2020 HACKTIVITY
The IT Security Festival in Central and Eastern Europe

Hacking the Hacktivity 2019 badge:

how to brick the device and resurrect it with another soul

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Linux enthusiast since 1993
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youtube.com/makemehack

What we will talk about …

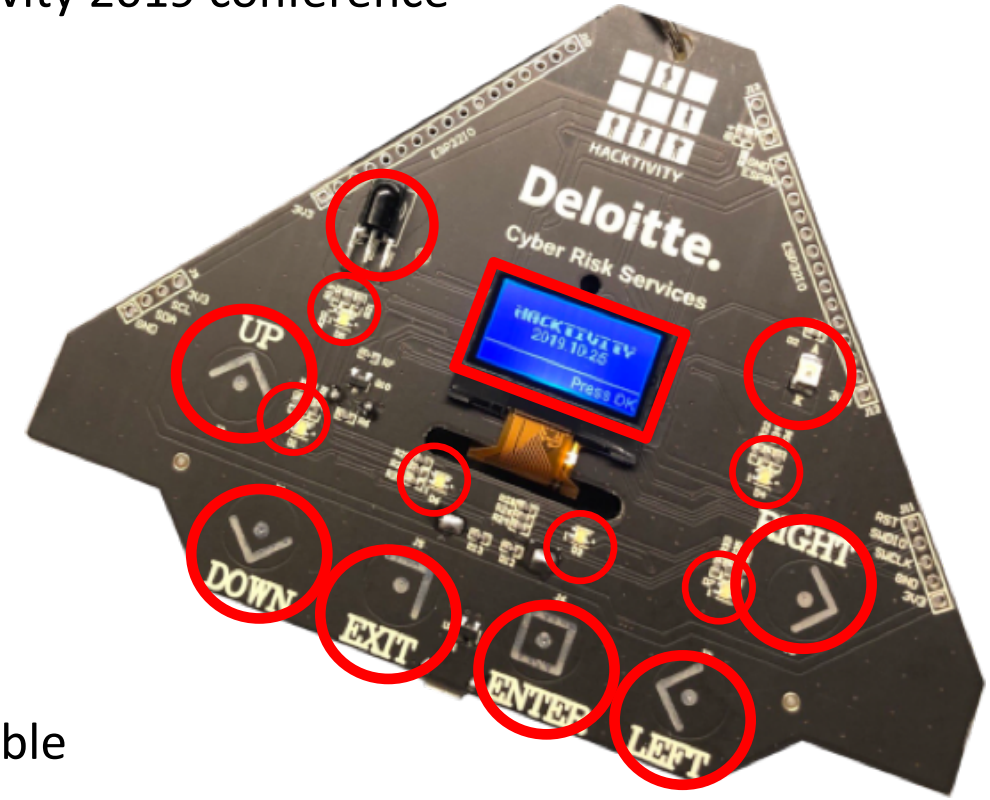
HACKTIVITY
The IT Security Festival in Central and Eastern Europe

- The Hacktivity 2019 Badge
- Bricking the Badge
- Reverse Engineering the PCB
- Arduino IDE on the ESP32
- Re-flashing the SAMD21

The Hacktivity 2019 badge

HACKTIVITY
The IT Security Festival in Central and Eastern Europe

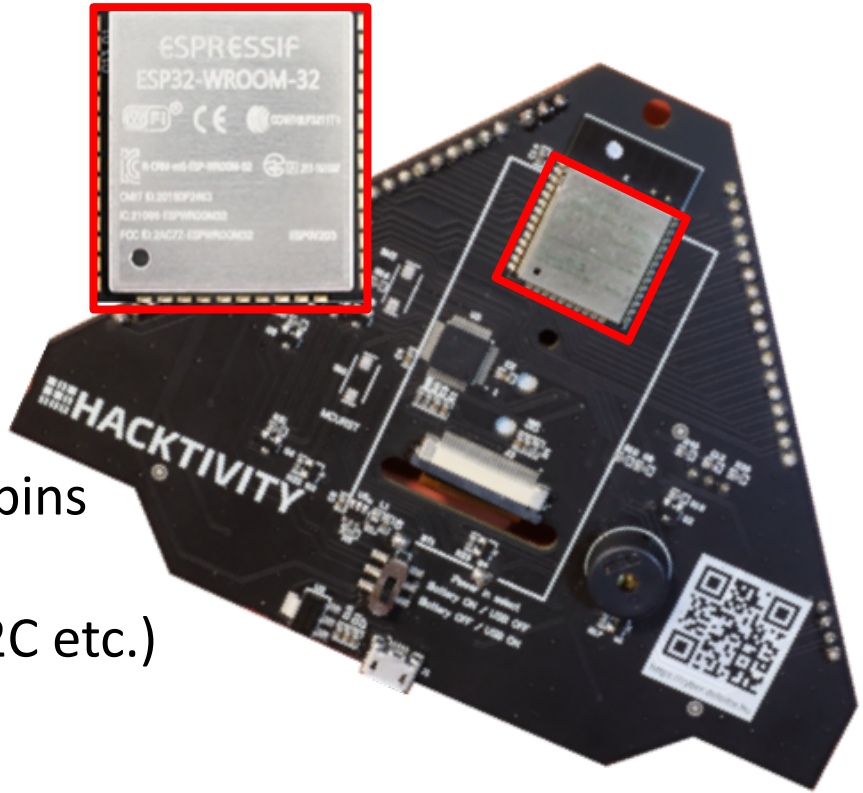
- Distributed last year at Hackitivity 2019 conference
- Features
  - Runs MicroPython
  - Has connectivity over USB, WiFi and IR
  - Has an appstore
  - 6 touch buttons
  - 128×64 LCD screen
  - 6 RGB LEDs
  - IR transmitter and receiver
  - Buzzer
  - Battery or USB powered
  - Designed to be hacked
- No detailed information available on hardware and firmware



The Hacktivity 2019 badge

HACKTIVITY
The IT Security Festival in Central and Eastern Europe

- Pretty “powerful” device
- ESP32-WROOM-32 module
  - 32bit, dual core Xtensa CPU
  - 4 Mb flash memory
  - 520Kb SRAM
  - WiFi/Bluetooth
  - Digital, analog and PWM I/O pins
  - Touch sensors
  - Serial interfaces (UART, SPI, I2C etc.)
  - Ultra low power mode



The Hacktivity 2019 badge

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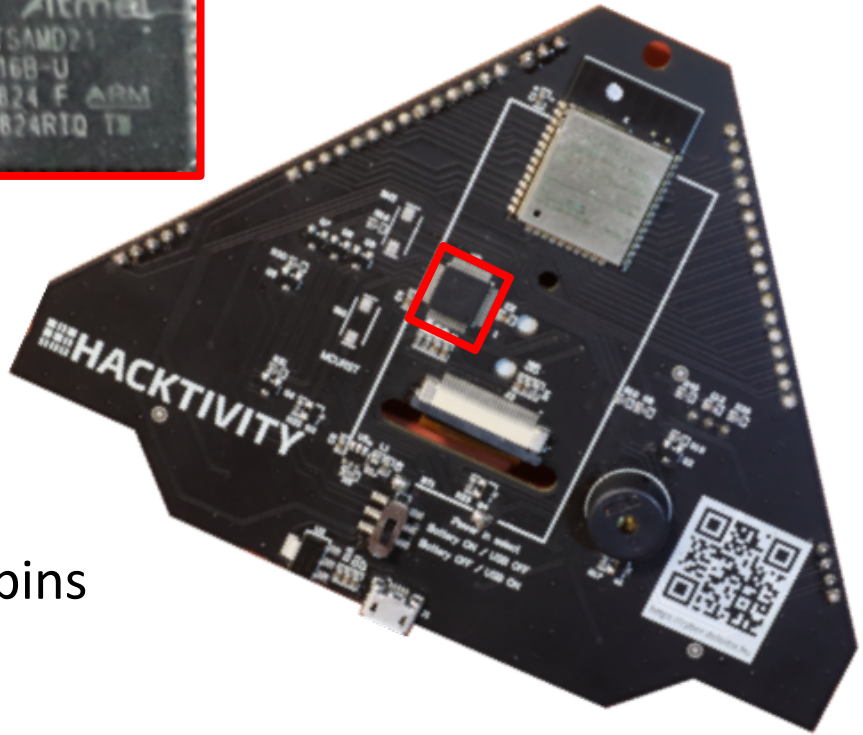
- Powerful co-processor
- ATSAMD21G16B
  - ARM Cortex-M0+ CPU
  - 64Kb flash memory
  - 8Kb SRAM
  - SWD interface
  - USB interface
  - Serial interfaces
  - Digital, analog and PWM I/O pins
  - Touch sensors

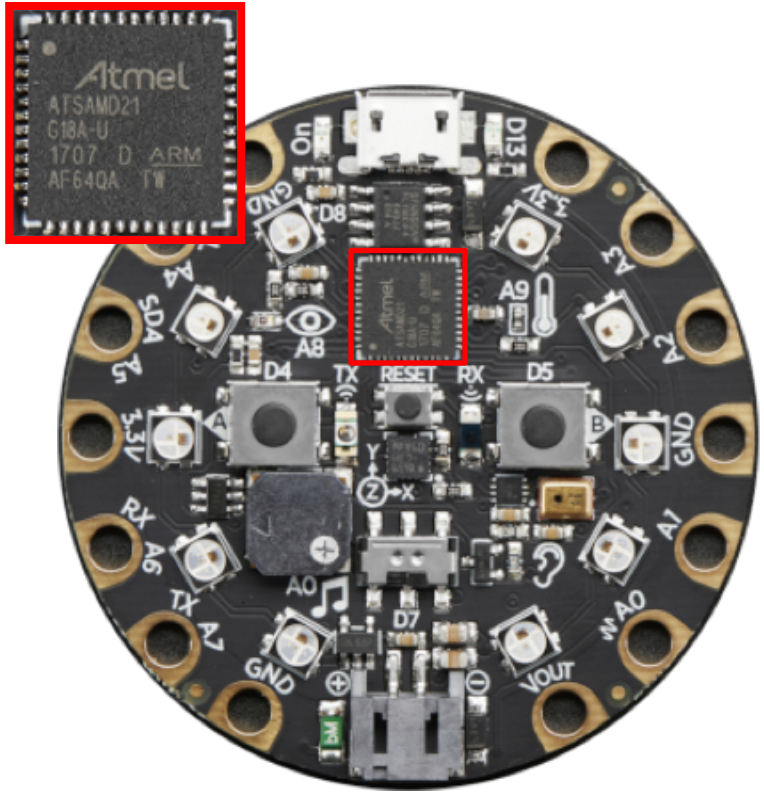


Bricking the badge

- Trying to use the Arduino IDE
- Badge recognized as «Adafruit Playground Express»
- Load the simple «blink» sketch
- Load successful, but the device is bricked!
- The badge is «dead»
- The USB is no more recognized

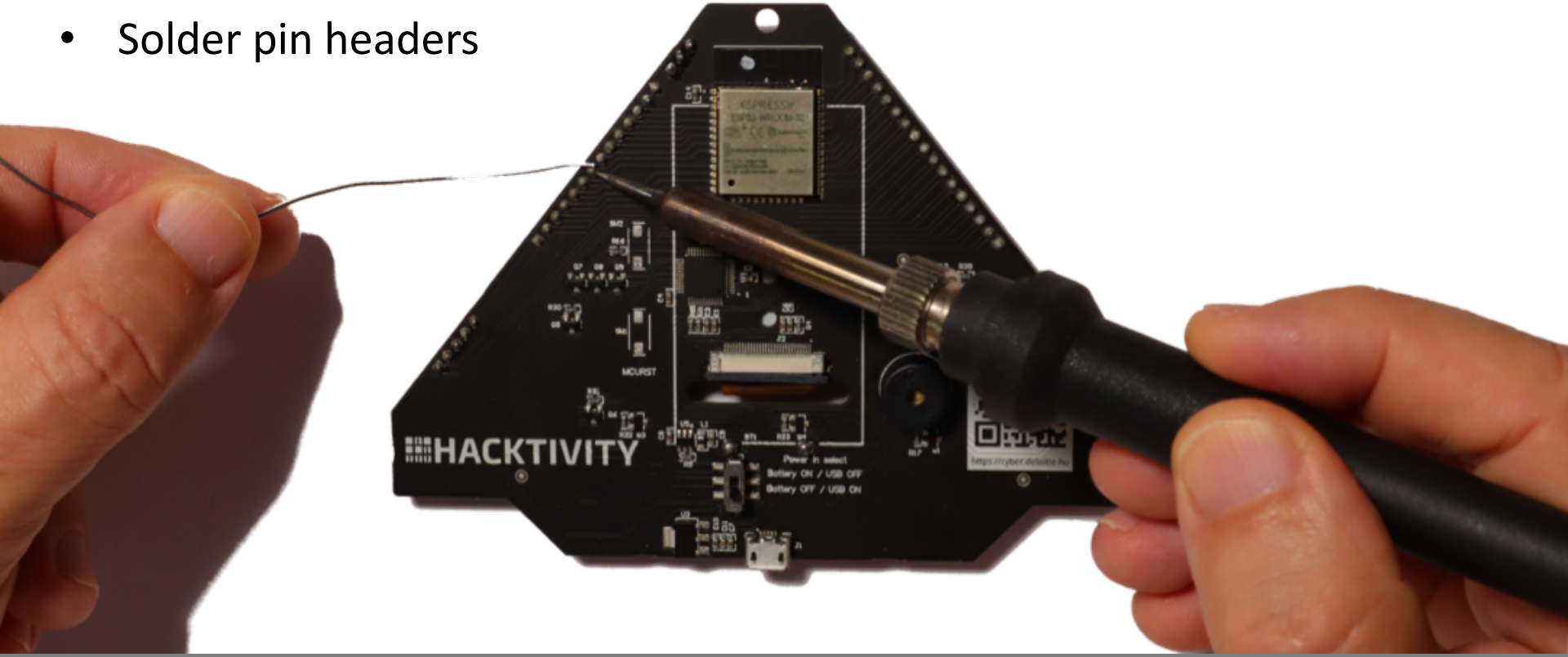
Bricking the badge

- «Adafruit Playground Express»
  - Based on ATSAMD21G18A
  - 256Kb flash memory (4x our badge)
  - 32Kb SRAM (4x our badge)



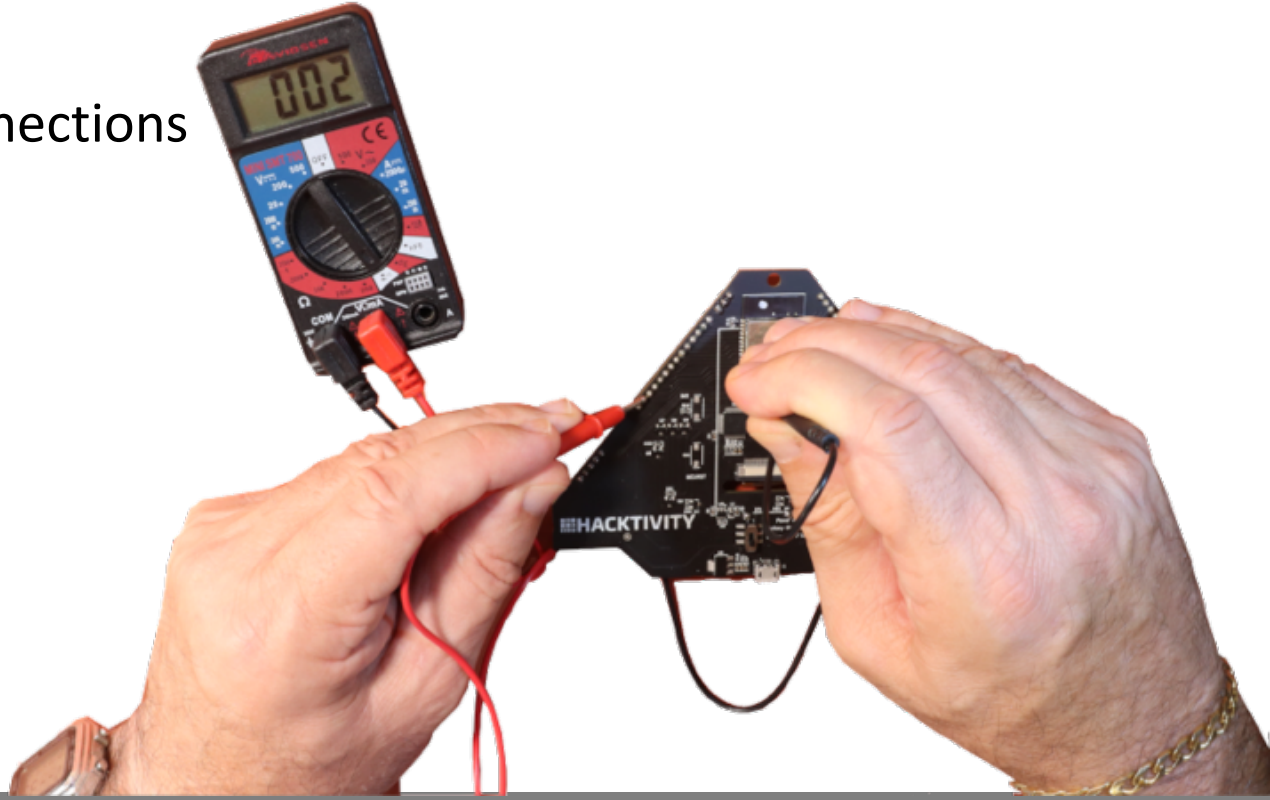
Reversing the PCB

- Solder pin headers



Reversing the PCB

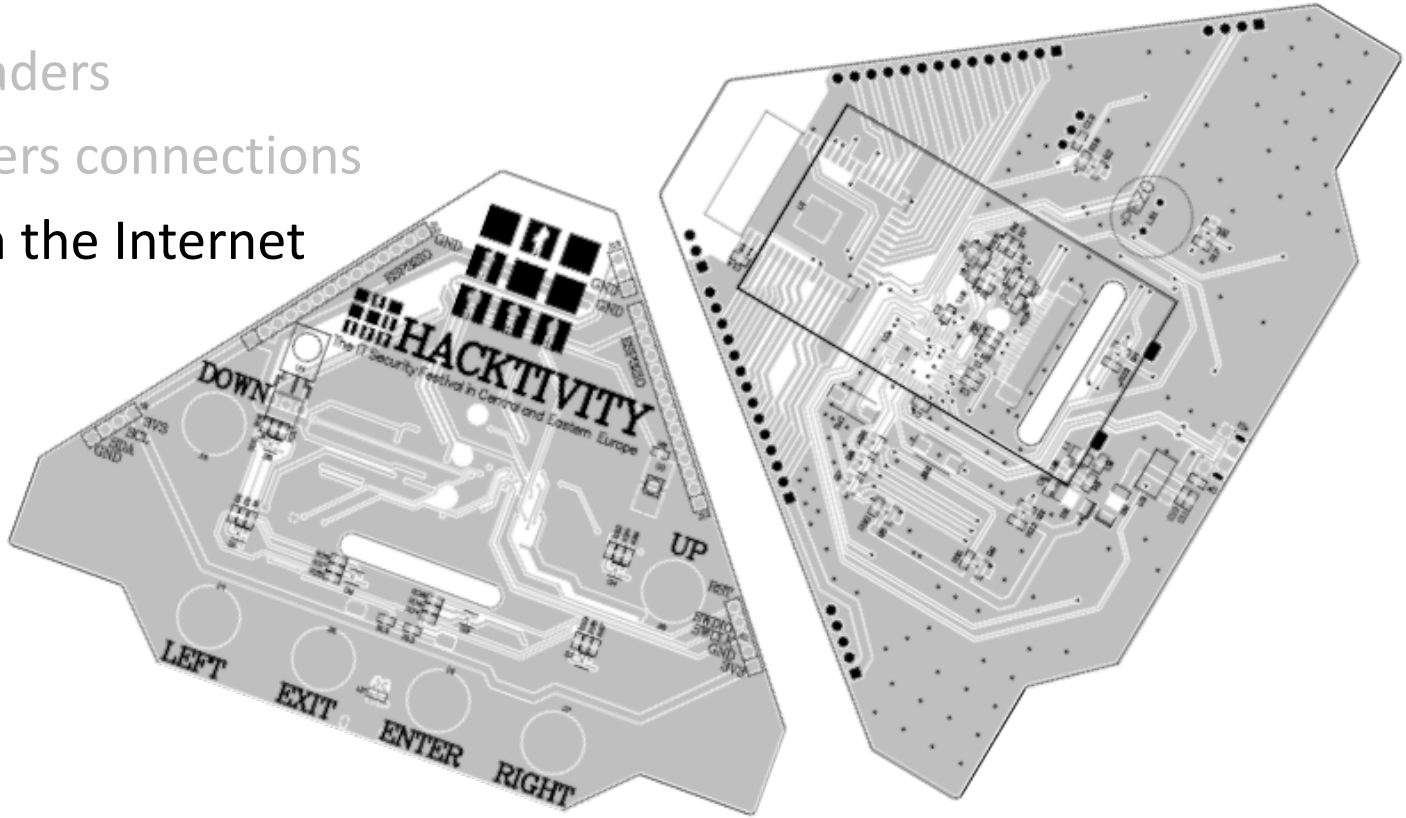
- Solder pin headers
- Find pin headers connections



Reversing the PCB

HACKTIVITY
The IT Security Festival in Central and Eastern Europe

- Solder pin headers
- Find pin headers connections
- Search info on the Internet



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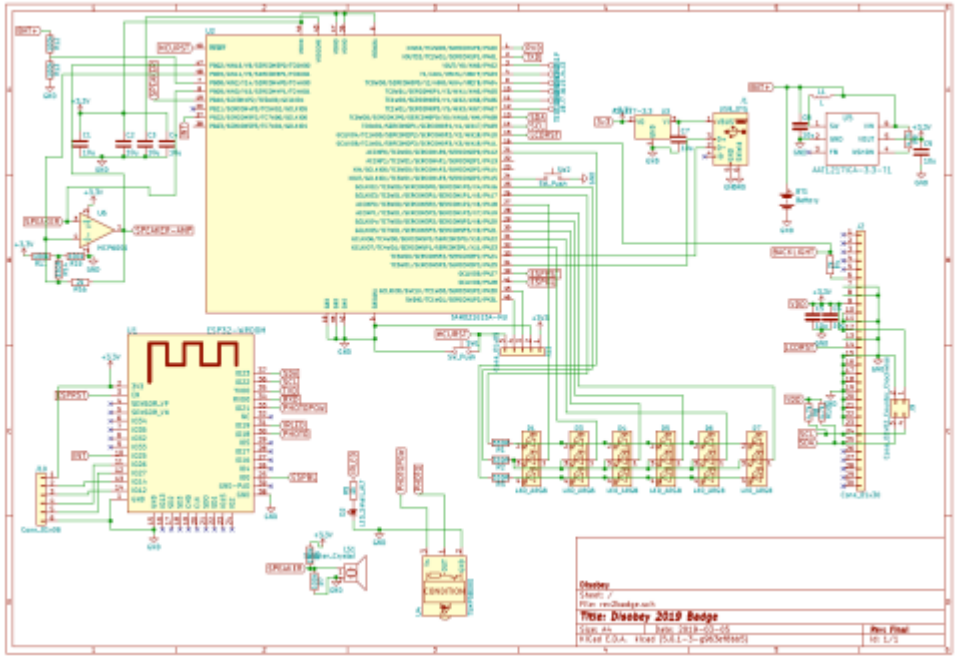

Reversing the PCB

- Solder pin headers
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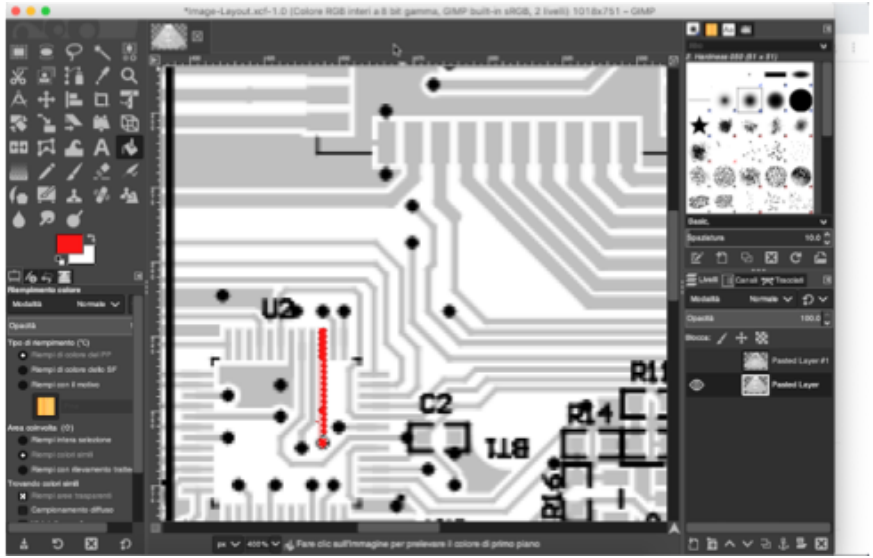
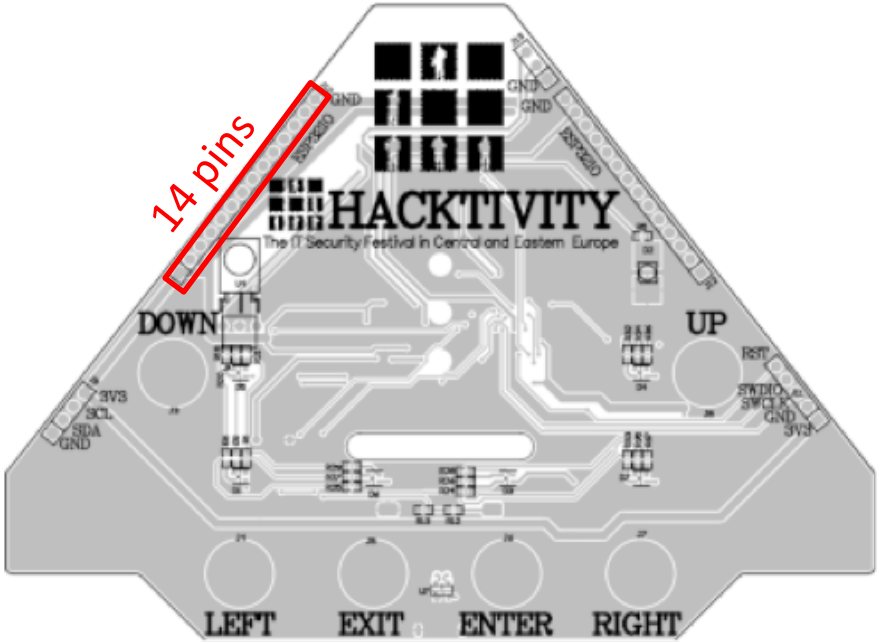
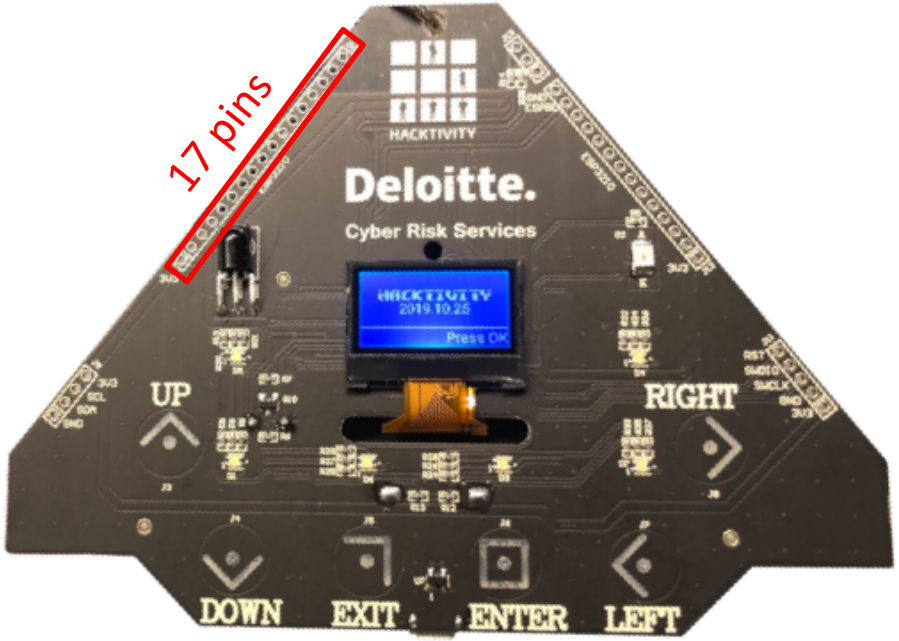
- Search info on the Internet
- Use Gimp to follow traces on 2 layers PCB



Reversing the PCB





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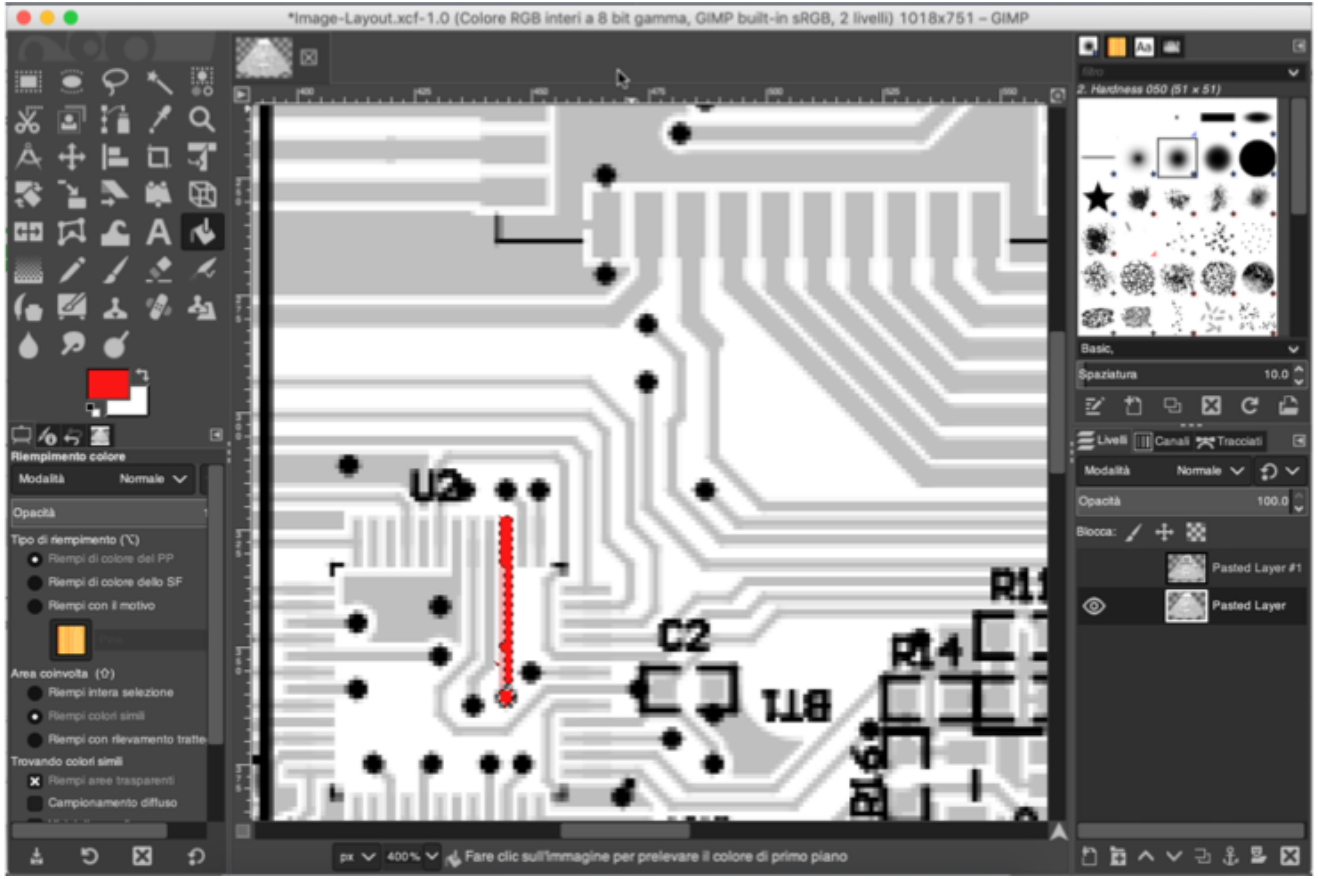

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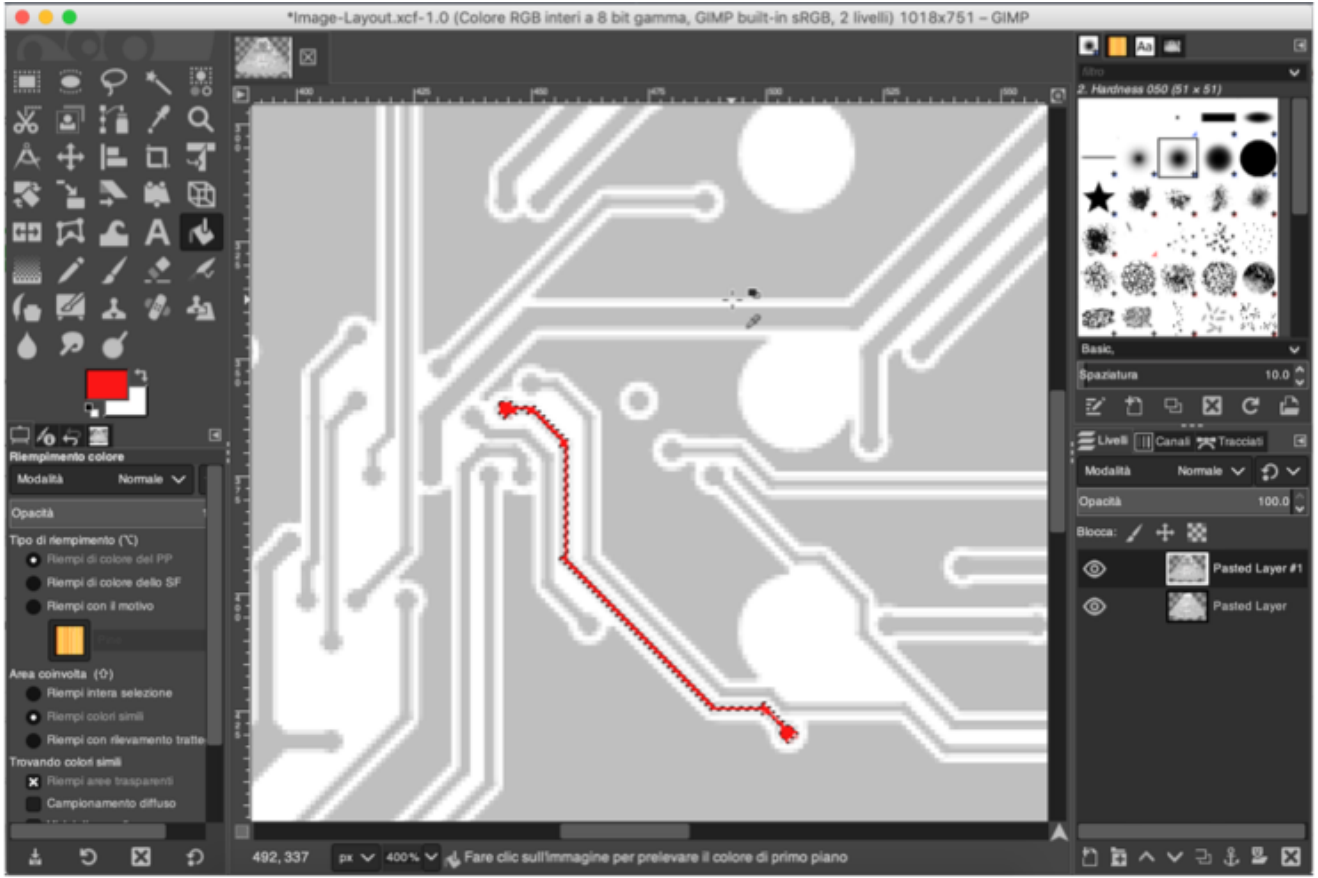

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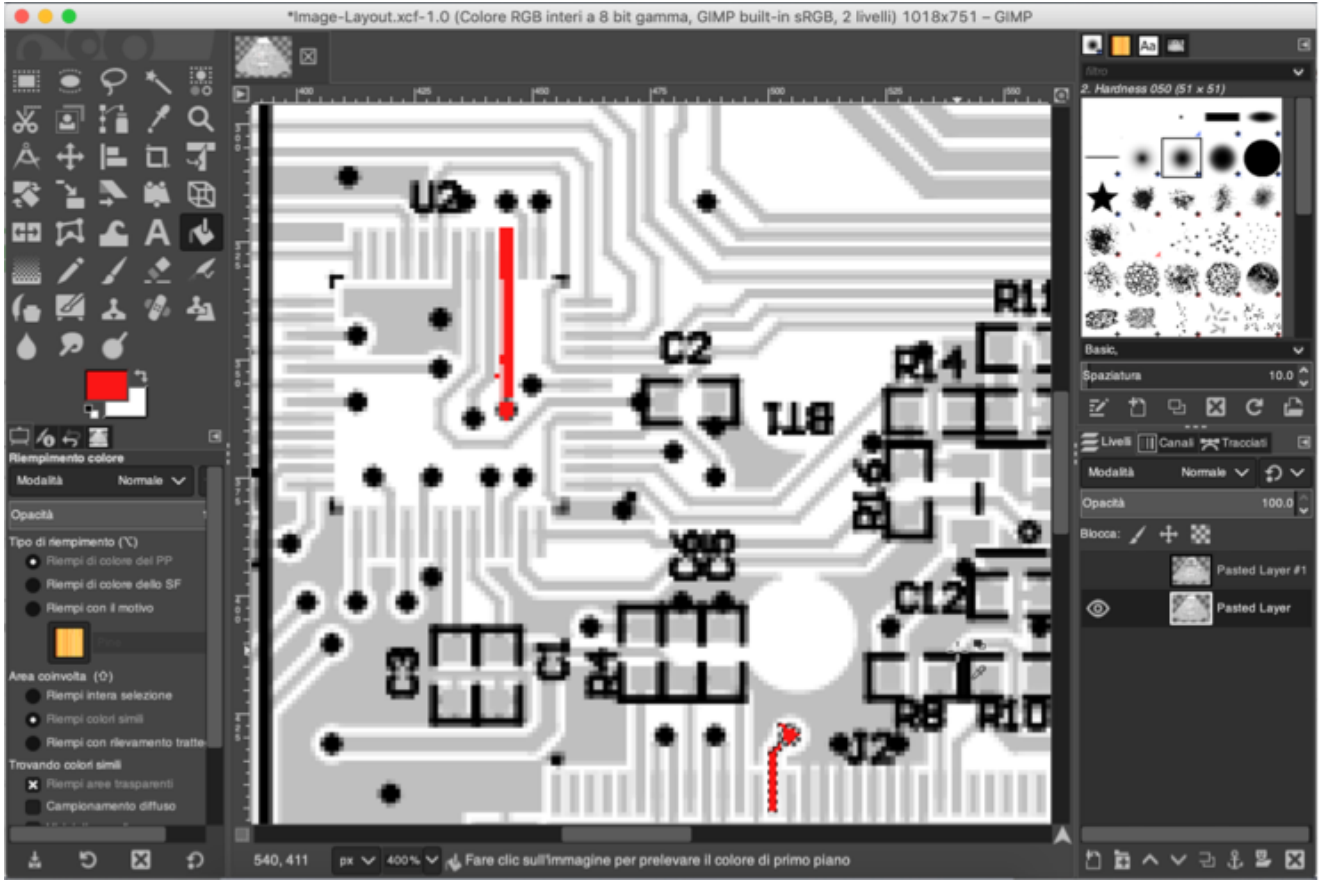

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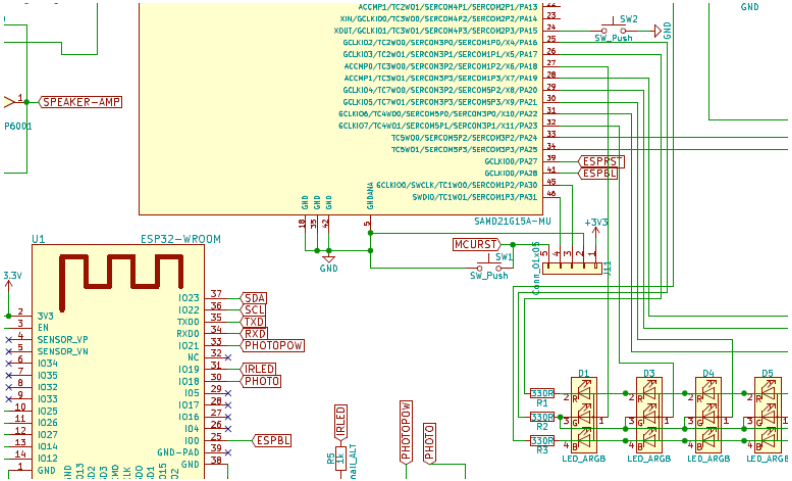
- Use a similar projects as hint



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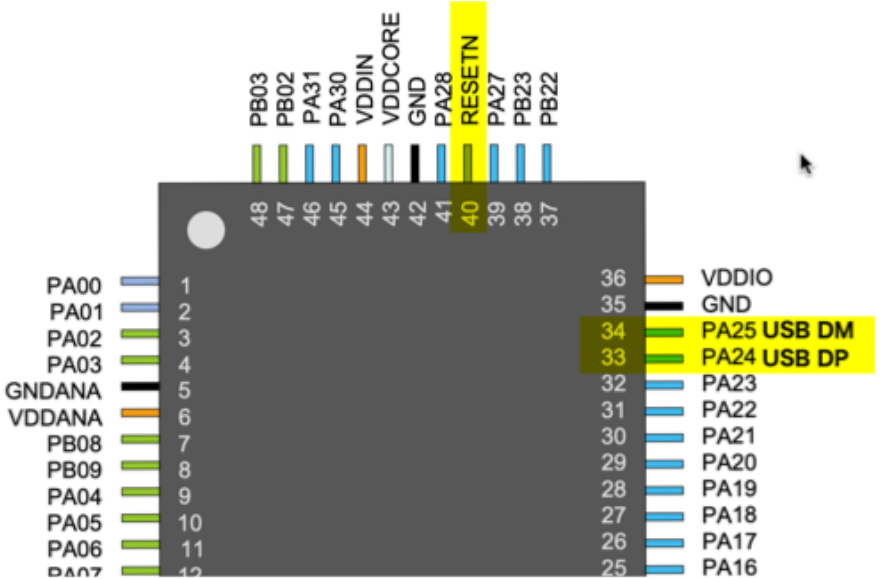
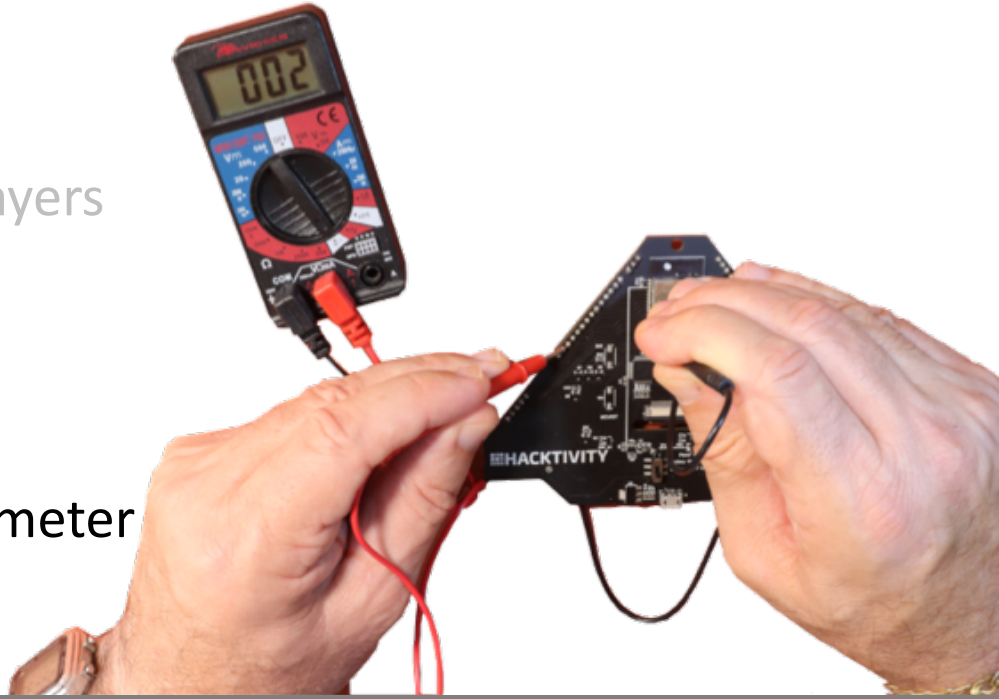
- Use SOCs data sheets as hint



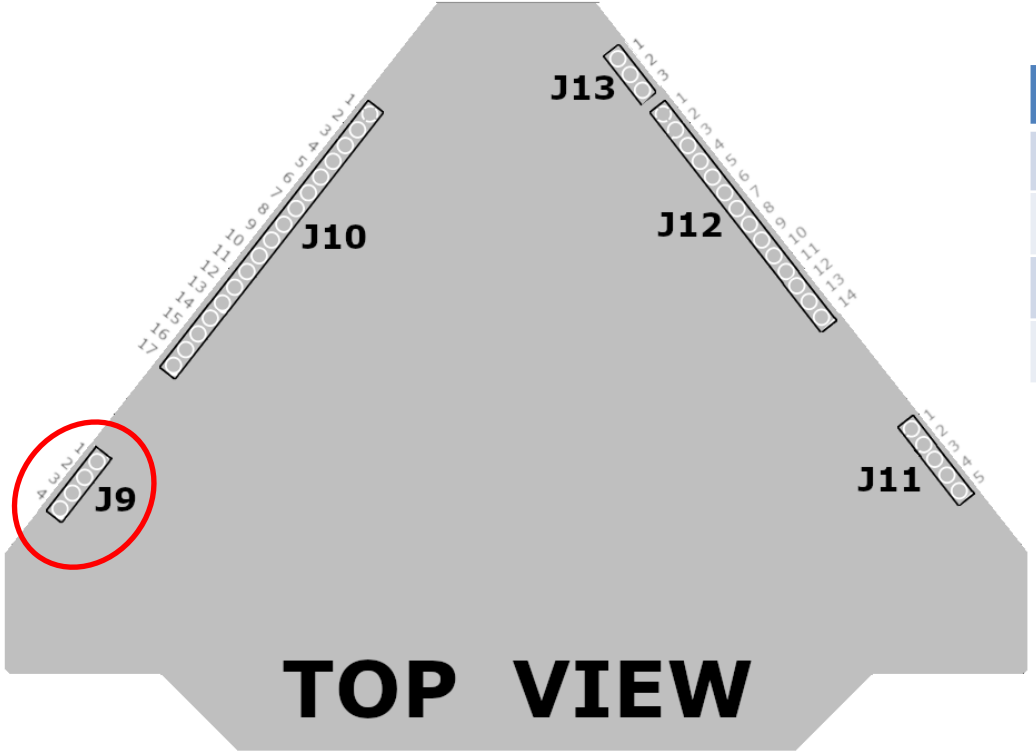
Pin[1]		C	D	E	F	G
SAMD21G	I/O Pin	SERCOM[2][3]	SERCOM-ALT	TC[4]/TCC	TCC	COM
33	PA24	SERCOM3/ PAD[2]	SERCOM5/ PAD[2]	TC5/WO[0]	TCC1/ WO[2]	USB/DM
34	PA25	SERCOM3/ PAD[3]	SERCOM5/ PAD[3]	TC5/WO[1]	TCC1/ WO[3]	USB/DP

Reversing the PCB

- Solder pin headers
- Find pin headers connections
- Search info on the Internet
- Use Gimp to follow traces on 2 layers PCB
- Use a similar projects as hint
- Use SOCs data sheets as hint
- Confirm connection with a multimeter



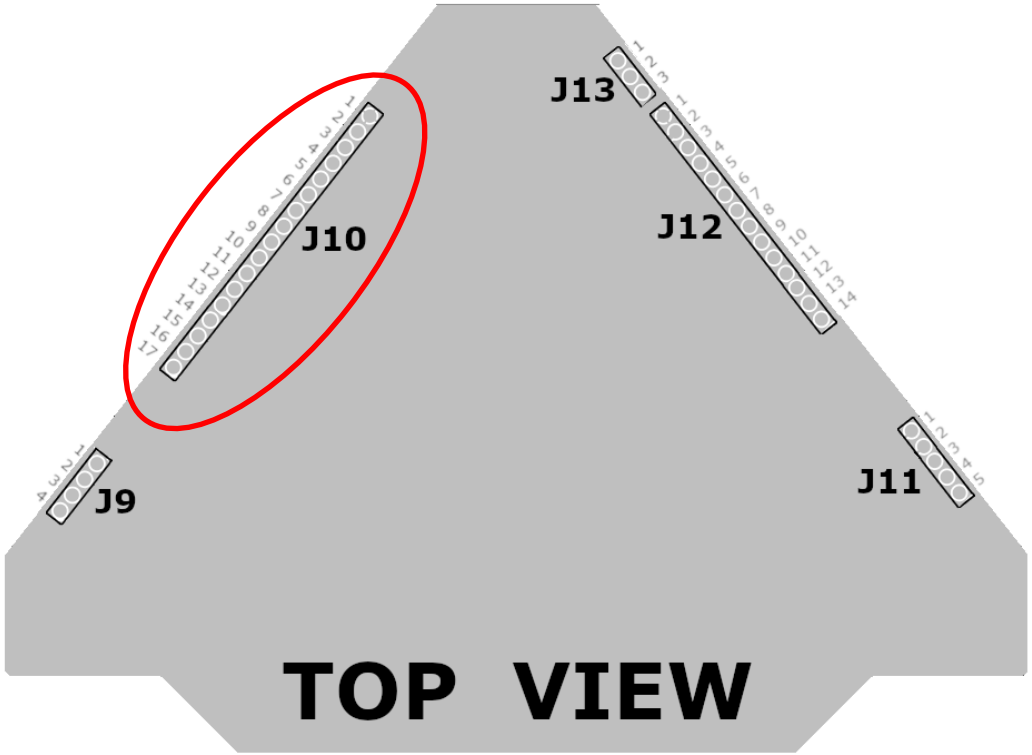
Pin headers – J9



J9 (I2C Bus)

PIN	Name	ESP32	SAMD21
1	VCC		
2	SCL	36 – IO22	14 – PA09
3	SDA	37 – IO23	13 – PA08
4	GND		

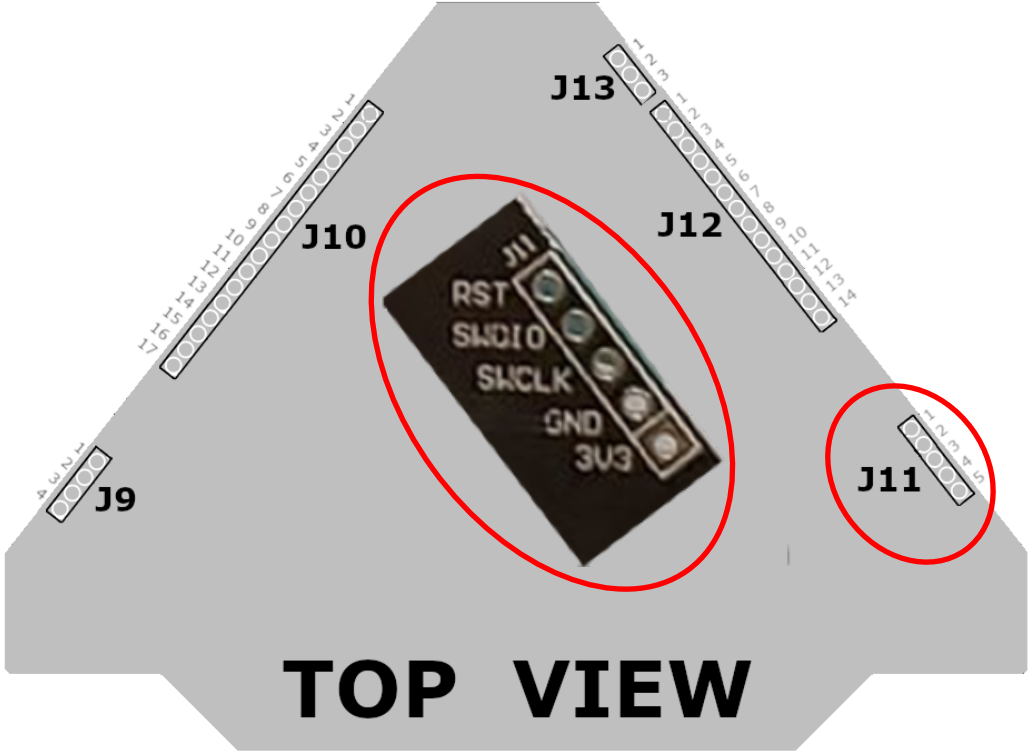
Pin headers – J10



J10 (to ESP32)

PIN	ESP32	PIN	ESP32
1	GND	10	23-IO15
2	33-IO21	11	22-IO8
3	31-IO21	12	21-IO7
4	30-IO18	13	20-IO6
5	29-IO15	14	19-IO11
6	28-IO17	15	18-IO10
7	27-IO16	16	17-IO9
8	26-IO4	17	VCC
9	24-IO2		

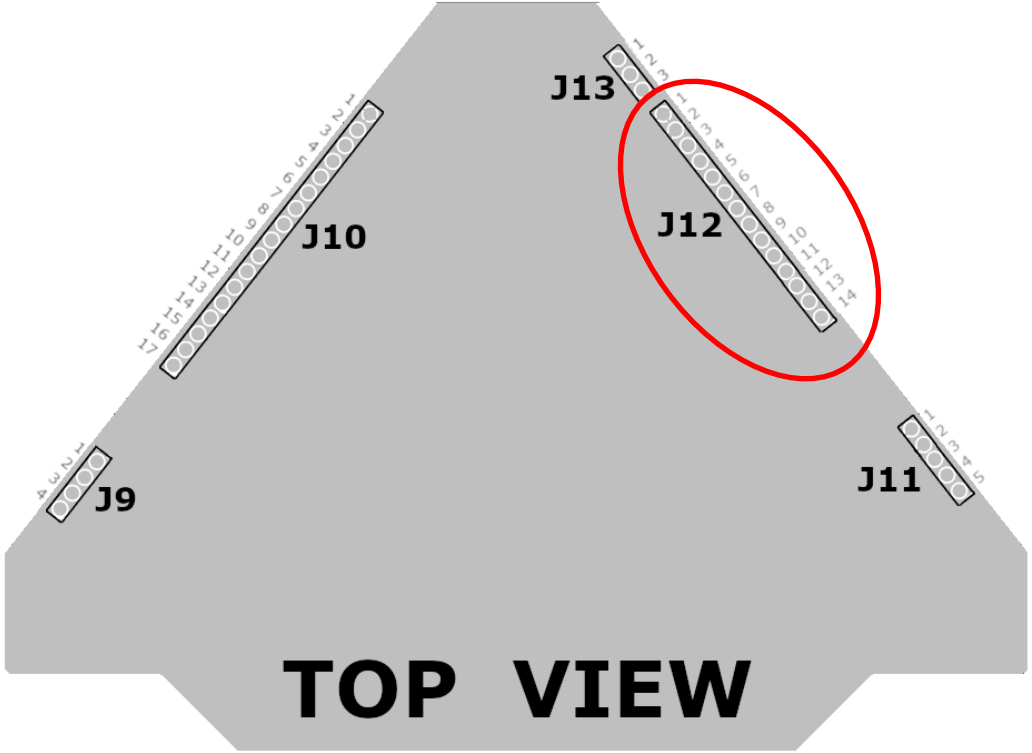
Pin headers – J11



J11 (SAMD21 programming interface)

PIN	SAMD21
1	40 - nRST
2	46 - SWDIO
3	45 - SWCLK
4	GND
5	VCC

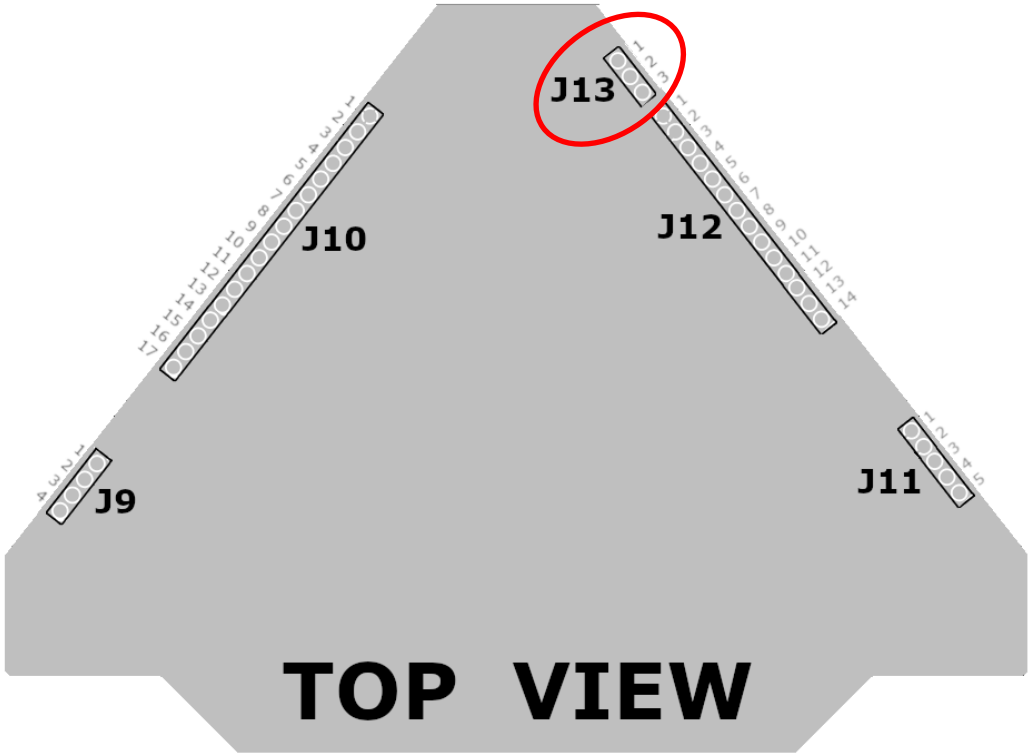
Pin headers – J12



J12 (to ESP32)

PIN	ESP32	PIN	ESP32
1	GND	8	9 – IO33
2	25 – IO0 (B.LDR)	9	11 – IO26
3	4 – IO36	10	12 – IO27
4	5 – IO39	11	13 – IO14
5	6 – IO34	12	14 – IO12
6	7 – IO35	13	16 – IO13
7	8 – IO32	14	VCC

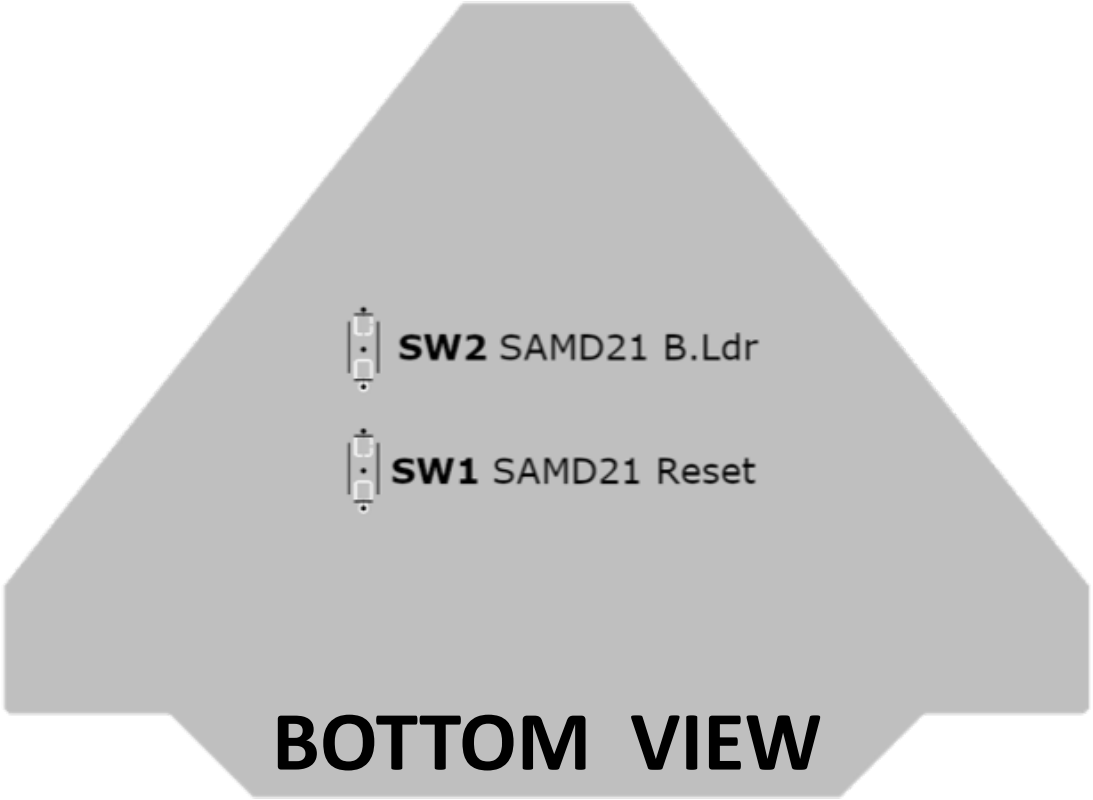
Pin headers – J13



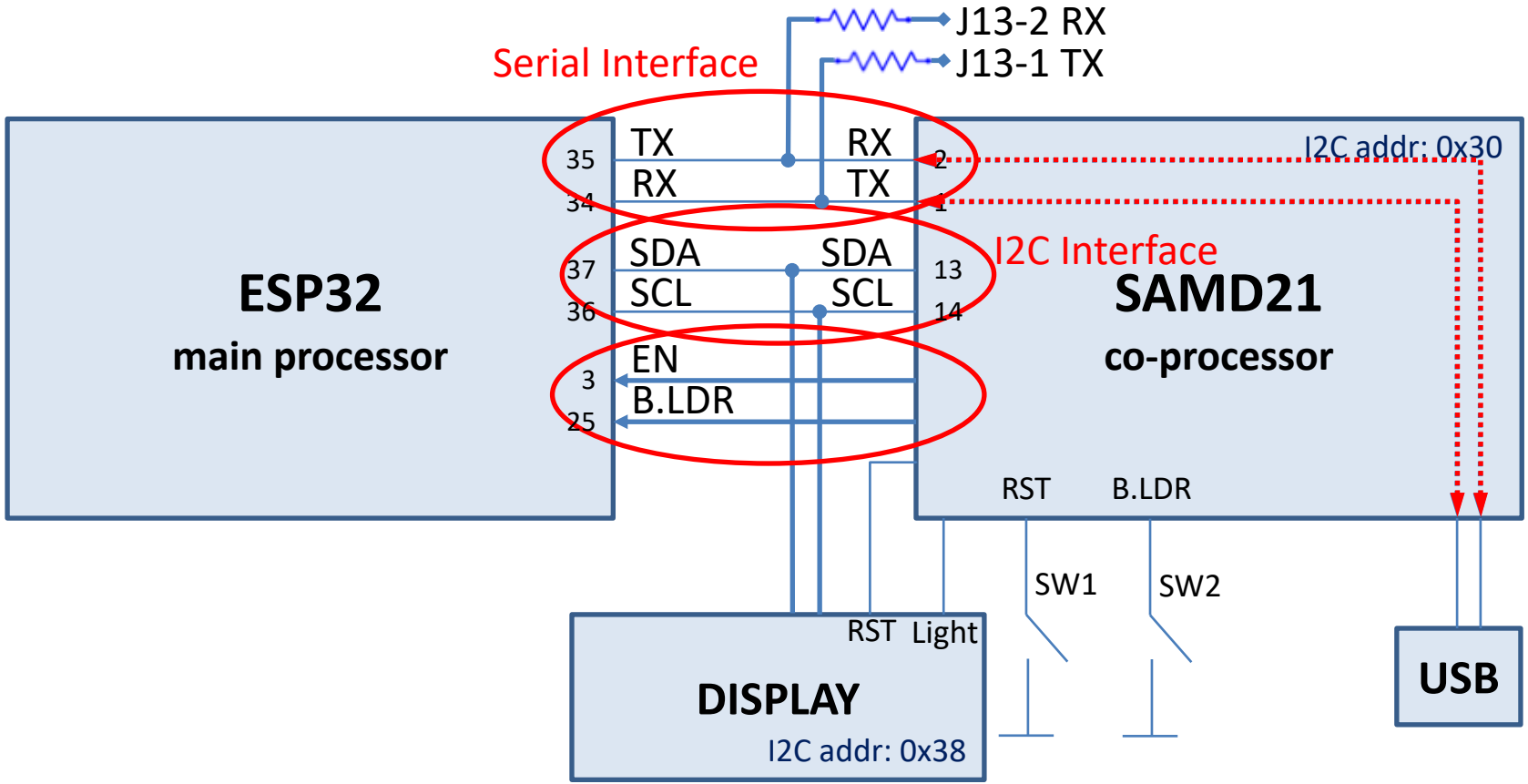
J13 (ESP32 serial interface)

PIN	NAME	ESP32	SAMD21
1	TX	35 (330 Ω)	2 - RX
2	RX	34 (330 Ω)	1 - TX
3	GND		

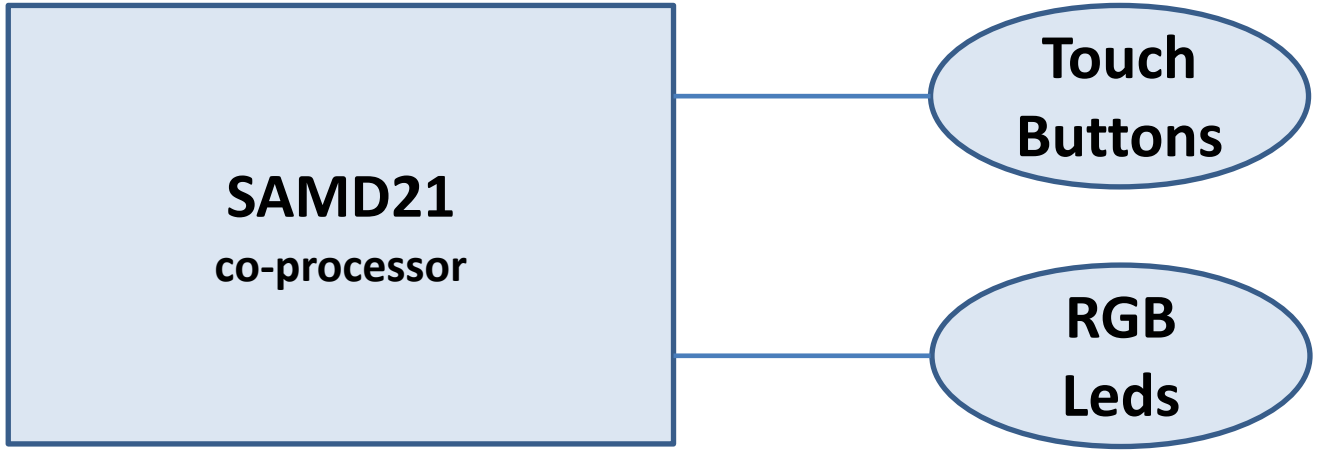
SAMD21 Switches



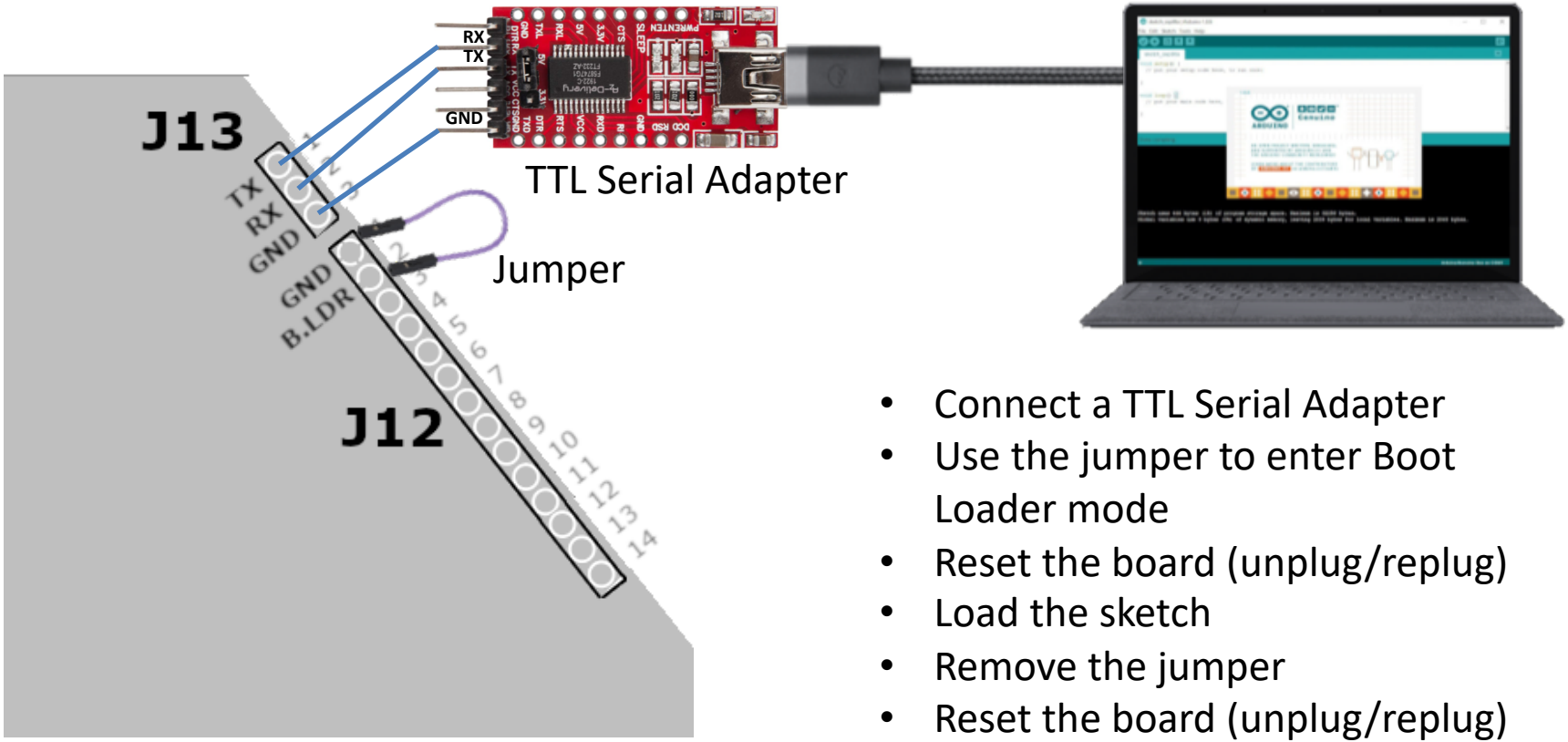
ESP32 – SAMD21



SAMD21 peripherals



ESP32 with Arduino IDE

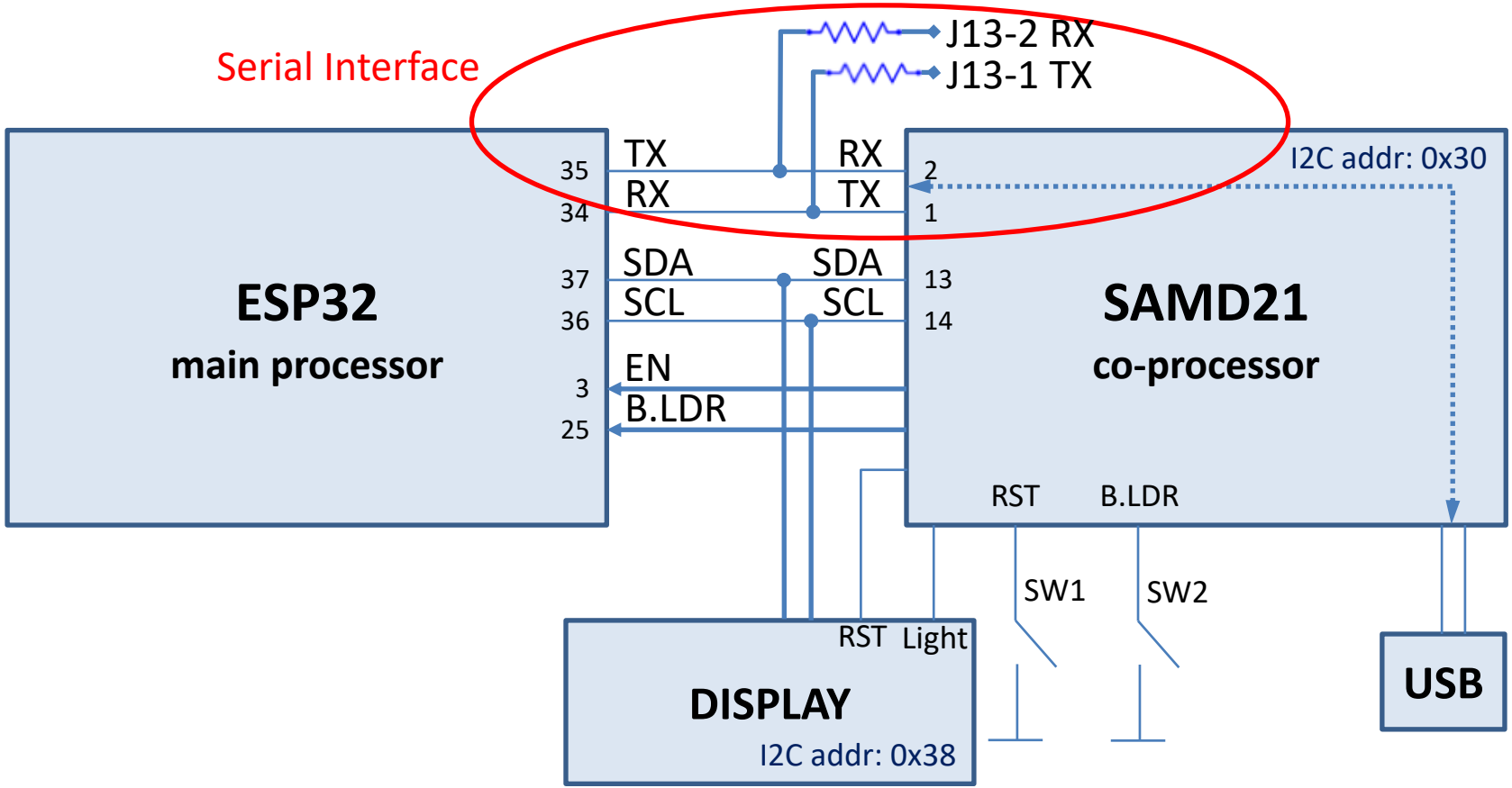


- Connect a TTL Serial Adapter
- Use the jumper to enter Boot Loader mode
- Reset the board (unplug/replug)
- Load the sketch
- Remove the jumper
- Reset the board (unplug/replug)

Hello World with a LED

Video loading the blinking LED on the ESP32

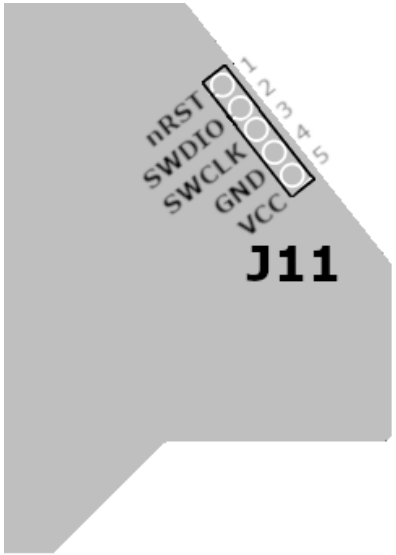
Hello World with a LED



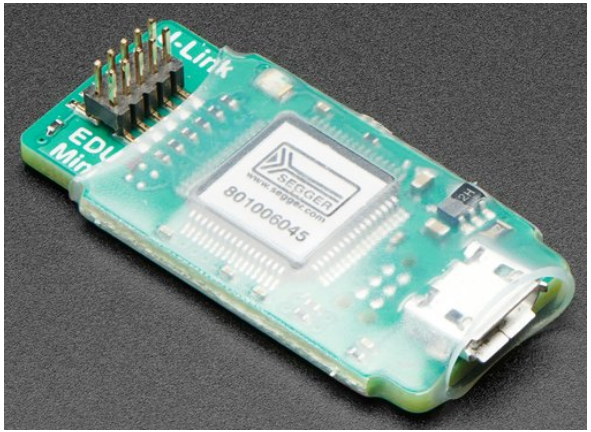
Why re-flash the SAMD21

- I want to use the badge USB interface to program the ESP32 with the Arduino IDE
  - The SAMD21 have to read from USB serial interface and write to the ESP32 serial interface and vice-versa
- I want to light the LEDs, attached to the SAMD21
- I want to use the touch buttons attached to the SAMD21

Re-flashing Hardware



- On the badge we have the SWD (Serial Wire Debug) interface headers
- We can use:
  - Segger J-Link Edu Mini, very good proprietary software

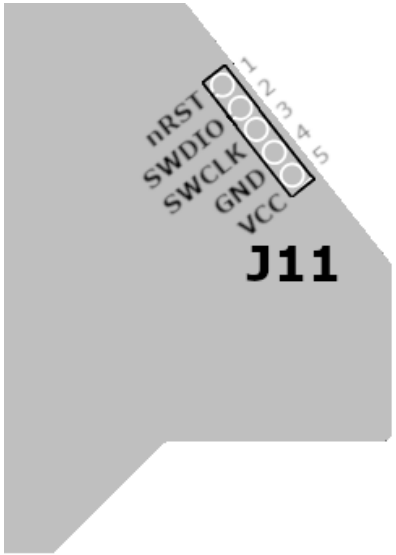


SEGGER J-Link EDU Mini - JTAG/SWD Debugger

PRODUCT ID: 3571

$19.95

Re-flashing Hardware



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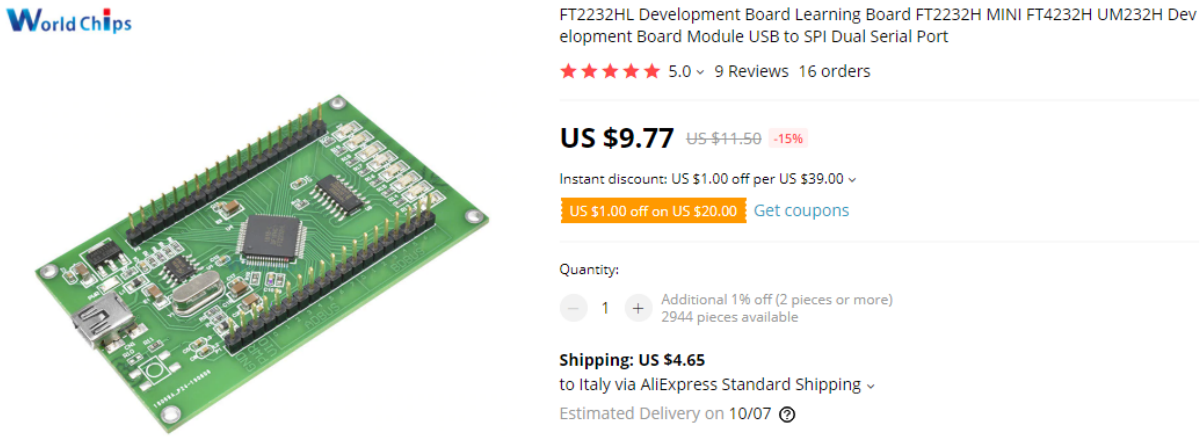

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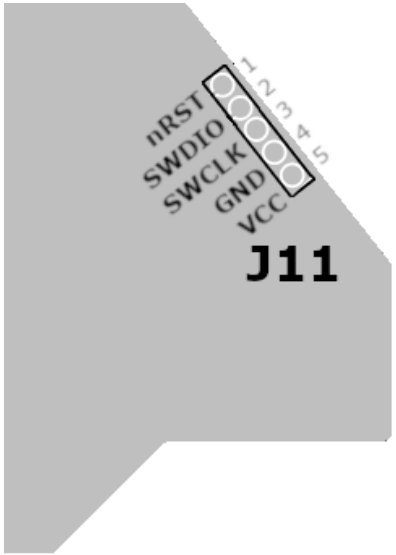

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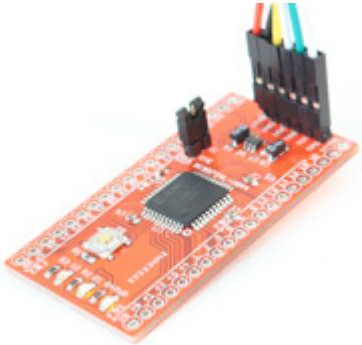
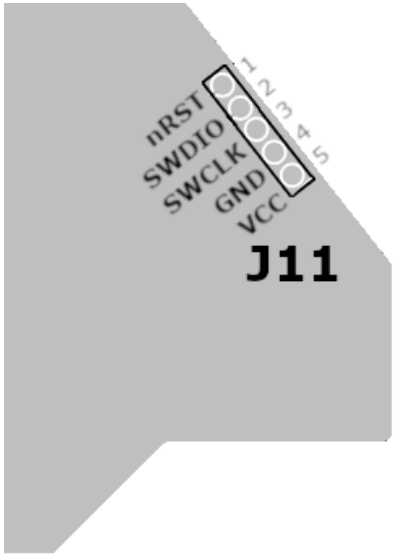
  - Bus Bluster (based on FT2232H) and OpenOCD software



Project Summary	
Name:	Bus Blaster
Buy it:	Get one for $34.95 at Seeed Studio
Price:	$34.95
Status:	Mature
Manufacturing:	Shipping
Forum:	Bus Blaster Forum

$ 34.95

Re-flashing Hardware



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  - Segger J-Link Edu Mini, very good proprietary software
  - Breakout boards with FT2232H and OpenOCD software
  - Bus Bluster (based on FT2232H) and OpenOCD software
  - Bus Pirate

BUS PIRATE - V3.6A

Item no.: TOL-12942

€29.95

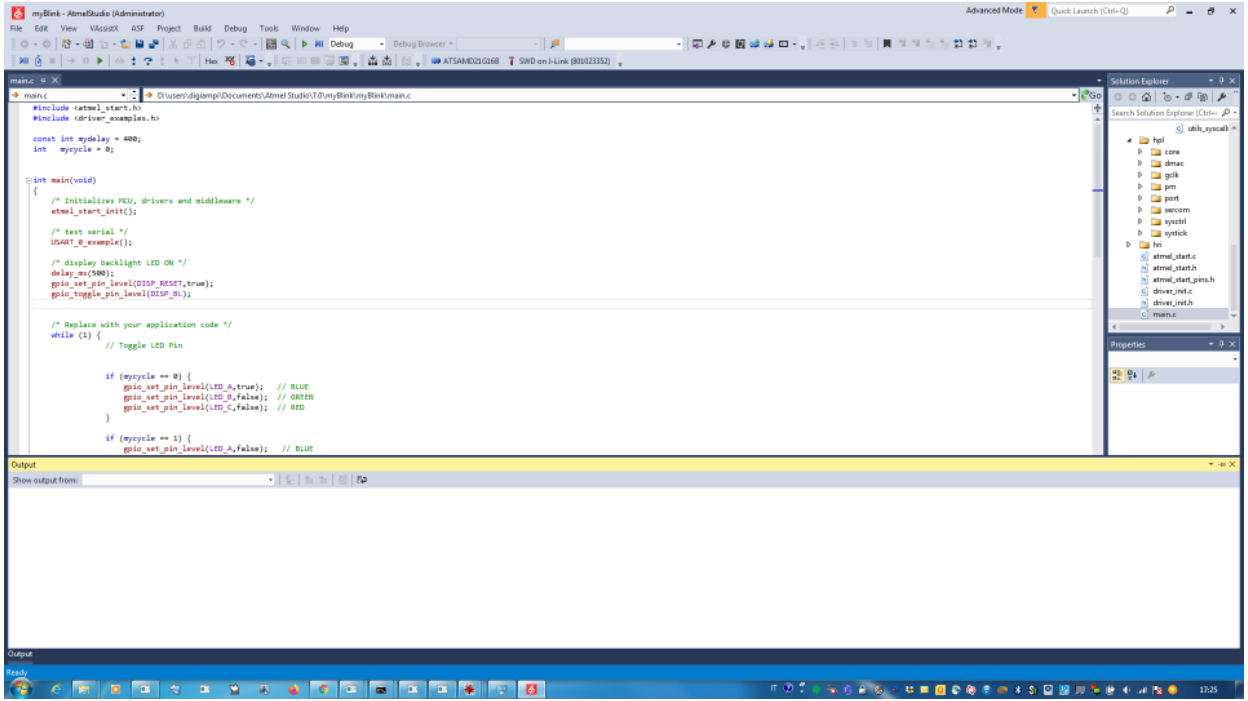
Incl. VAT: €36.24

Qty: 1

In stock

Atmel Studio

- Windows Only



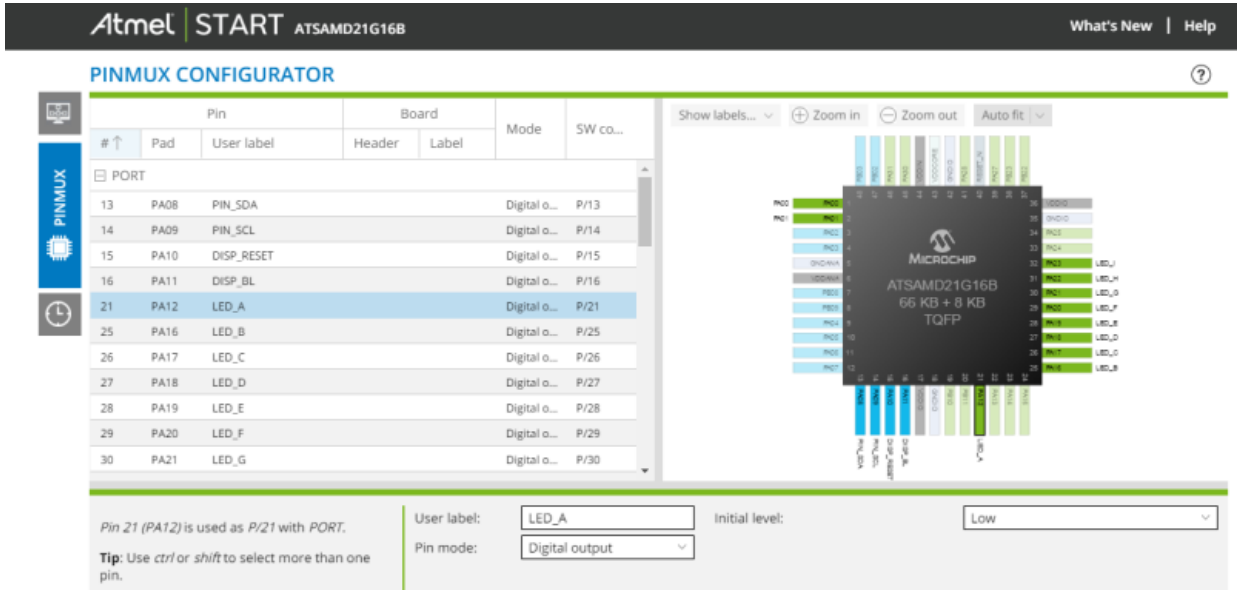
Atmel Studio

- Windows Only
- Over-bloated

Microsoft .NET Framework 4.5.1 Multi-Targeting Pack (ENU)	Microsoft Corporation	26/08/2020	74,5 MB	4.5.50932
Atmel LibUSB0 Driver (x64)	Atmel	26/08/2020	725 KB	7.0.125
Microsoft .NET Framework 4.5.2 Multi-Targeting Pack	Microsoft Corporation	26/08/2020	49,4 MB	4.5.51209
Microsoft System CLR Types for SQL Server 2014	Microsoft Corporation	26/08/2020	5,69 MB	12.0.2402.11
Microsoft .NET Framework 4.5.1 Multi-Targeting Pack	Microsoft Corporation	26/08/2020	49,3 MB	4.5.50932
Microsoft .NET Framework 4.5 Multi-Targeting Pack	Microsoft Corporation	26/08/2020	41,8 MB	4.5.50710
Atmel Driver Files	Atmel Corporation	26/08/2020	5,05 MB	8.1.39
Microsoft .NET Framework 4.5.2 Multi-Targeting Pack (ENU)	Microsoft Corporation	26/08/2020	74,4 MB	4.5.51209
Microsoft SQL Server 2014 Management Objects	Microsoft Corporation	26/08/2020	24,7 MB	12.0.2000.8
Atmel WinUSB	Atmel	26/08/2020	2,58 MB	6.2.32
Microsoft .NET Framework 4.5.1 SDK	Microsoft Corporation	26/08/2020	19,4 MB	4.5.51641
Atmel Segger USB Drivers (501e)	Atmel	26/08/2020	1,90 MB	7.0.417
Microsoft Visual Studio 2015 Shell (Isolated)	Microsoft Corporation	26/08/2020	1,50 GB	14.0.23107.10
Microsoft Visual C++ 2013 Redistributable (x86) - 12.0.21005	Microsoft Corporation	26/08/2020		12.0.21005.1
Microsoft Visual C++ 2013 Redistributable (x64) - 12.0.21005	Microsoft Corporation	26/08/2020		12.0.21005.1
Atmel Studio 7.0	Atmel	26/08/2020	4,12 GB	7.0.2397

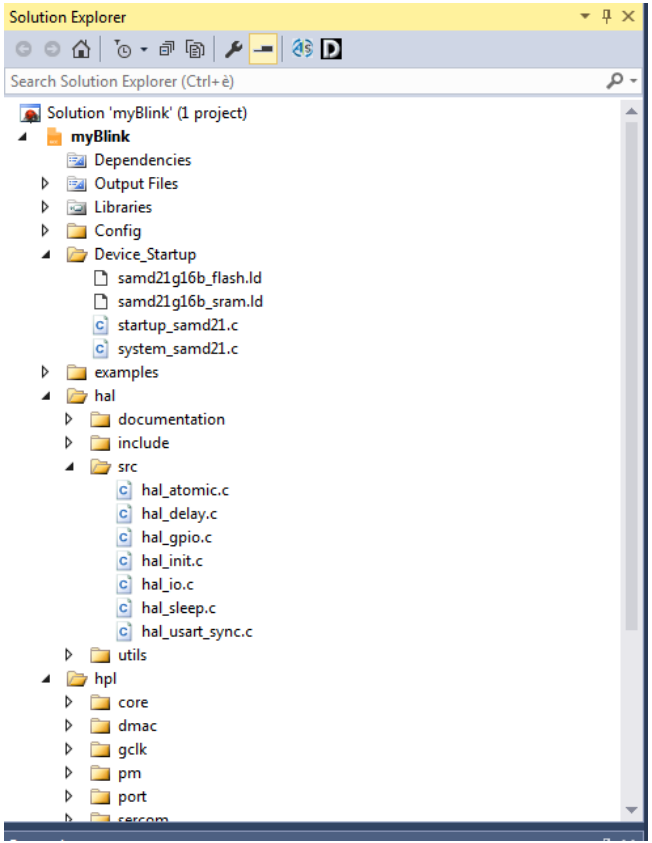
Atmel Studio

- Windows Only
- Over-bloated
- GUI for everything



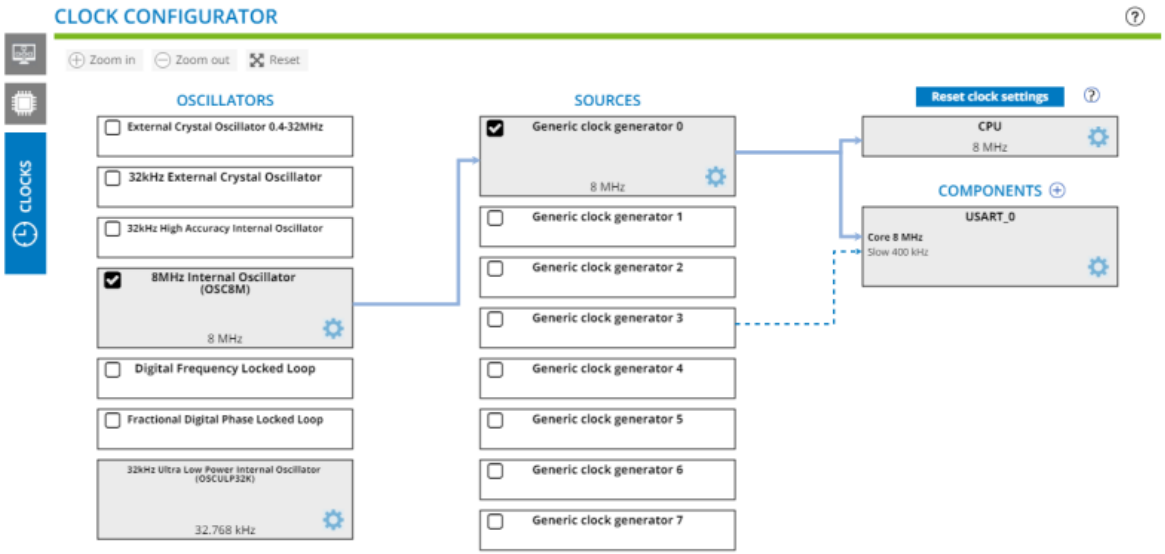
Atmel Studio

- Windows Only
- Over-bloated
- GUI for everything
- Over-bloated ASF framework



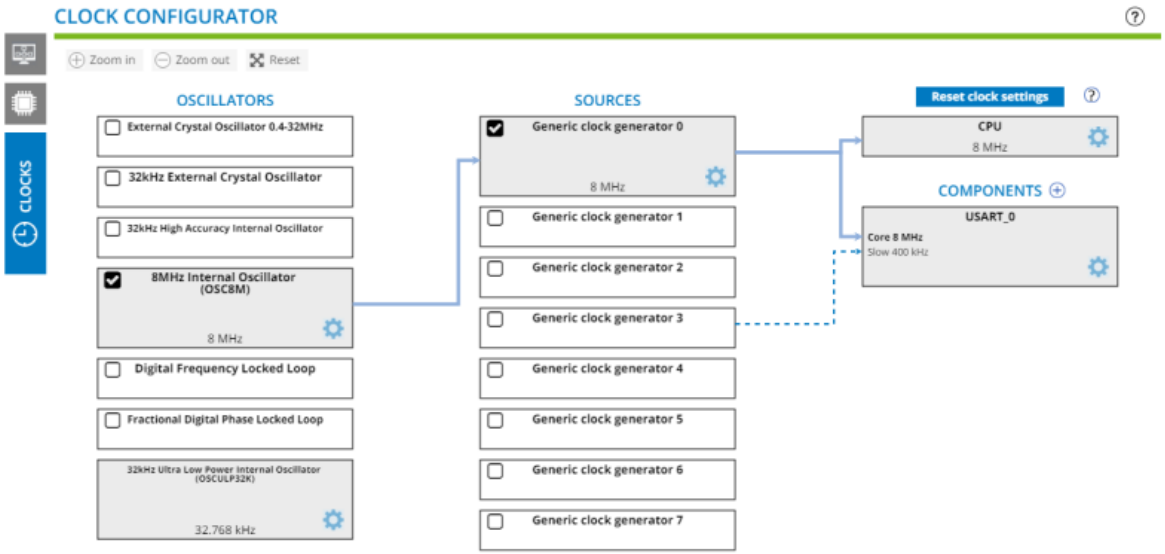
Atmel Studio

- Windows Only
- Over-bloated
- GUI for everything
- Over-bloated ASF framework
- GUI allows illegal configurations



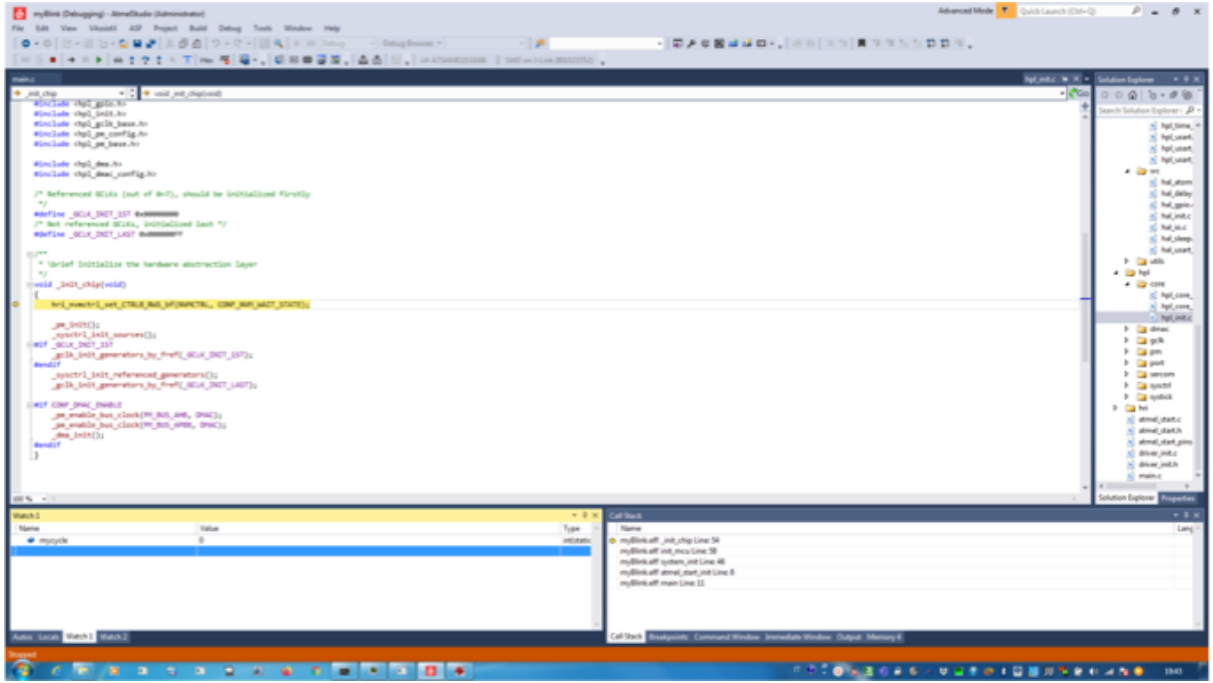
Atmel Studio

- Windows Only
- Over-bloated
- GUI for everything
- Over-bloated ASF framework
- GUI allows illegal configurations
- Complex clocks configuration



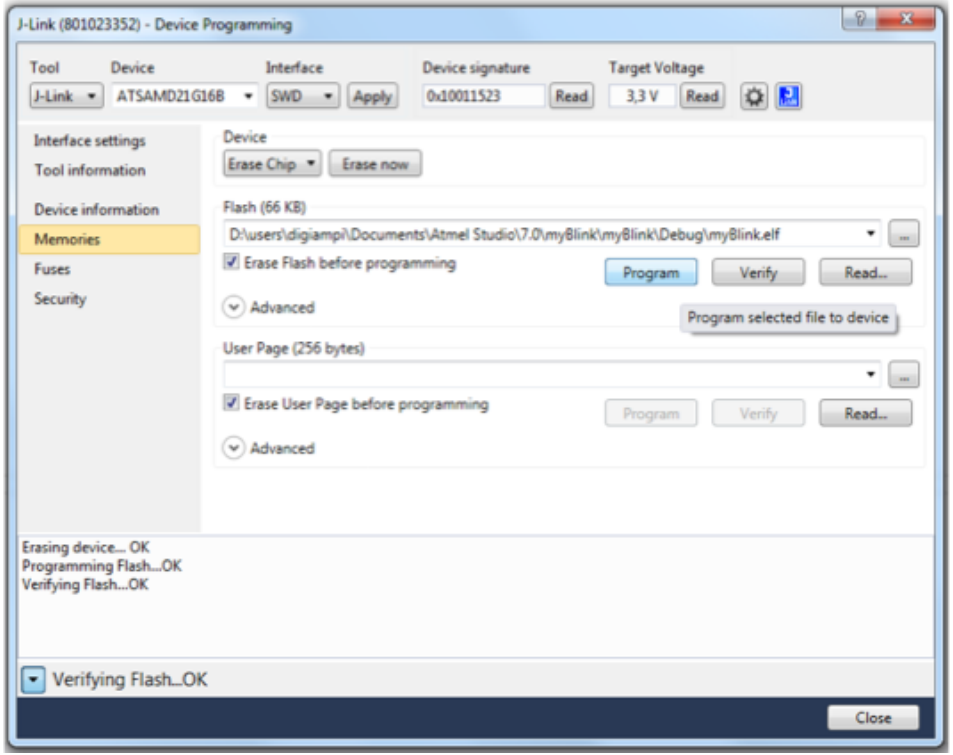
Atmel Studio

- Visual Studio is a good and pleasant GUI



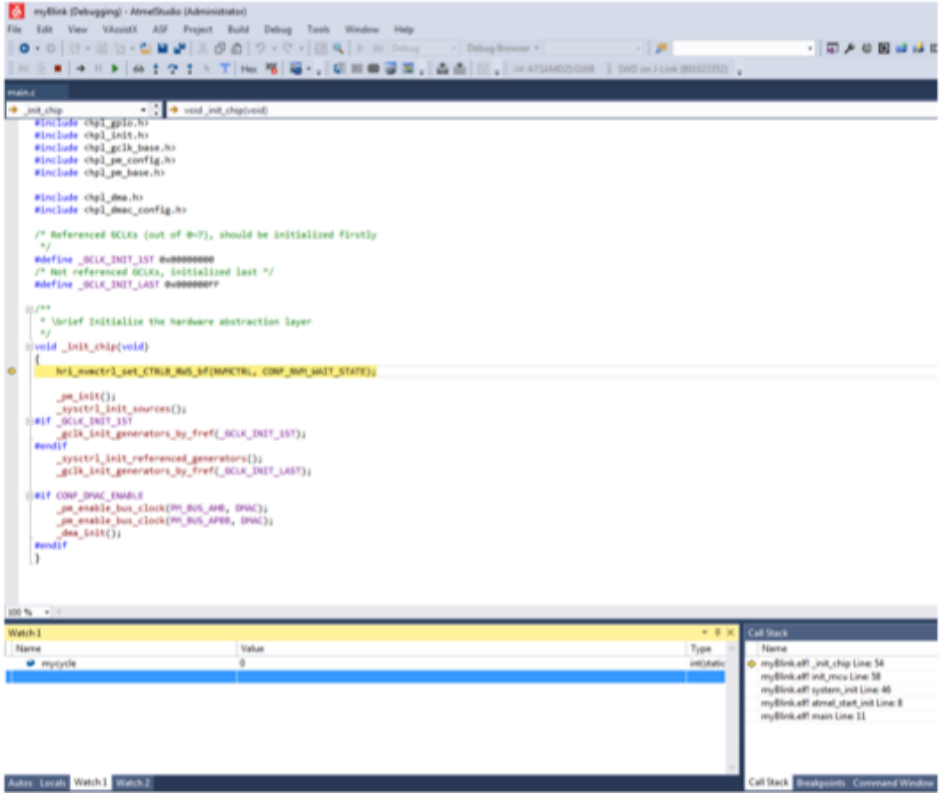
Atmel Studio

- Visual Studio is a good and pleasant GUI
- Good integration with J-Link probe to flash the device



Atmel Studio

- Visual Studio is a good and pleasant GUI
- Good integration with J-Link probe to flash the device
- Easy debugging interface using the J-Link probe and GDB



Hello World with Atmel Studio

- Confirm LED position with a «Hello World» program

Atmel | START main.c

main int main(void)

```c
        while (1) {
                // Toggle LED Pin


                if (mycycle == 0) {
                    gpio_set_pin_level(LED_A,true);   // BLUE
                    gpio_set_pin_level(LED_B,false);  // GREEN
                    gpio_set_pin_level(LED_C,false);  // RED
                }

                if (mycycle == 1) {
                    gpio_set_pin_level(LED_A,false);   // BLUE
                    gpio_set_pin_level(LED_B,true);    // GREEN
                    gpio_set_pin_level(LED_C,false);   // RED
                }

                if (mycycle == 2) {
                    gpio_set_pin_level(LED_A,false);   // BLUE
                    gpio_set_pin_level(LED_B,false);   // GREEN
                    gpio_set_pin_level(LED_C,true);    // RED
                }

                mycycle++;
                if (mycycle > 2) {mycycle = 0;}

                delay_ms(mydelay);

                gpio_toggle_pin_level(LED_F);  // from 0 to 1 LED D5 off
                delay_ms(mydelay);

                gpio_toggle_pin_level(LED_D);  // from 0 to 1 LED D1 off
                delay_ms(mydelay);

                gpio_toggle_pin_level(LED_H);  // from 0 to 1 LED D6 off
                delay_ms(mydelay);

                gpio_toggle_pin_level(LED_I);  // from 0 to 1 LED D3 off
                delay_ms(mydelay);

                gpio_toggle_pin_level(LED_E);  // from 0 to 1 LED D7 off
                delay_ms(mydelay);

                gpio_toggle_pin_level(LED_G);  // from 0 to 1 LED D4 off
                delay_ms(mydelay);

                USART_0_example();

        }
}
```

100 %

Hello World with Atmel Studio

- Confirm LED position with a ~~«Hello World»~~ program

  Merry Christmas

Hello World with Atmel Studio

Video loading the blinking LED on the ESP32

Working with Atmel Studio

- Spent few weeks trying to program a USB serial to ESP32 serial bridge
- Difficult to find mix and merge available examples
- Writing something from scratch seems impossible without studying the 1000+ pages SAMD21 data sheet and the 500+ pages Atmel Studio manual!
- The ”Atmel Studio” way is the opposite of the ”Arduino way”
- Restart searching on Internet how to bring our SAMD21 in the Arduino IDE platform

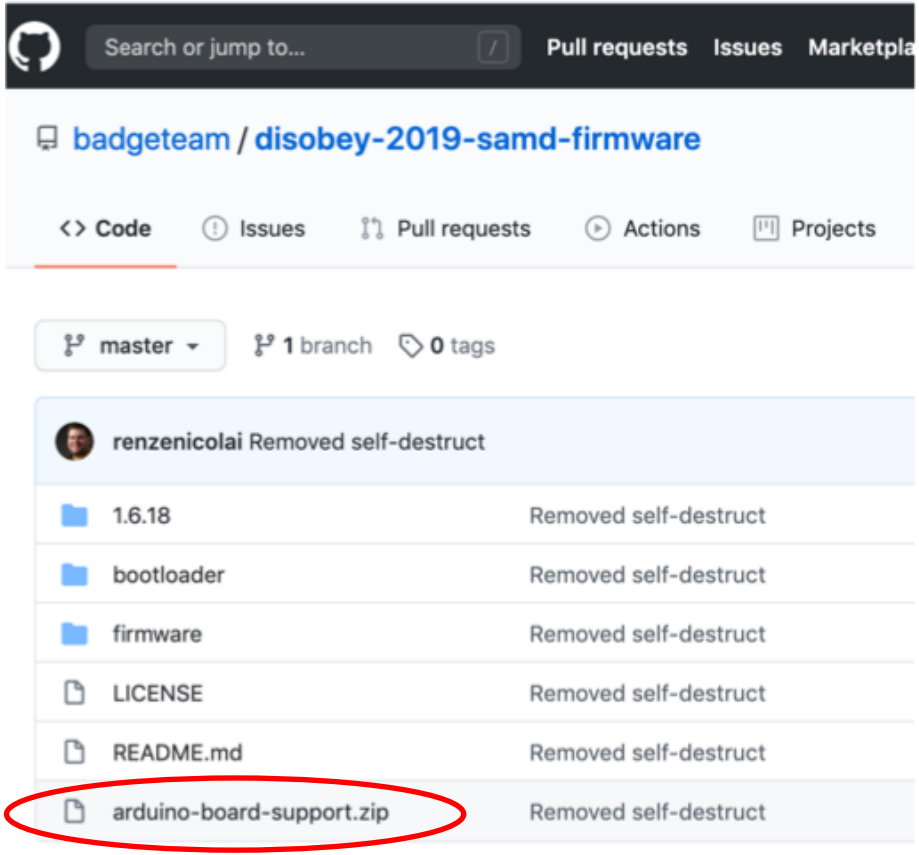
The Arduino Way

A lot of beginners approaching electronics for the first time think that they have to learn how to build everything from scratch. This is a waste of energy: what you want is to be able to confirm that something's working very quickly so that you can motivate yourself to take the next step.

Massimo Banzi
co-founder of Arduino

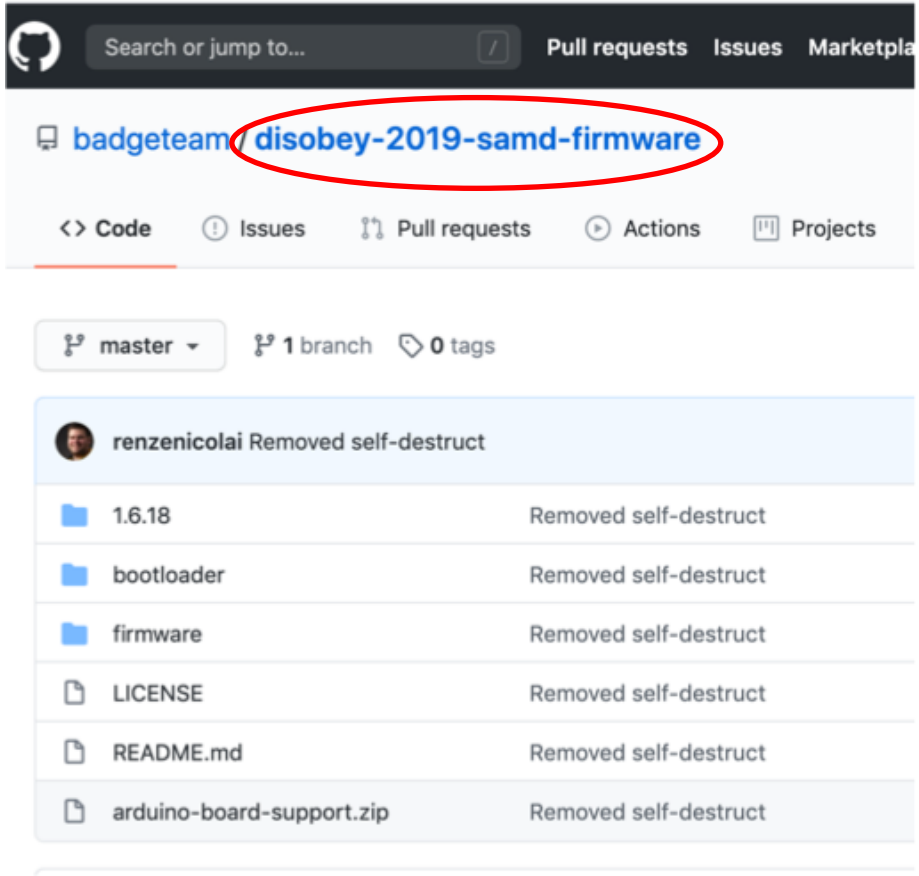
SAMD21 Arduino IDE

- On GitHub the SAMD21G16 was already ported to Arduino IDE



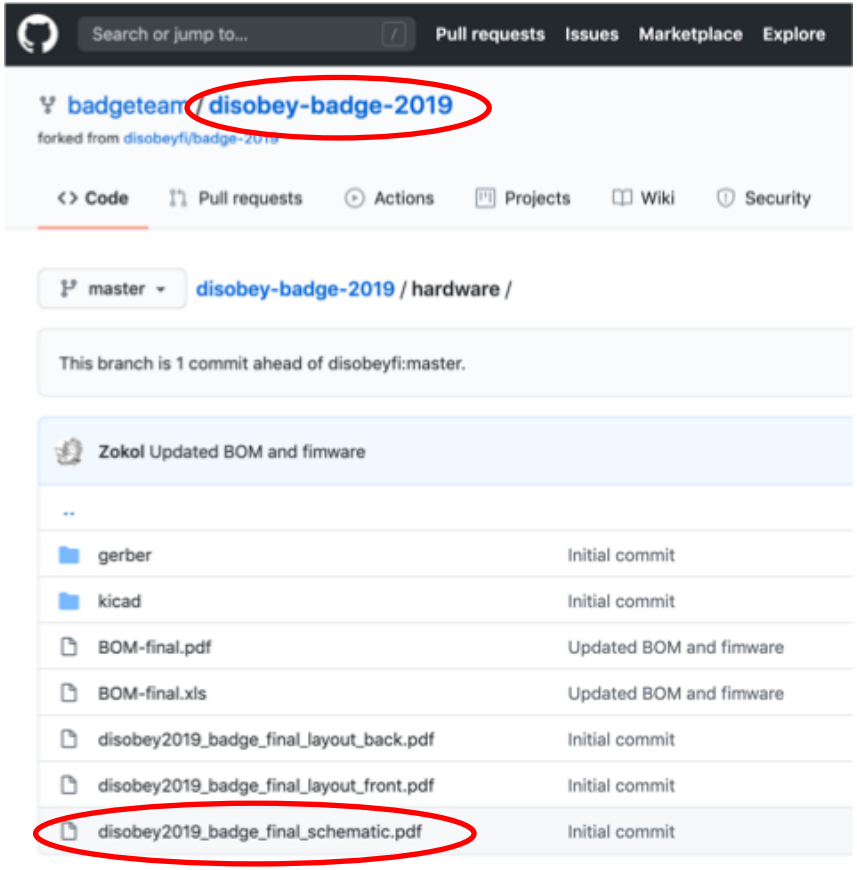
SAMD21 Arduino IDE

- On GitHub the SAMD21G16 was already ported to Arduino IDE
- The project has the firmware for the “Disobey 2019” badge, very similar to our badge



SAMD21 Arduino IDE

- On GitHub the SAMD21G16 was already ported to Arduino IDE
- The project has the firmware for the “Disobey 2019” badge, very similar to our badge
- Related repository with badge details, including schematics



USB Serial to ESP2 serial bridge

- In the Arduino IDE the USB Serial to ESP32 serial bridge is only 10 lines of code!

```
inline void update_serial()
{
  while (Serial.available()) {
    Serial1.write(Serial.read());
  }

  while (Serial1.available()) {
    Serial.write(Serial1.read());
  }
}
```

USB Serial to ESP2 serial bridge

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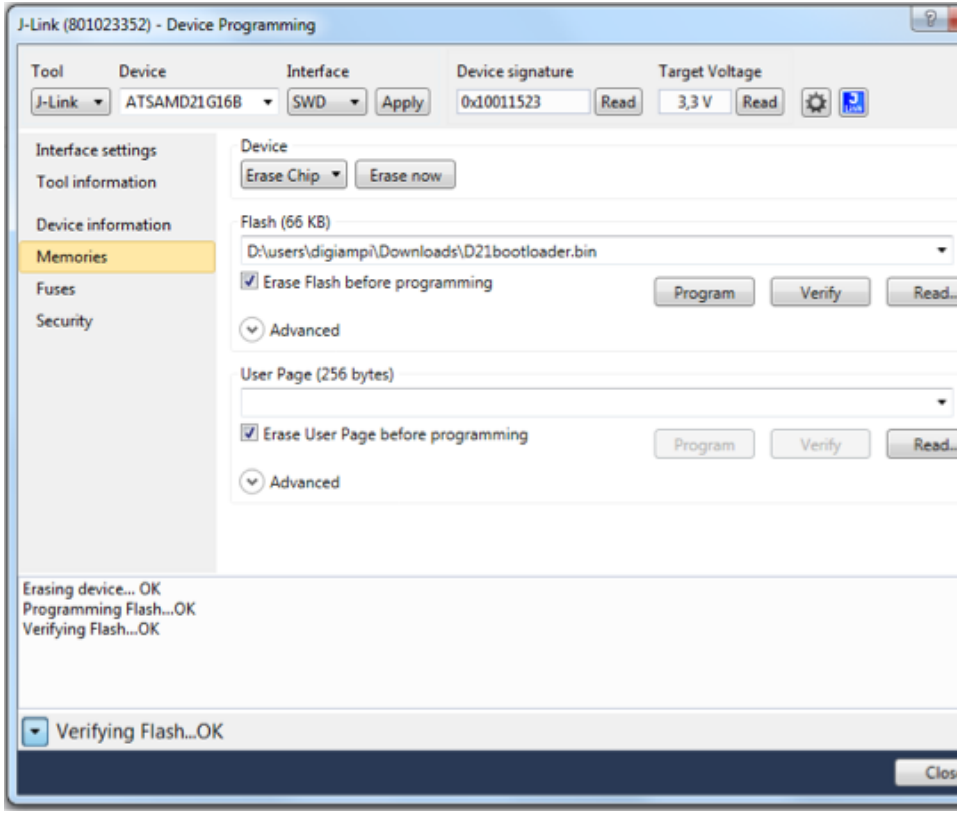
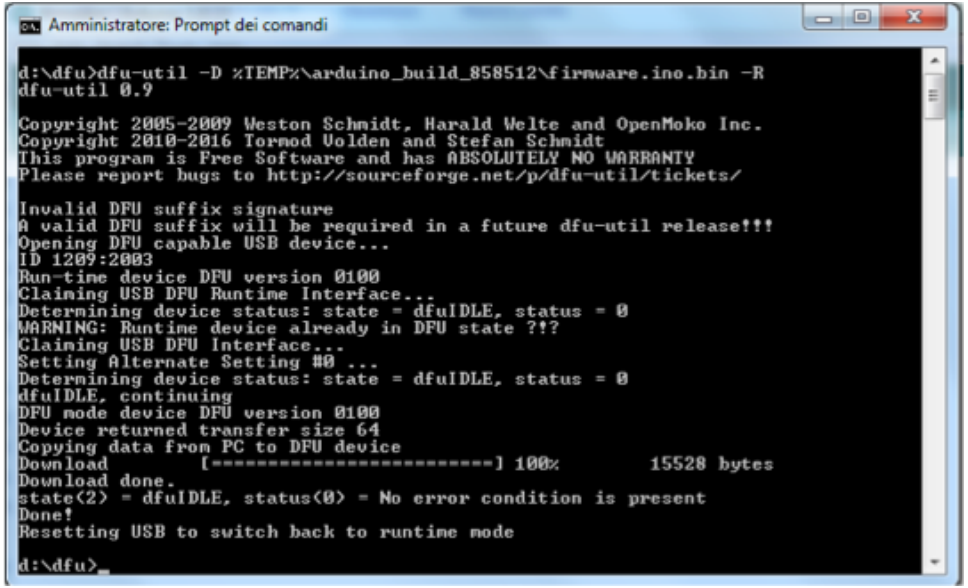
- Write the bootloader to the SAMD21 using Atmel Studio



USB Serial to ESP2 serial bridge

- In the Arduino IDE the USB Serial to ESP2 serial bridge is only 10 lines of code!
- Write the bootloader to the SAMD21 using Atmel Studio
- Compile the “firmware.ino” and load to the SAMD21 using dfu-util



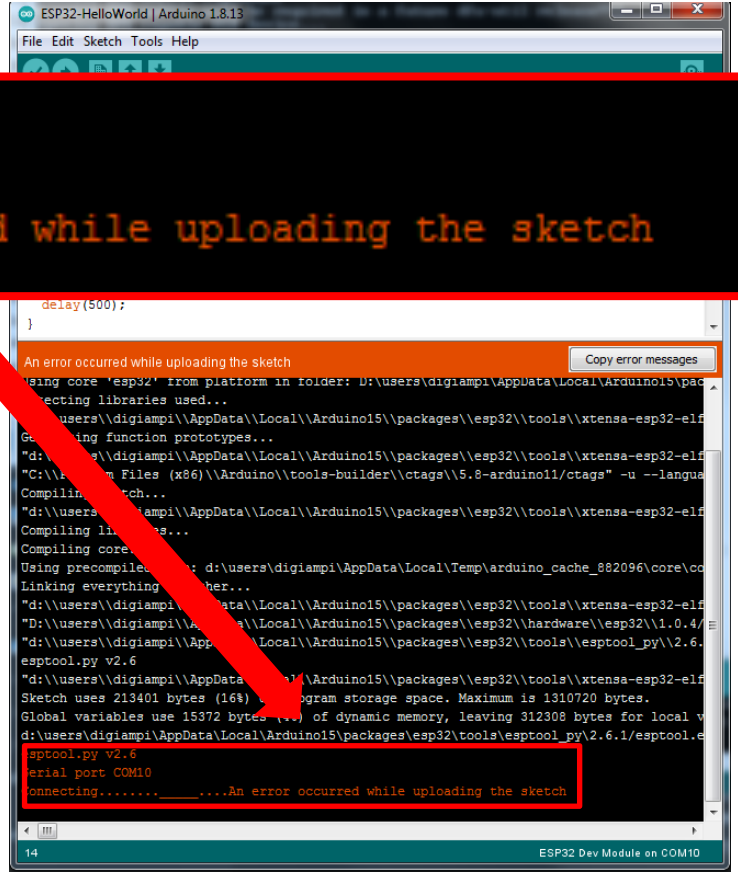
USB Serial to ESP2 serial bridge

HACKTIVITY
The IT Security Festival in Central and Eastern Europe

- In the Arduino IDE the USB

```
esptool.py v2.6
Serial port COM10
Connecting........_____....An error occurred while uploading the sketch
```

- Write the bootloader to the SAMD21 using Atmel Studio
- Compile the “firmware.ino” and load to the SAMD21 using dfu-util
- Use the Arduino IDE with ESP32: timeout!



USB Serial to ESP2 serial bridge

- The problem was that the serial bridge was not fast enough

```
inline void update_serial()
{
  while (Serial.available()) {
    Serial1.write(Serial.read());
  }

  while (Serial1.available()) {
    Serial.write(Serial1.read());
  }
}
```

USB Serial to ESP2 serial bridge

- The problem was that the serial bridge was not fast enough
- Arduino IDE hides complexity, but can generate code that can be very inefficient

```
inline void update_serial()
{
  while (Serial.available()) {
    Serial1.write(Serial.read());
  }

  while (Serial1.available()) {
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}
```

USB Serial to ESP2 serial bridge

- The problem was that the serial bridge was not fast enough
- Arduino IDE hides complexity, but can generate code that can be very inefficient
- Increase the serial buffer in the SAMD21 Arduino configuration

```
// Define constants and variables for buffering incoming serial data.  We're
// using a ring buffer (I think), in which head is the index of the location
// to which to write the next incoming character and tail is the index of the
// location from which to read.
#define SERIAL_BUFFER_SIZE 64
```

```
// Define constants and variables for buffering incoming serial data.  We're
// using a ring buffer (I think), in which head is the index of the location
// to which to write the next incoming character and tail is the index of the
// location from which to read.
#define SERIAL_BUFFER_SIZE 512
```

USB Serial to ESP2 serial bridge

- The problem was that the serial bridge was not fast enough
- Arduino IDE hides complexity, but can generated code that can be very inefficient
- Increase the serial buffer in the SAMD21 Arduino configuration
- Rewrite the “serial bridge” function to be non-blocking

```
inline void my_update_serial()
{
  while ((Serial.available()  and Serial1.availableForWrite())
      or (Serial1.available() and Serial.availableForWrite())) {

    if (Serial.peek() >= 0) {
      if (Serial1.availableForWrite() > 0) {
        Serial1.write(Serial.read());
      }
    }

    if (Serial1.peek() >= 0) {
      if (Serial.availableForWrite() > 0) {
        Serial.write(Serial1.read());
      }
    }

  }
}
```

Serial bridge Working!

Demo Video loading an ESP32 sketch

Conclusion

- Success in using Arduino IDE to program the ESP32 on the badge
- Still to do: modifying an existing, SPI based, library do drive our I2C display
- Something learned once more
  - Don’t get stuck, move on with a different approach
  - Partial info and similar product info can be very useful in any reverse engineering project

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Thank You
Question Time

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