50600
00000030  30 30 42 42 30 36 30 30 30 30 37 41 0D 0A 3A 31  00BB0600007A..:1
00000040  30 30 30 31 30 30 30 30 30 30 30 30 30 30 30 30  0001000000000000
00000050  30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30  0000000000000000
00000060  30 30 30 30 30 30 30 45 30 0D 0A 3A 31 30 30 30  0000000E0..:1000
00000070  32 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30  2000000000000000
00000080  30 30 30 30 30 30 30 30 30 30 30 30 35 33 32 32  0000000000005322
00000090  30 30 30 30 35 42 0D 0A 3A 31 30 30 30 33 30 30  00005B..:1000300
000000A0  30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30  0000000000000000
000000B0  30 39 39 32 32 30 30 30 30 43 33 32 32 30 30 30  099220000C322000
000000C0  30 32 30 0D 0A 3A 31 30 30 30 34 30 30 30 34 35  020..:1000400045
000000D0  30 31 30 30 30 30 34 35 30 31 30 30 30 30 34 35  0100004501000045
000000E0  30 31 30 30 30 30 34 35 30 31 30 30 30 30 39 38  0100004501000098
000000F0  0D 0A 3A 31 30 30 30 35 30 30 30 34 35 30 31 30  ..:1000500045010
00000100  30 30 30 34 35 30 31 30 30 30 30 34 35 30 31 30  0004501000045010
00000110  30 30 30 34 35 30 31 30 30 30 30 38 38 0D 0A 3A  0004501000088..:
00000120  31 30 30 30 36 30 30 30 34 35 30 31 30 30 30 30  1000600045010000
00000130  34 35 30 31 30 30 30 30 34 35 30 31 30 30 30 30  4501000045010000
00000140  34 35 30 31 30 30 30 30 37 38 0D 0A 3A 31 30 30  4501000078..:100
00000150  30 37 30 30 30 34 35 30 31 30 30 30 30 34 35 30  0700045010000450
00000160  31 30 30 30 30 34 35 30 31 30 30 30 30 34 35 30  1000045010000450
00000170  31 30 30 30 30 36 38 0D 0A 3A 31 30 30 30 38 30  1000068..:100080
00000180  30 30 34 35 30 31 30 30 30 30 34 35 30 31 30 30  0045010000450100
00000190  30 30 34 35 30 31 30 30 30 30 34 35 30 31 30 30  0045010000450100
000001A0  30 30 35 38 0D 0A 3A 31 30 30 30 39 30 30 30 34  0058..:100090004
000001B0  35 30 31 30 30 30 30 34 35 30 31 30 30 30 30 34  5010000450100004
000001C0  35 30 31 30 30 30 30 34 35 30 31 30 30 30 30 34  5010000450100004
000001D0  38 0D 0A 3A 31 30 30 30 41 30 30 30 34 35 30 31  8..:1000A0004501
000001E0  30 30 30 30 34 35 30 31 30 30 30 30 34 35 30 31  0000450100004501
000001F0  30 30 30 30 34 35 30 31 30 30 30 30 33 38 0D 0A  00004501000038..
00000200  3A 31 30 30 30 42 30 30 30 34 35 30 31 30 30 30  :1000B0004501000
00000210  30 34 35 30 31 30 30 30 30 30 30 30 30 30 30 30  0450100000000000
00000220  30 30 30 30 30 30 30 30 30 42 34 0D 0A 3A 31 30  000000000B4..:10
```

Binary (8 bit)	00111010
Int8 go to:	58
UInt8 go to:	58
Int16 go to:	12346
UInt16 go to:	12346
Int24 go to:	3289146
UInt24 go to:	3289146
Int32 go to:	808595514
UInt32 go to:	808595514
Int64 go to:	3472328296227811386
UInt64 go to:	3472328296227811386
LEB128 go to:	58
ULEB128 go to:	58
AnsiChar / char8_t	:
WideChar / char16_t	卅
UTF-8 code point	: (U+003A)
Single (float32)	6.48245568335426E-10
Double (float64)	1.39804328613551E-76
OLETIME	12/30/1899
FILETIME	Invalid
DOS date	1/26/2004
DOS time	6:01:52 AM
DOS time & date	1/18/2004 6:01:52 AM
time_t (32 bit)	8/16/1995 5:51:54 PM

Byte order
● Little endian ○ Big endian
☐ Hexadecimal basis (for integral numbers)

Fig. 8. Opening .hex file in HxD to save it as .bin file

Now we upload the infinitime.bin file in the esp32 provided web interface. And then clicked the flash file by showing the .bin file in the web interface it then started flashing the Chip.



Download Flash Contents Offset 0x 0 Size 0x 100

(All values in HEX)

Status

Ok: file flash task created
Flash state 31%

nRF info

nRF is connected

Flash_Size: 512 kB / 0x80000
Part: 52832

SoftDevice: 0xa0d

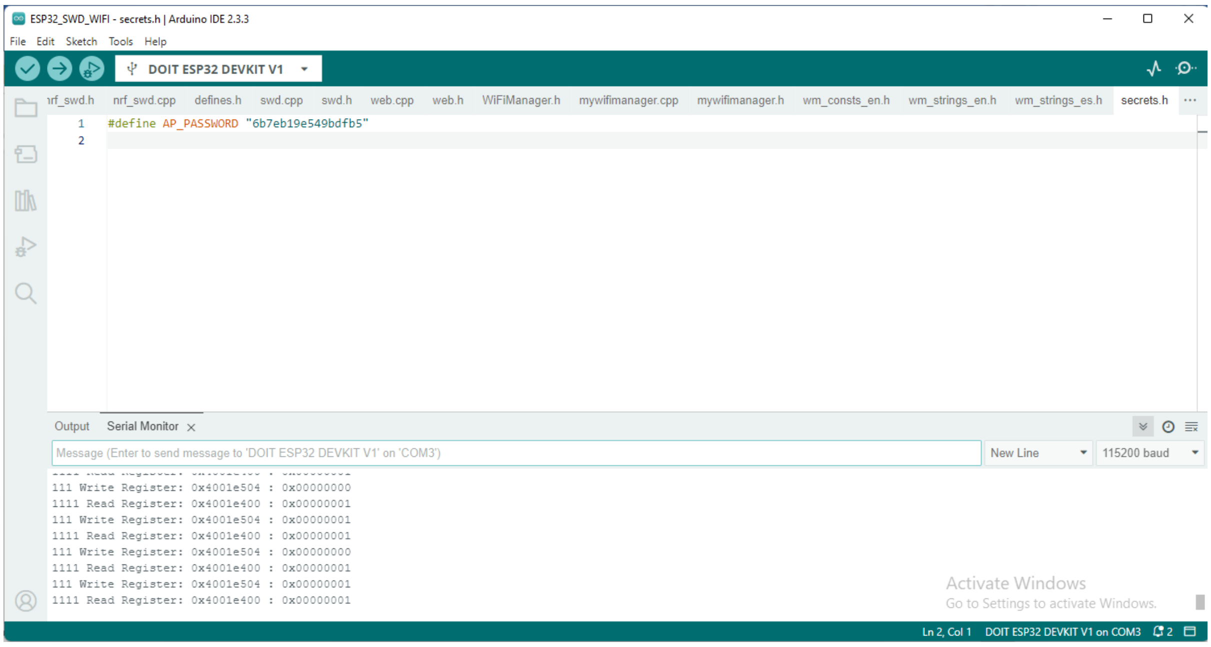
ESP32 Memory Size: **1287** kB
ESP32 Free Memory: **151** kB

Glitch Osciliscope

Time 300 Delay 2000

Fig. 9. Flash task is running 31%

During this time we can check the arduino IDE terminal that Register Read and Write operation is performing.

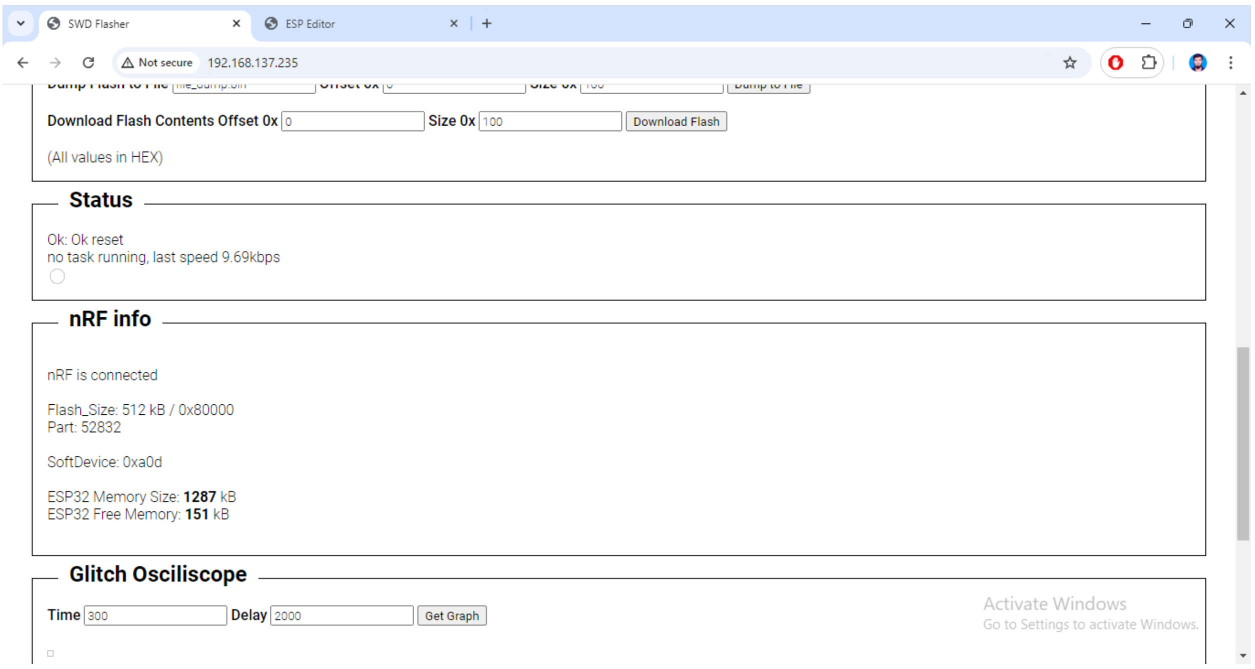

ESP32_SWD_WIFI - secrets.h | Arduino IDE 2.3.3
File Edit Sketch Tools Help
DOIT ESP32 DEVKIT V1
nrf_swd.h nrf_swd.cpp defines.h swd.cpp swd.h web.cpp web.h WiFiManager.h mywifimanager.cpp mywifimanager.h wm_consts_en.h wm_strings_en.h wm_strings_es.h secrets.h
Output Serial Monitor
Message (Enter to send message to 'DOIT ESP32 DEVKIT V1' on 'COM3')
New Line
115200 baud
Ln 2, Col 1 DOIT ESP32 DEVKIT V1 on COM3

```
#define AP_PASSWORD "6b7eb19e549bdfb5"
```

```
111 Write Register: 0x4001e504 : 0x00000000
1111 Read Register: 0x4001e400 : 0x00000001
111 Write Register: 0x4001e504 : 0x00000001
1111 Read Register: 0x4001e400 : 0x00000001
111 Write Register: 0x4001e504 : 0x00000000
1111 Read Register: 0x4001e400 : 0x00000001
111 Write Register: 0x4001e504 : 0x00000001
1111 Read Register: 0x4001e400 : 0x00000001
```

Fig. 10. During Flash operation Register Read and Write is performing

After flashing the chip we clicked on the reset button to start the watch



Download Flash Contents Offset 0x 0 Size 0x 100

(All values in HEX)

Status

Ok: Ok reset
no task running, last speed 9.69kbps

nRF info

nRF is connected

Flash_Size: 512 kB / 0x80000
Part: 52832

SoftDevice: 0xa0d

ESP32 Memory Size: **1287** kB
ESP32 Free Memory: **151** kB

Glitch Osciliscope

Time 300 Delay 2000 Get Graph

Fig. 11. PineTime smart reset after Flash

Outcomes:

We found that the watch didn't boot. We several time performed the flash operation with other .hex files from the git release. But couldn't find the glitch, in addition to this we can't check whether the firmware is correct or not. Though the flash operation was successful. We hope that we will investigate this later.

References

[1] Micro XRCE-DDS (https://micro.ros.org/docs/concepts/middleware/Micro_XRCE-DDS/)

[2] PineTime, https://pine64.org/documentation/PineTime/

[3] nRF52, NordicSemiconductor, https://docs.nordicsemi.com/

[4] PineTime SWD pinout, https://wiki.pine64.org/wiki/PineTime_Devkit_Wiring