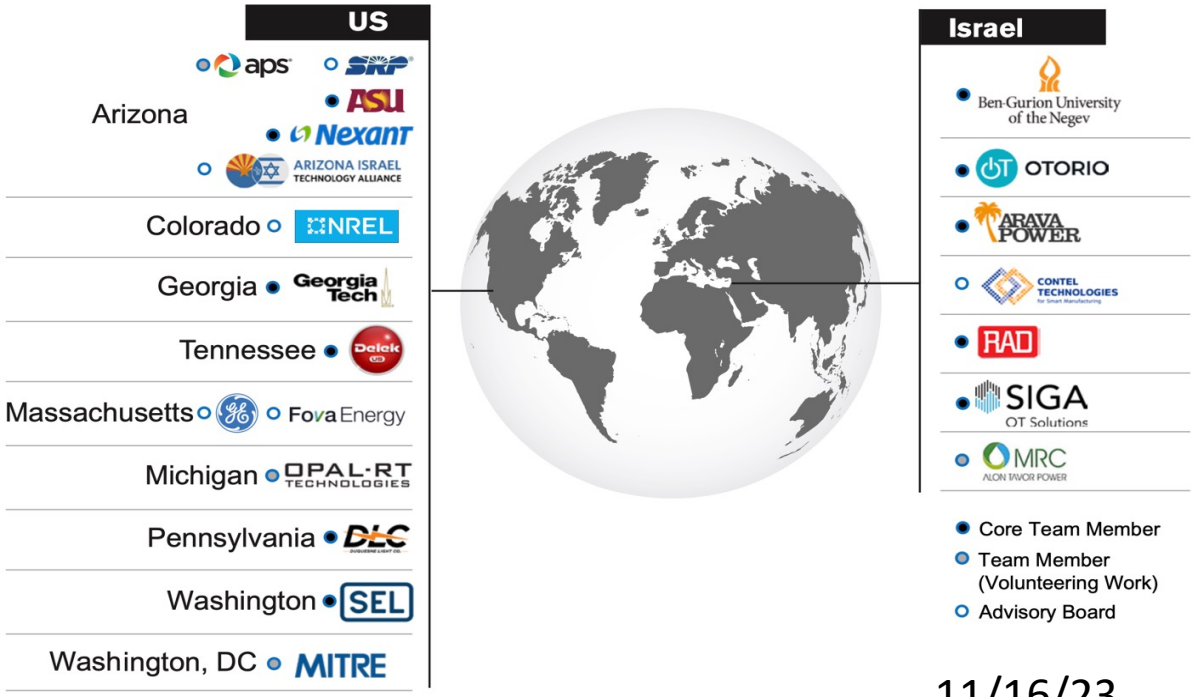
Safeguarding Embedded Controllers through Side Channel Analysis



11/16/23

Task 13

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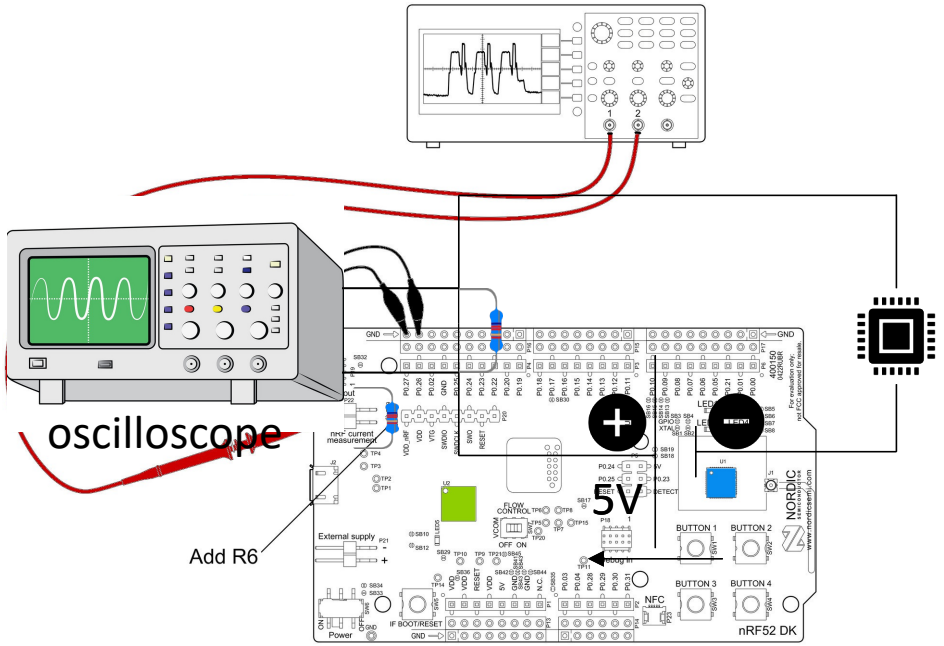
Task Goals

- Firmware Verification on edge devices (programmable controllers)
- Monitor code execution
- Maintain low overhead

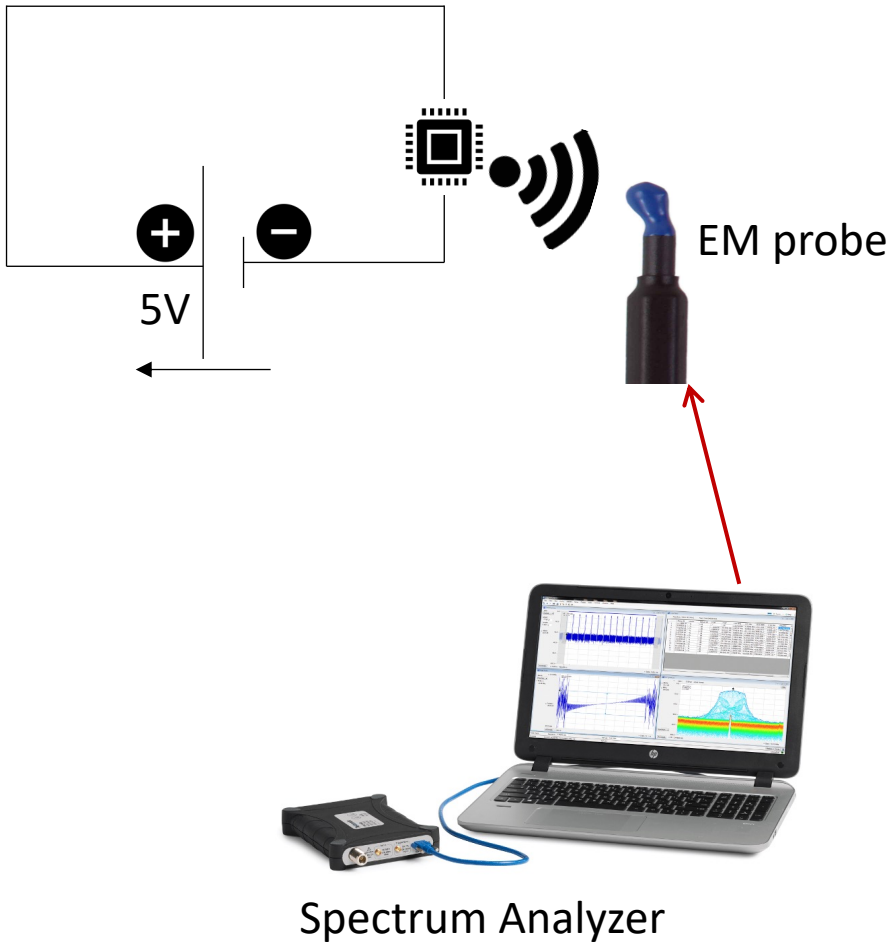
The power side channel

- Executing instructions causes transistors to switch on and off
- Ohms Law: $V = R * I$
  - Voltage is constant
  - Transistors switching causes varying resistance → varying current
- The transitions cause fluctuating power consumption
- Different instructions consume power differently

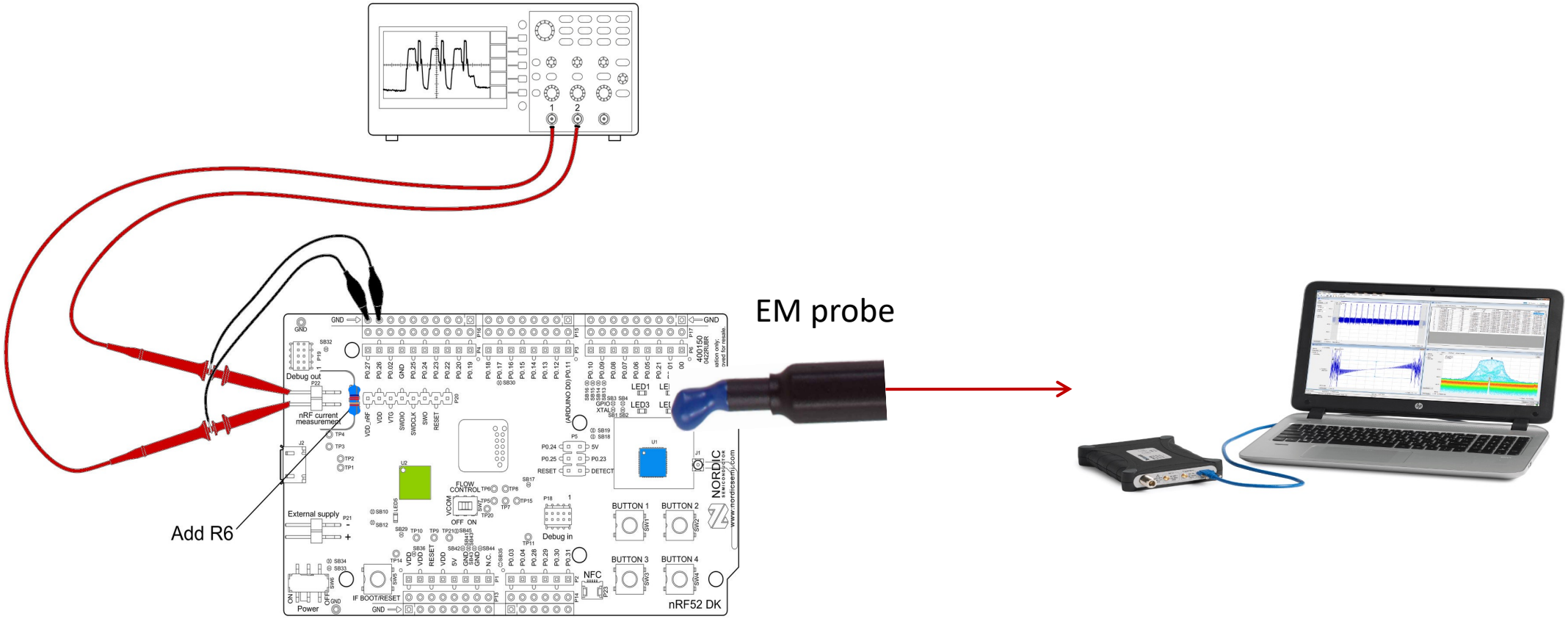


The Electromagnetic side channel

- Transistors switching cause varying resistance → varying current
- Any metallic substance becomes an antenna
- Current variations are translated into EM waves
- Wave characteristics depends on the power consumption (which depends on the executed instructions)

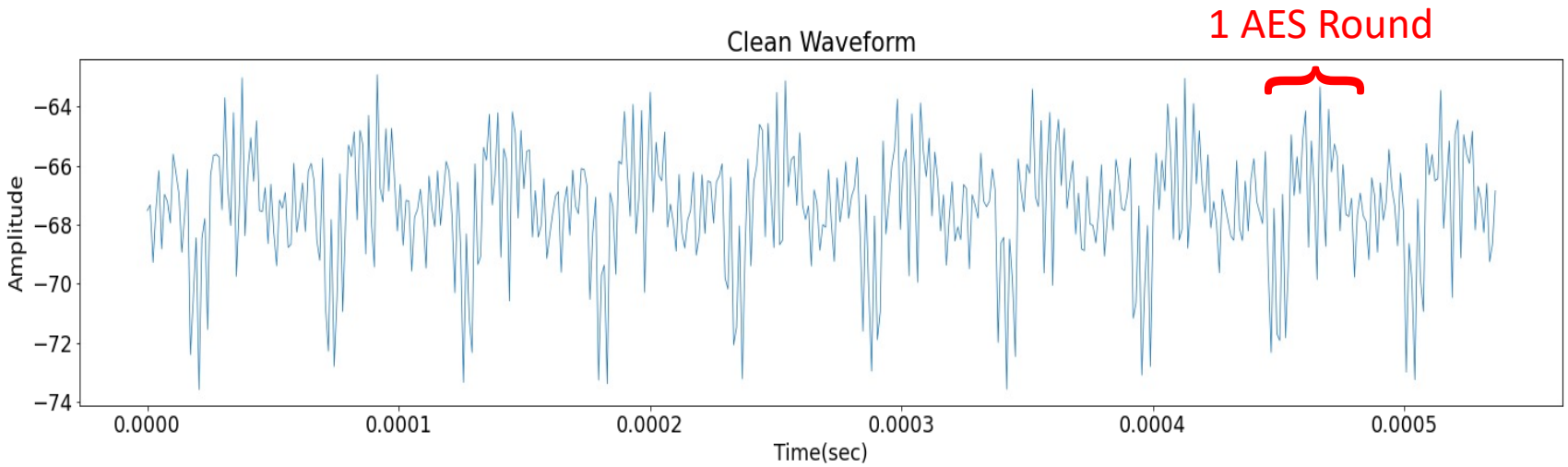


Experimental Environment



Example

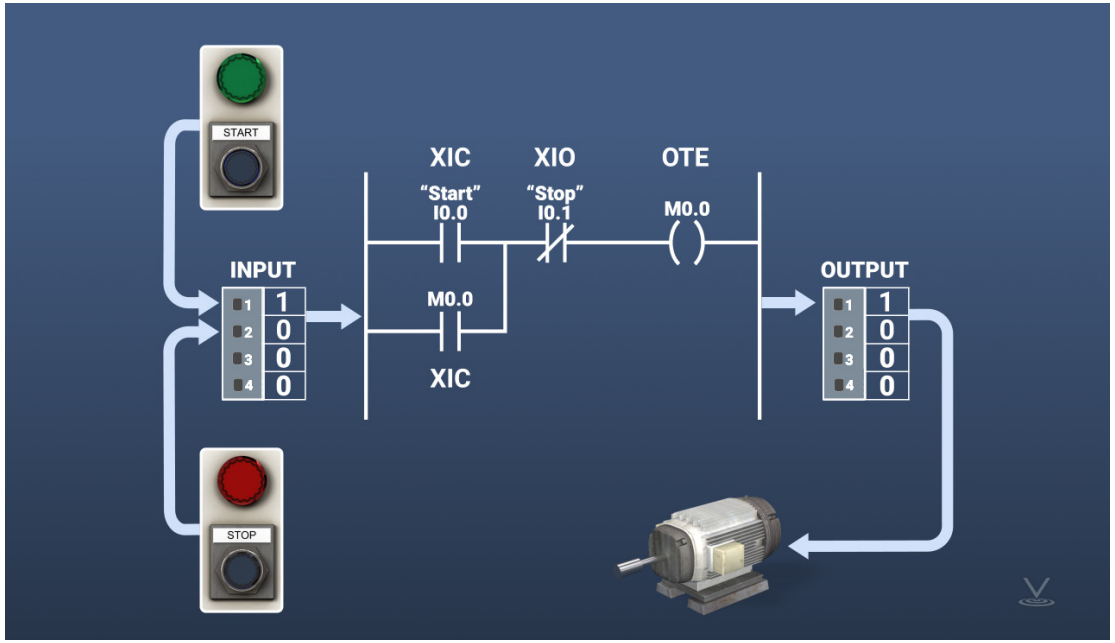
- EM signal
- Taken while executing AES encryption
- Reduced noise with FFT filter



Task 13 Goal

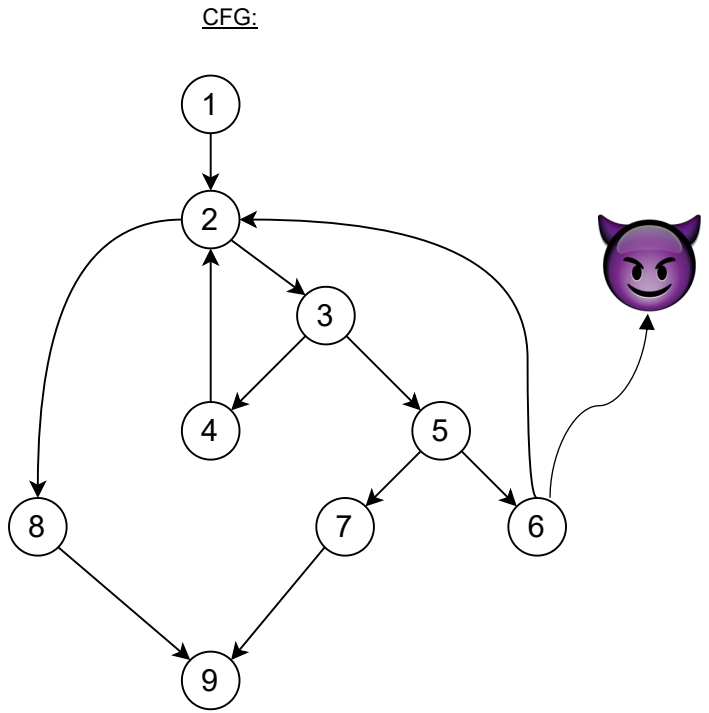
- Detect code hijackings

- Focus on Programmable Logic Controllers
  - Used to automate industrial processes
  - Used in power stations, water facilities, oil facility …
  - Programmed with Ladder Logic
  - Code is rarely updated



Creating a behavioral baseline

- One program have multiple flows
- We want to characterize all
- Represent code as a control flow graph (CFG)
  - Node = Basic blocks
  - Directed edge = transition between blocks
- Control Flow Integrity
  - Verify transitions are legitimate
  - Common approach is instrumentation



Generating Test Cases

- Use static analysis tools
  - Symbolic execution engine

- Example:
  To follow 1→2→3→5→7→9, we need:
  $$\{low \leq high, \quad x = v[mid]\}$$

- Satisfiability solvers (SAT) returns actual assignment to the variables

- Repeat this process for all control flows

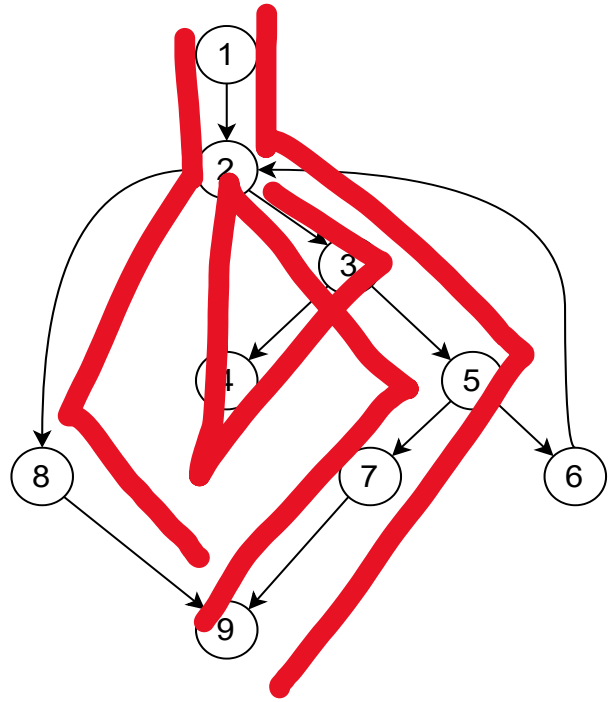
Number of flows explodes very fast

SAT problems are NP-complete

Source Program:

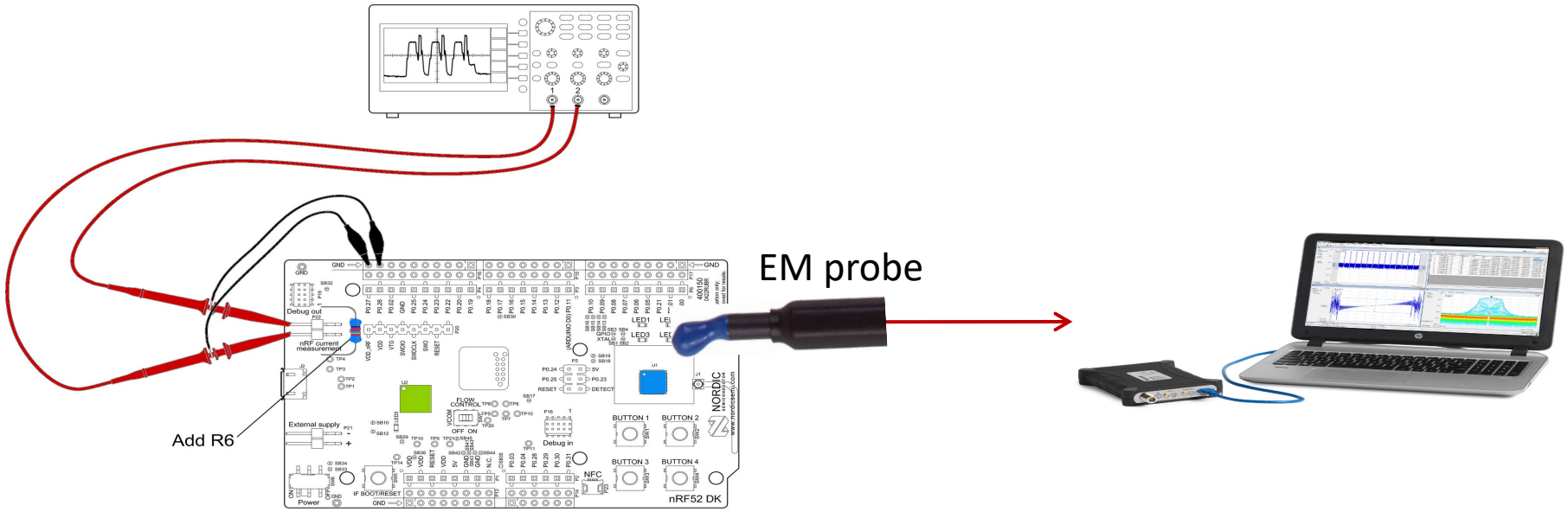
```
int binsearch(int x, int v[], int n)
{
1   | int low, high, mid;
    | low = 0;
    | high = n - 1;
    | while (low <= high)   | 2
    | {
3   |   | mid = (low + high) /2;
    |   | if (x<v[mid])
    |   |       high = mid -1;   | 4
5   |   | else if (x > v[mid])
    |   |       low = mid + 1;   | 6
7   |   | else return mid;
    | }
    | return -1;   | 8
}   | 9
```

CFG:



Creating a dataset

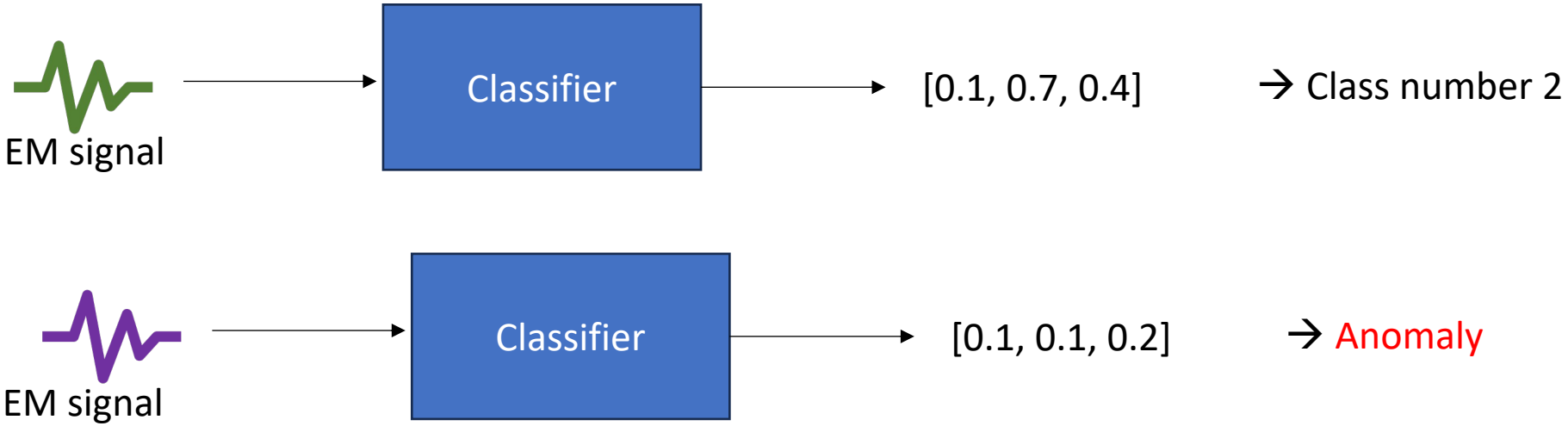
- Each test case (control flow) was executed multiple times
- Collect EM & power signals simultaneously



Anomaly detection

- We translated our problem into a classification problem
  - Each control flow is a class
  - Anomaly is low confidence in all classes
  - No need for anomaly samples!

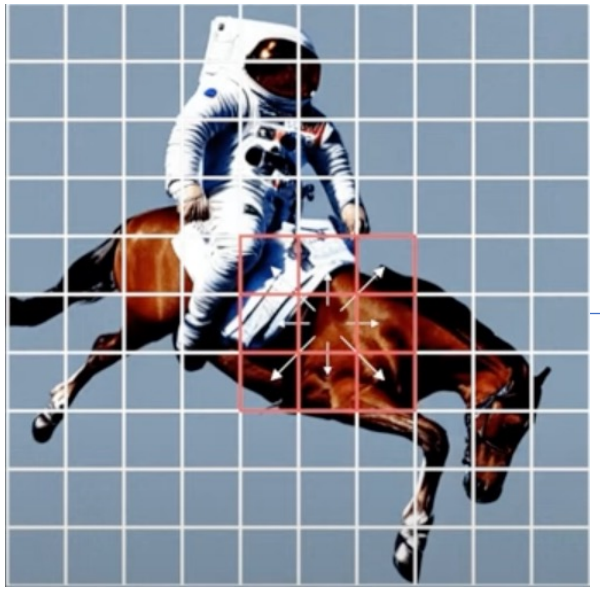
- Examples:



Classifier architecture

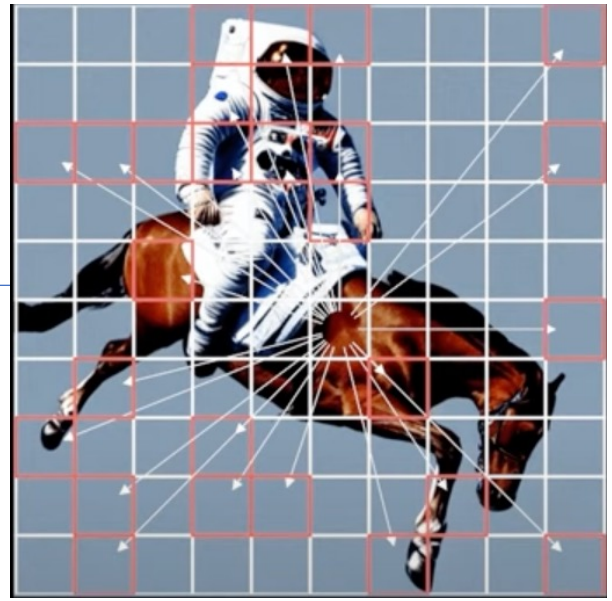
- Transformer based classifier
- Based on self attention mechanism
- Revolutionized the NLP world
- Faster than traditional RNNs

CNN



CNN edge detection Filter

Attention

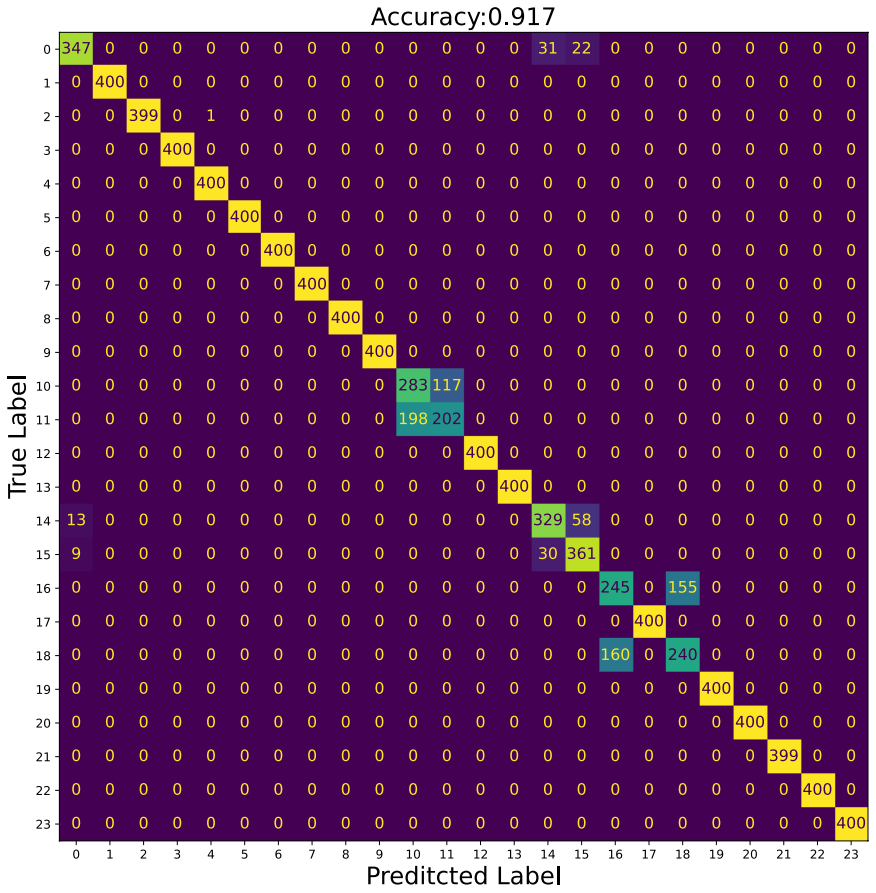


Our Dataset

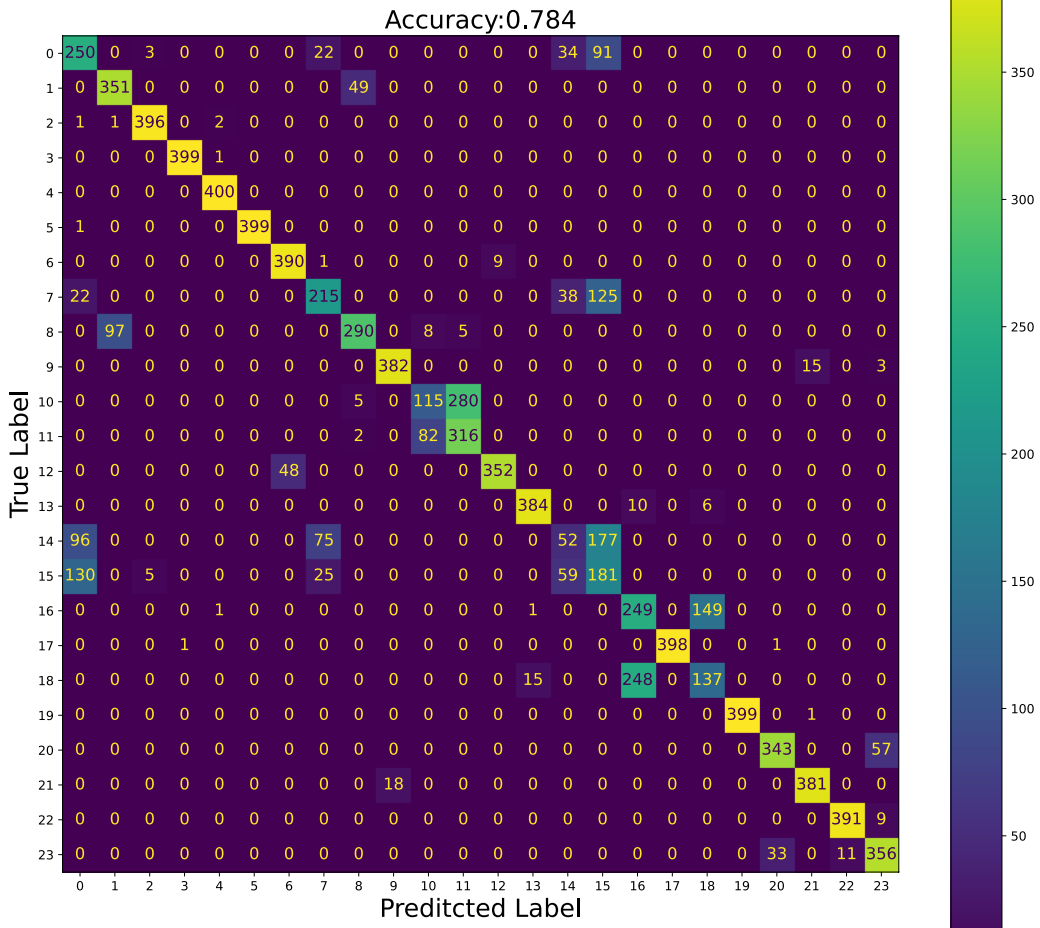
- 24 classes (24 flows)
- 2000 samples per class (power, EM)
- Simulated 2 types of attack
  - Code injection (5-10 NOP instructions)
  - Data exfiltration (through UART pins)

- We trained 2 different classifiers
  - 1 Based on EM signals
  - 1 Based on power signals

Results - classification

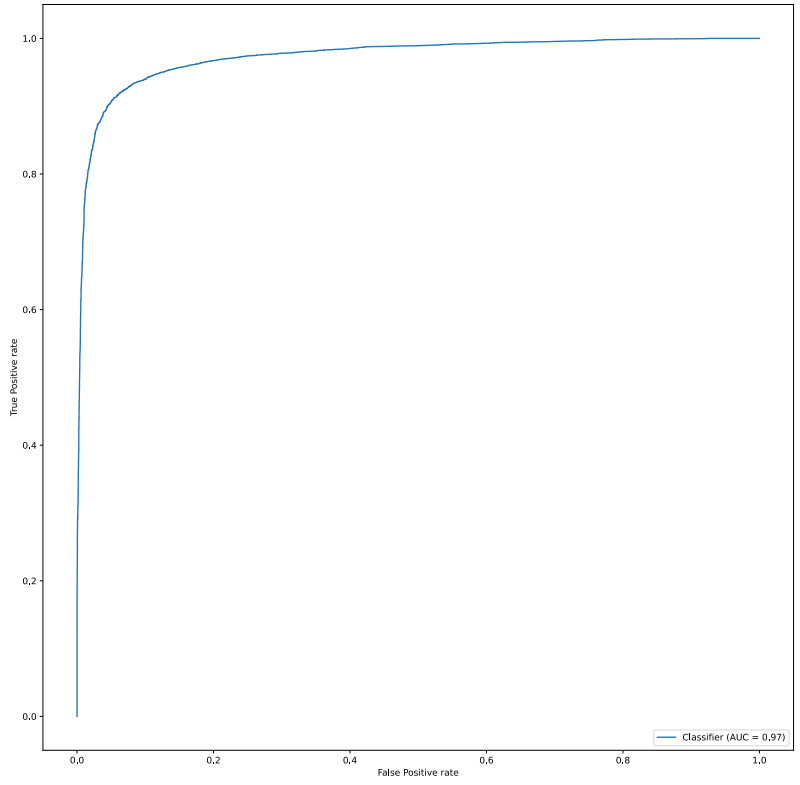


EM Based model

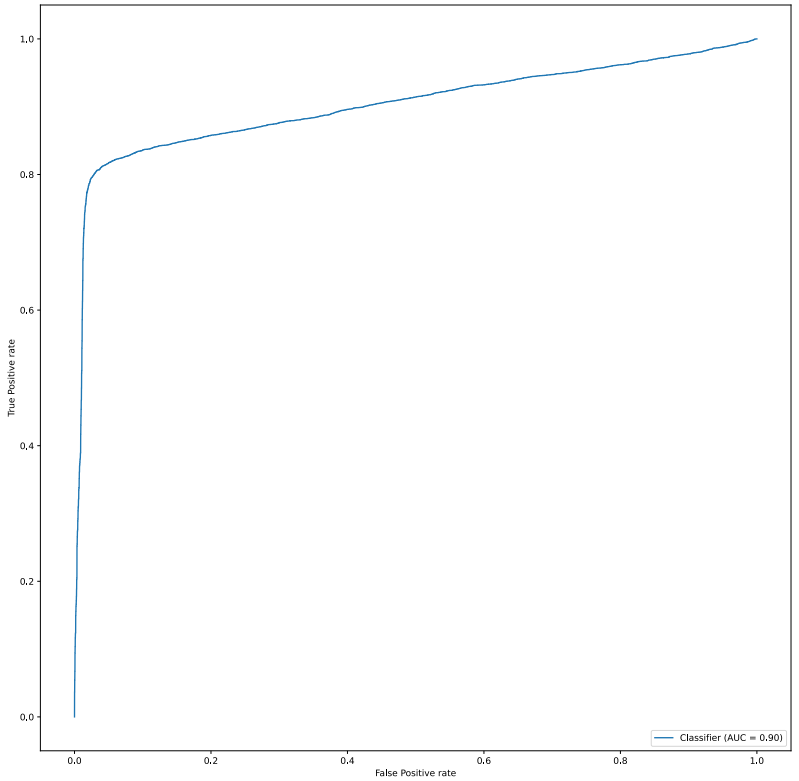


Power Based model

Results – anomaly detection



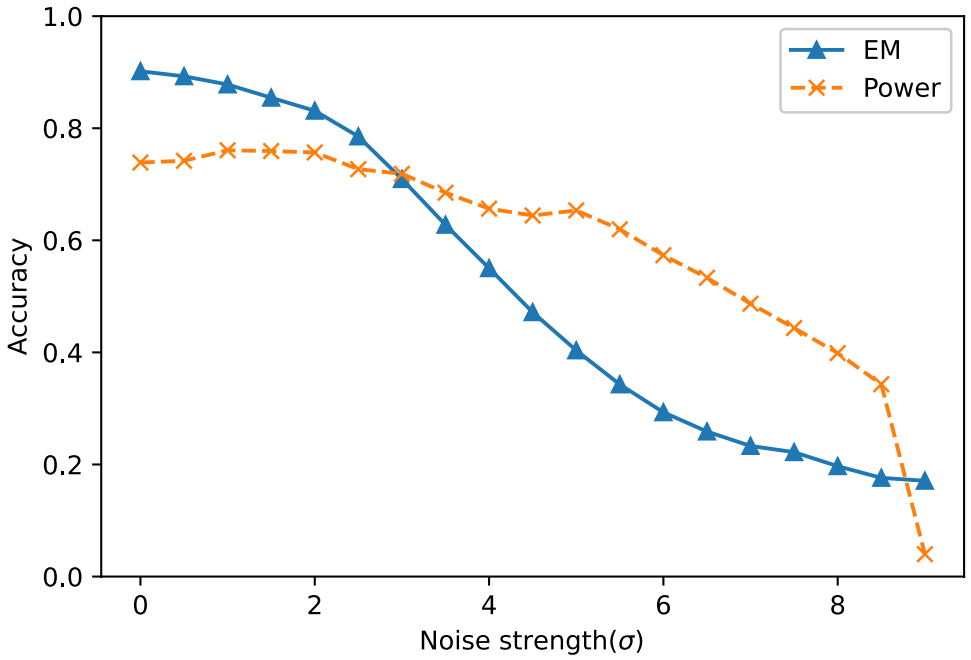
EM based model

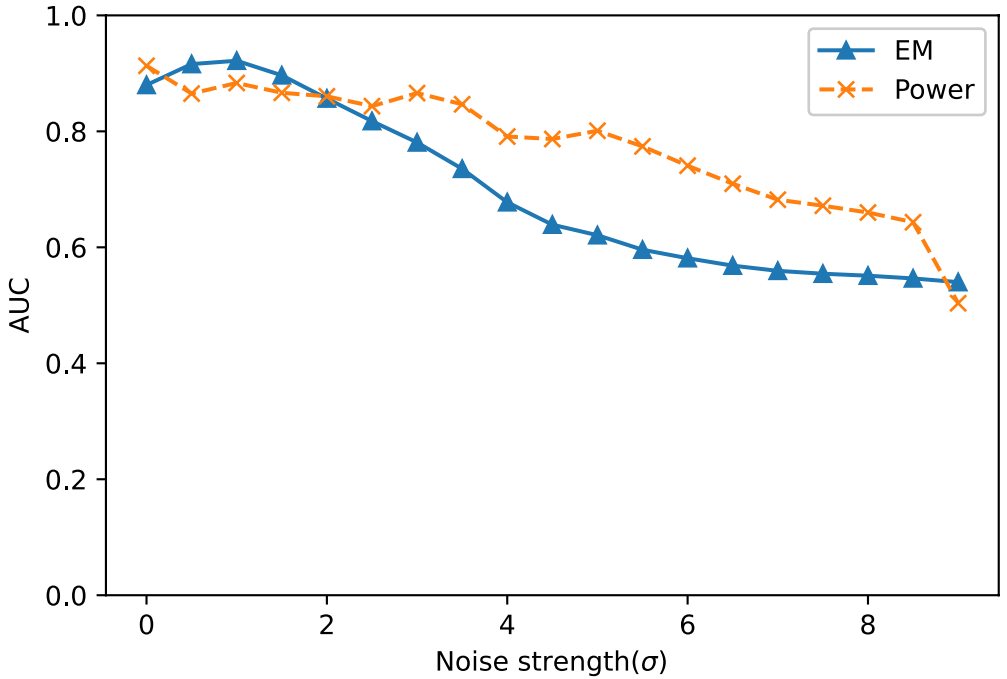


Power based model

Effect of noise

- Samples are collected in nearly optimal environment
- In reality, noise is present





Choosing the output layer

- Usually, SoftMax is used for classification
  - Returns a distribution function:
    - Each output value is [0,1]
    - Sum output vector is 1
    - Example: [0.4, 0.5, 0.1]

- An increase for 1 class is a decrease for another

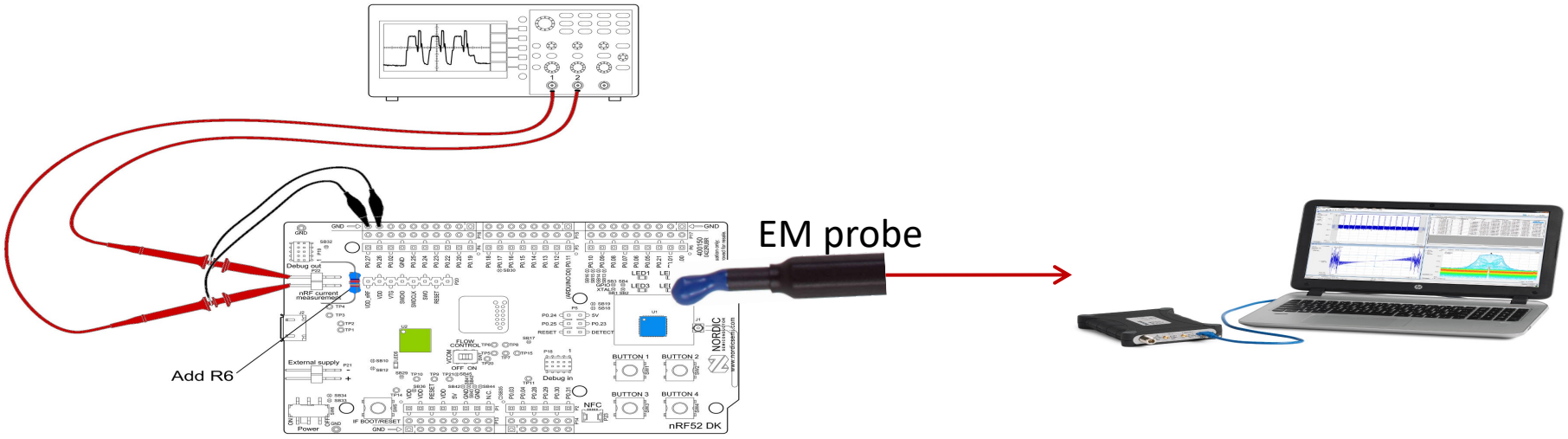
- In our use case, low confidence in all classes is desired: [0.1, 0.1, 0.1]

- → We use sigmoid as the final output layer
  - Mostly used for multilabel classification
  - Each output value is [0,1]
  - Sum output vector is not 1

Cartography

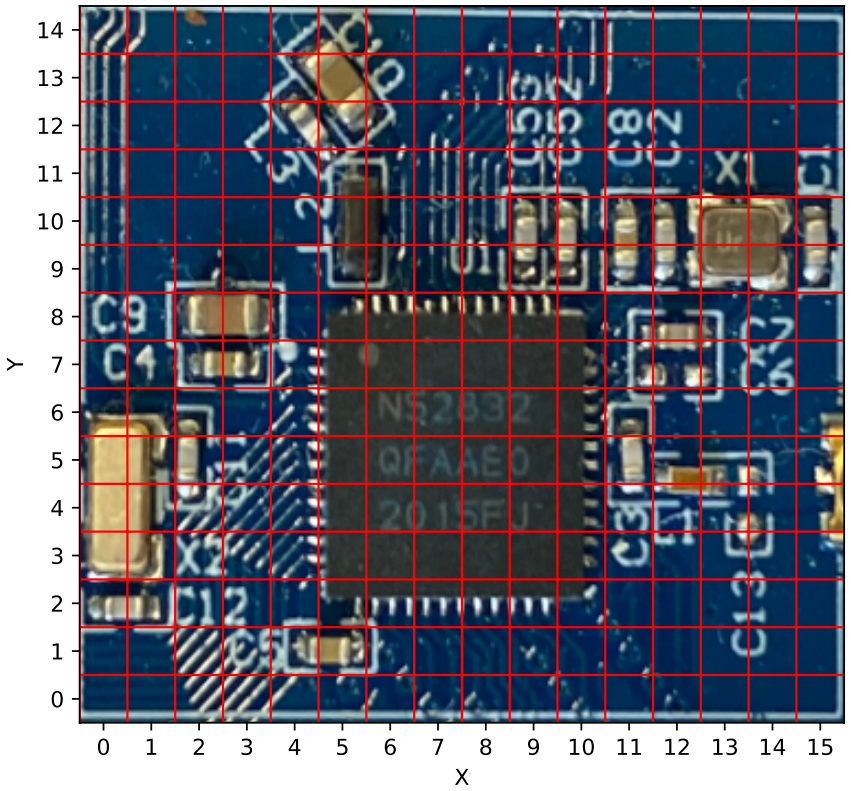
- Quality of the EM signal depends on several variables:
  - Capture frequency (range of frequencies)
  - Location of the EM probe

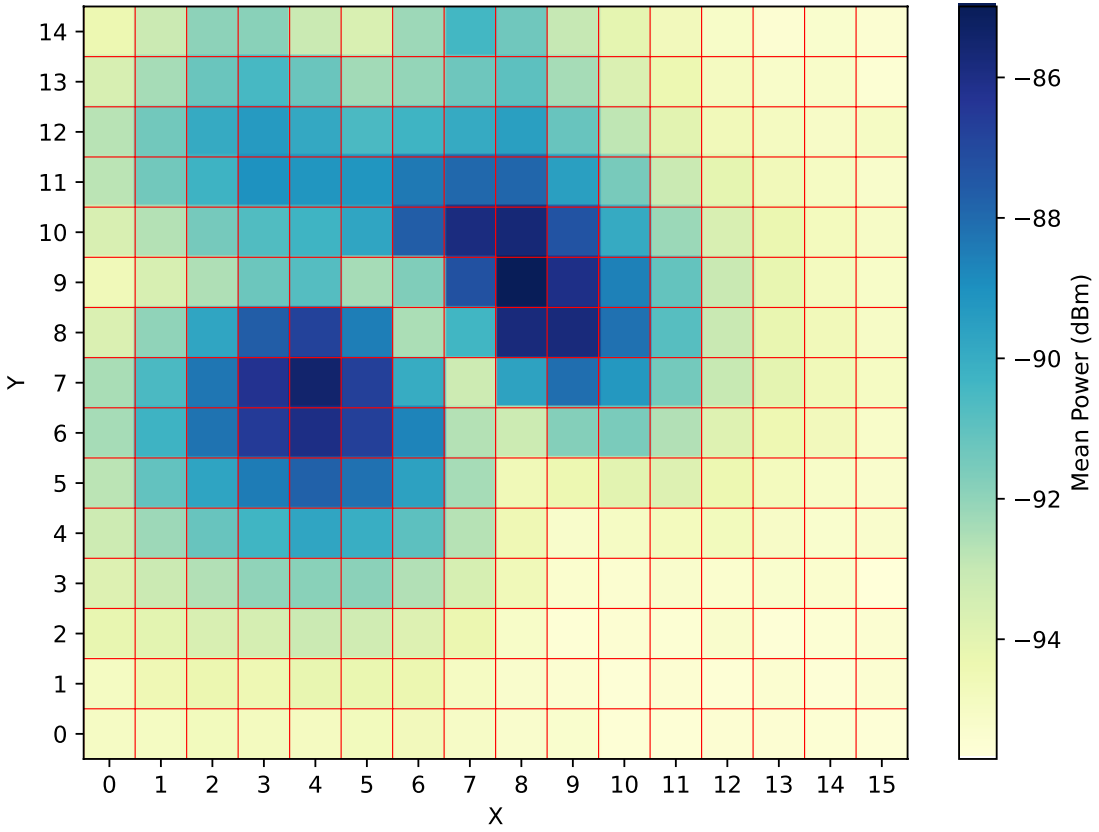
- We want to optimize those variables



Cartography – finding the sweet-spots

- For each point we calculate the power of the EM signal

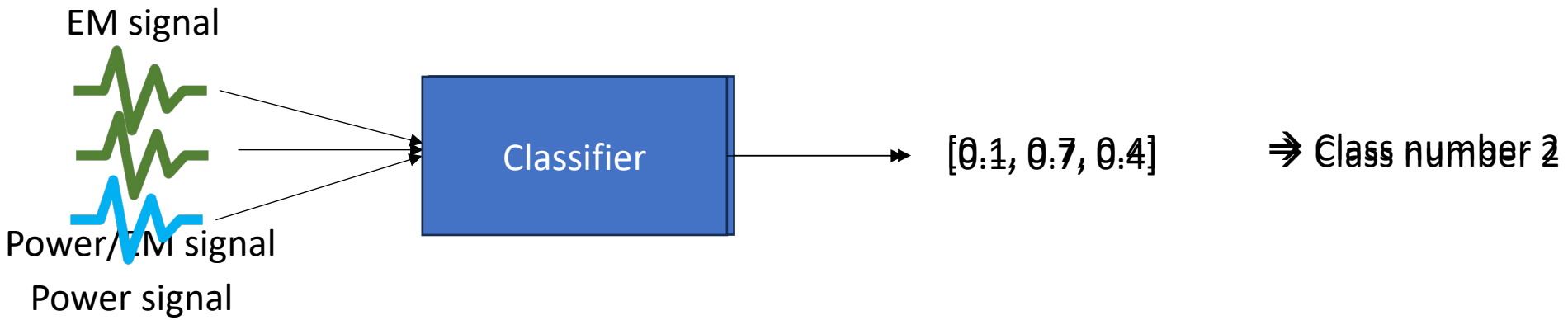




On Going

- We have 2 different models
  - EM based model
  - Power consumption-based model

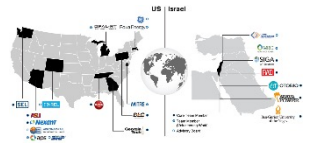
- Why not multimodal?



Commercialization

- Our process is implemented on an edge device

- Looking for an edge manufacturer to collaborate



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