



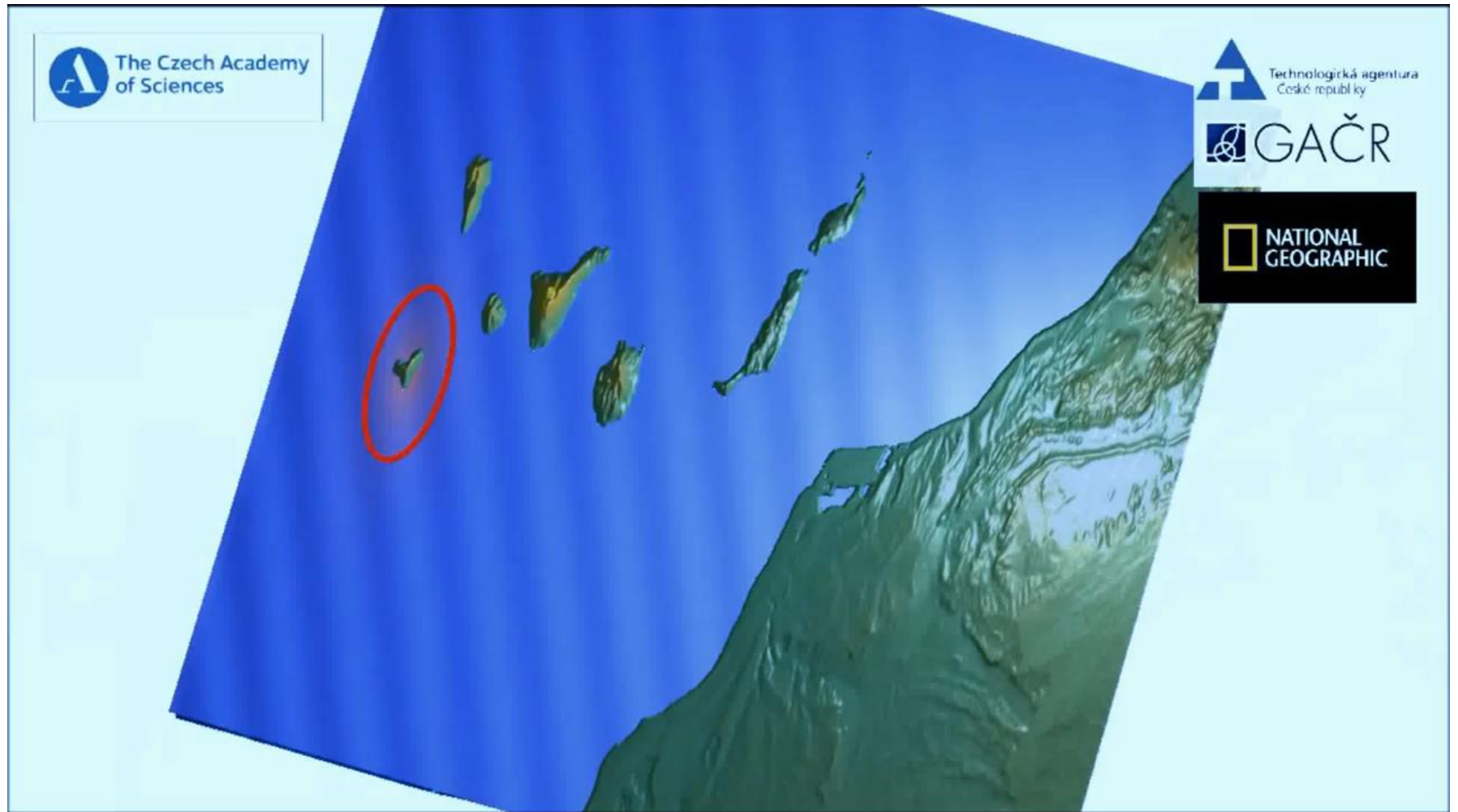
Applications for antiferromagnets

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One month ago, at SPICE channel...

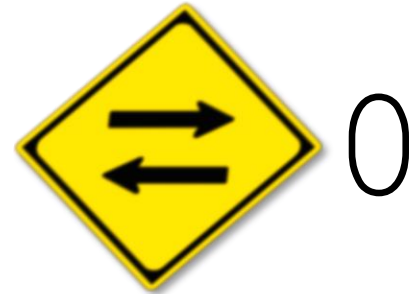
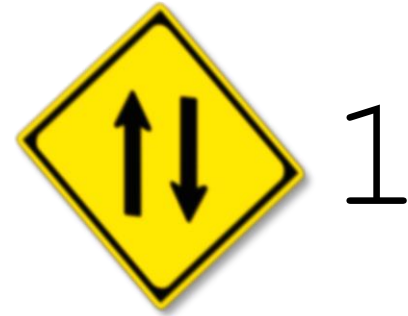


Today, spintronics from geo to nano



Very fast recent development



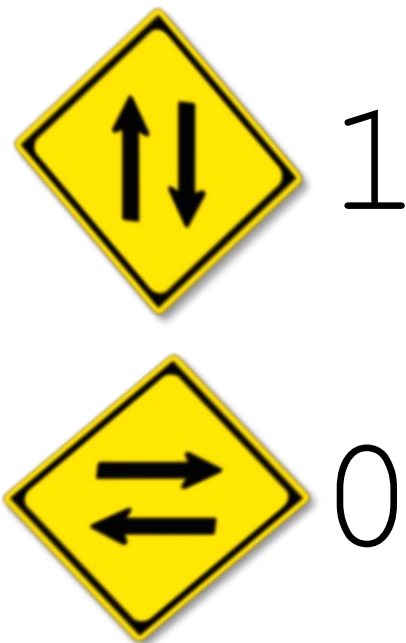
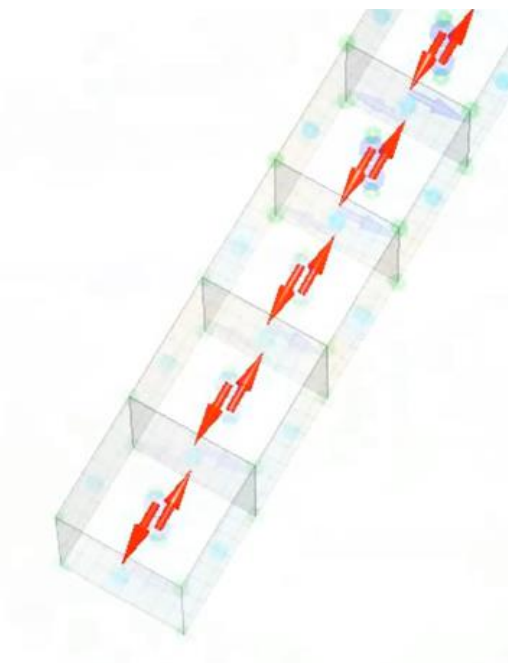


2014

Marti et al.

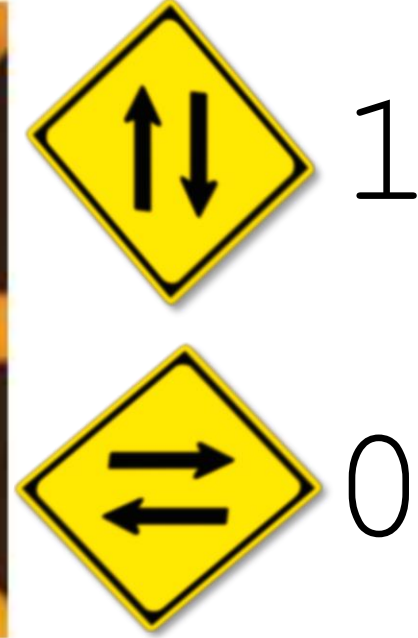
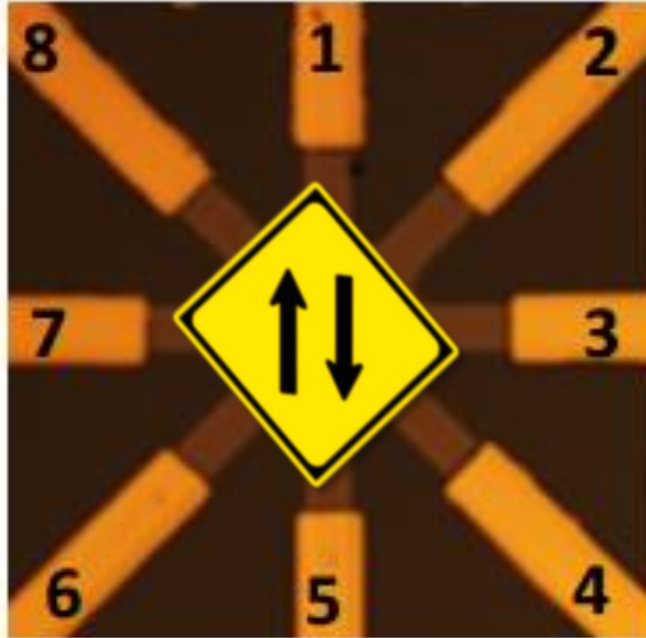
1971

Muir & Strom-Olsen



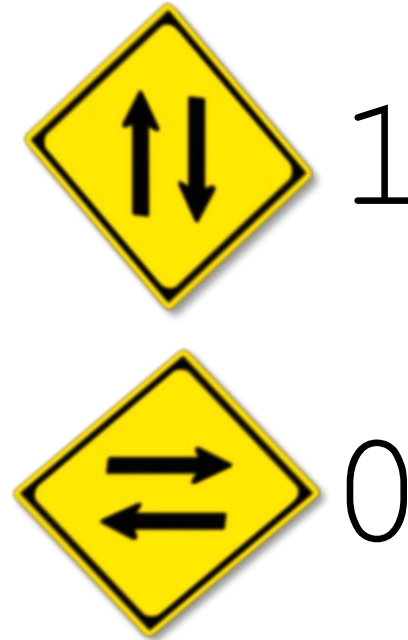
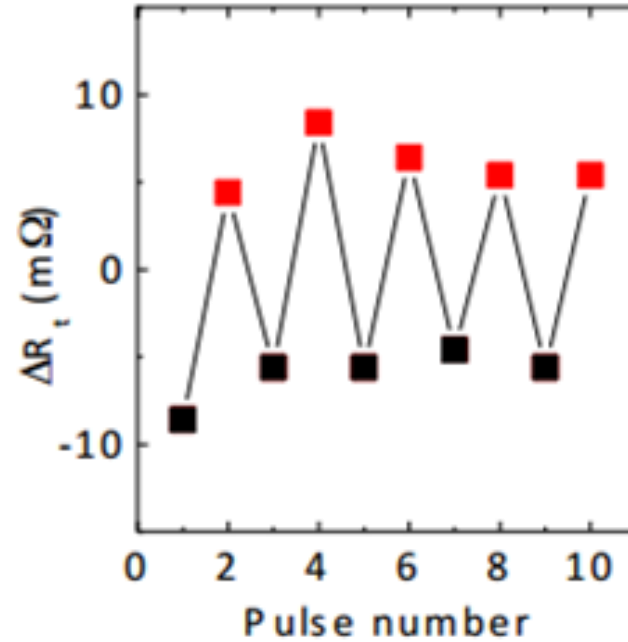
2014

Jakub Železný et al.



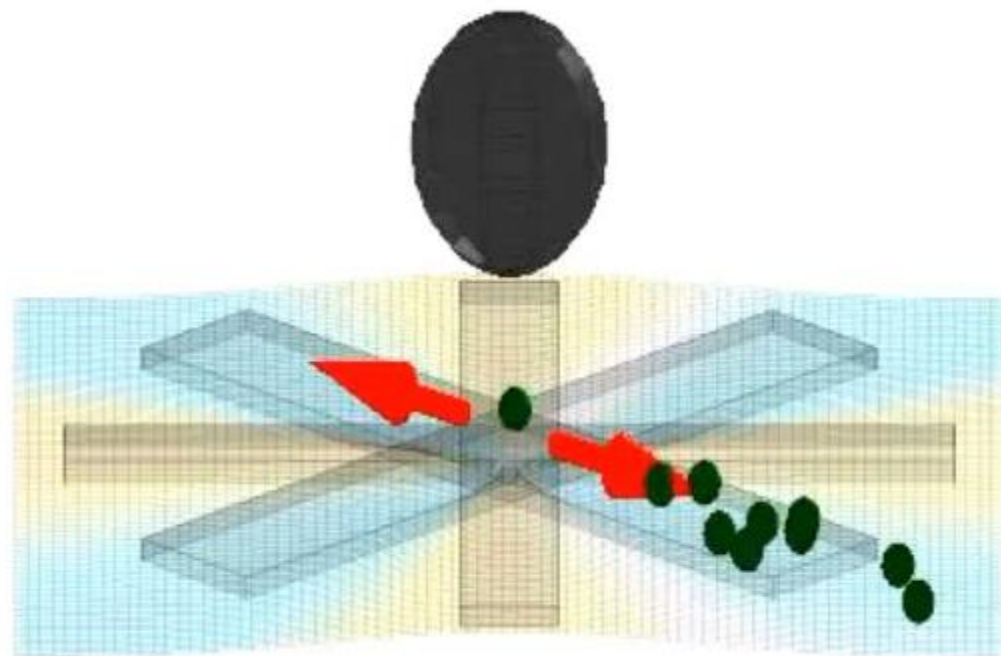
2016

Peter Wadley et al.

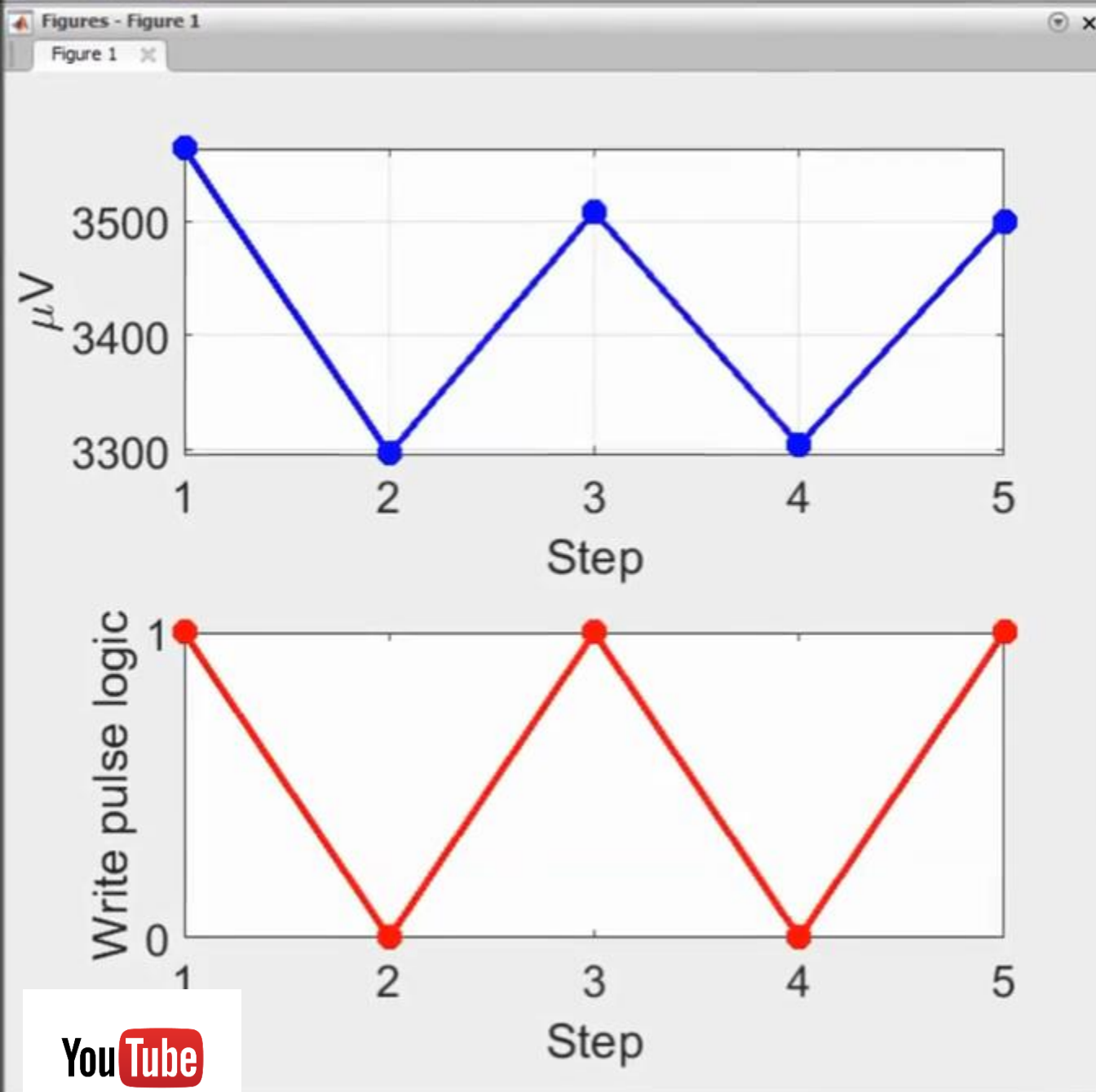


2016

Peter Wadley et al.



2016
USB device



```
afmem.m  x  reading.m  x  +
31      fwrite(comm,51); pause(0.5); % warming up comms
32      disp('Buffer bytes:'); disp(comm.BytesAvailable);
33      fread(comm,comm.BytesAvailable);
34      disp('Ready. '); pause(0.5);
35
36      % Warm up pulses
37      fwrite(comm,50); % "0"
38      disp('Initializing...');
39      pause(5)
40
41      % The long loop is here...
42      counts = 0;
43      beats = 0;
44      for n = 1:5; % number of switches
45
46          % Writing #0
47          pause(1);
48          state = 1;
49          fwrite(comm,49); % "0"
50          for k = 1:10
51              pause(0.5);
52              counts = counts + 1;
53              % if k == 2
54              reading; % reading
55              % end
56          end
57      end
```

Command Window

3492

3484

3477



2016

USB-powered portable AFM lab



Why a portable device is important

Without



With



With



With

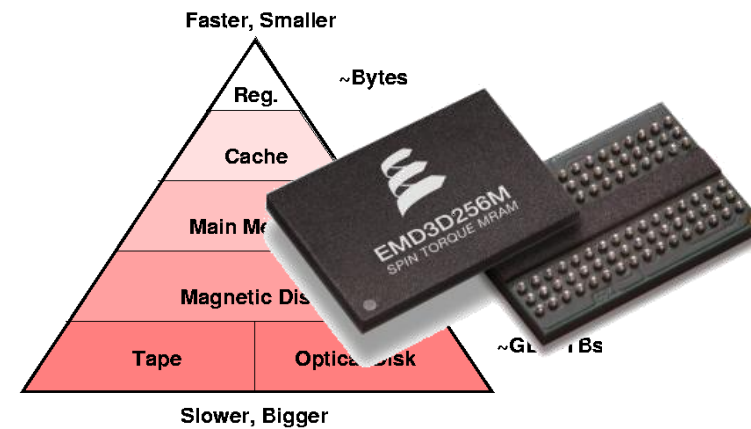


You detect improvements when you **use** things

Costs

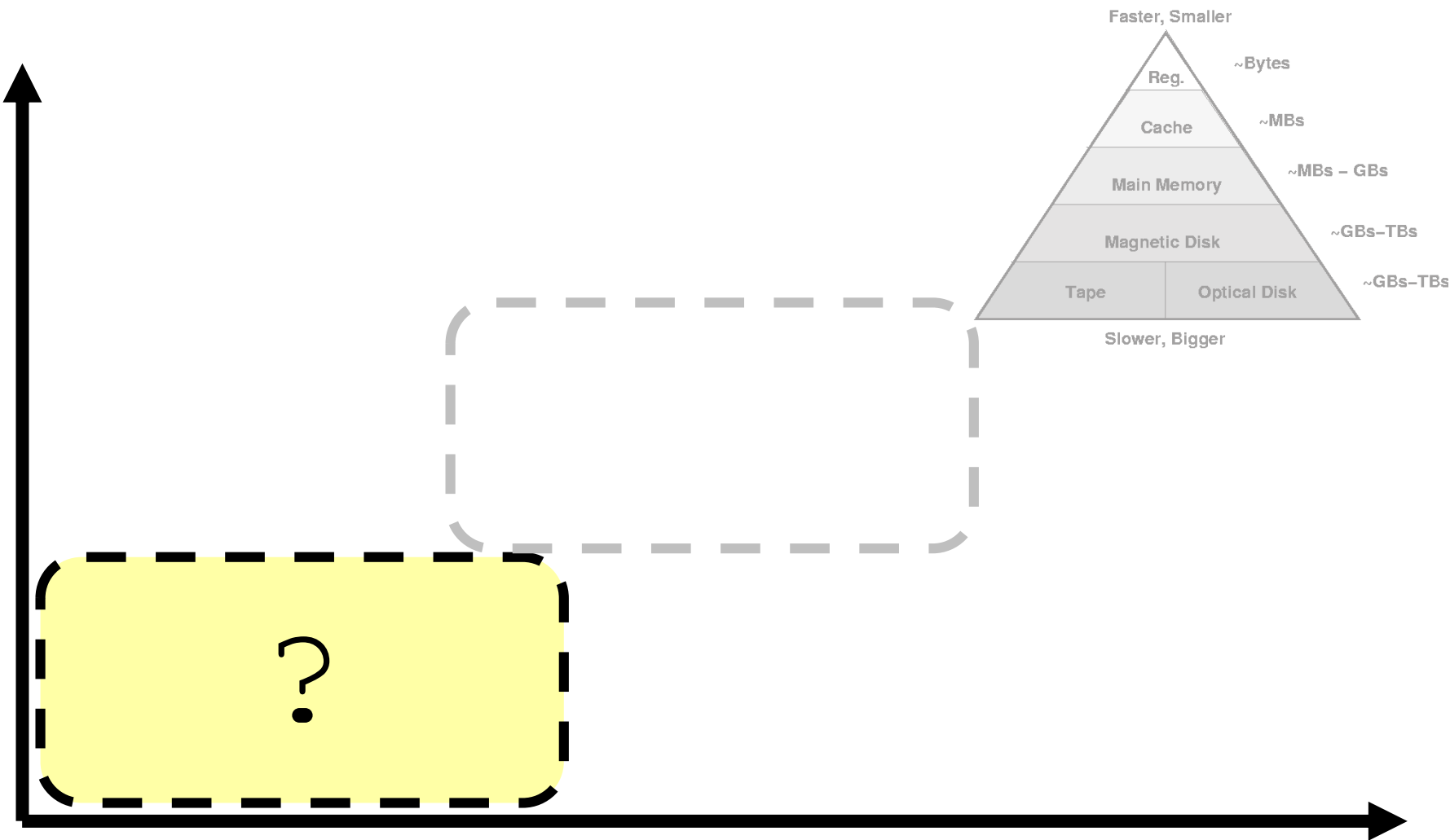
Budget, 1m 2y

Time



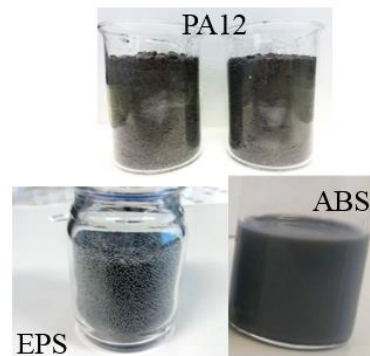
Costs

Time



External example: graphene flagship

Esempi



Products



Chairman of the Executive Board is Vittorio Pellegrini, IIT, Italy. Co-owner of Bedimensional.

LA STAMPA ECONOMIA

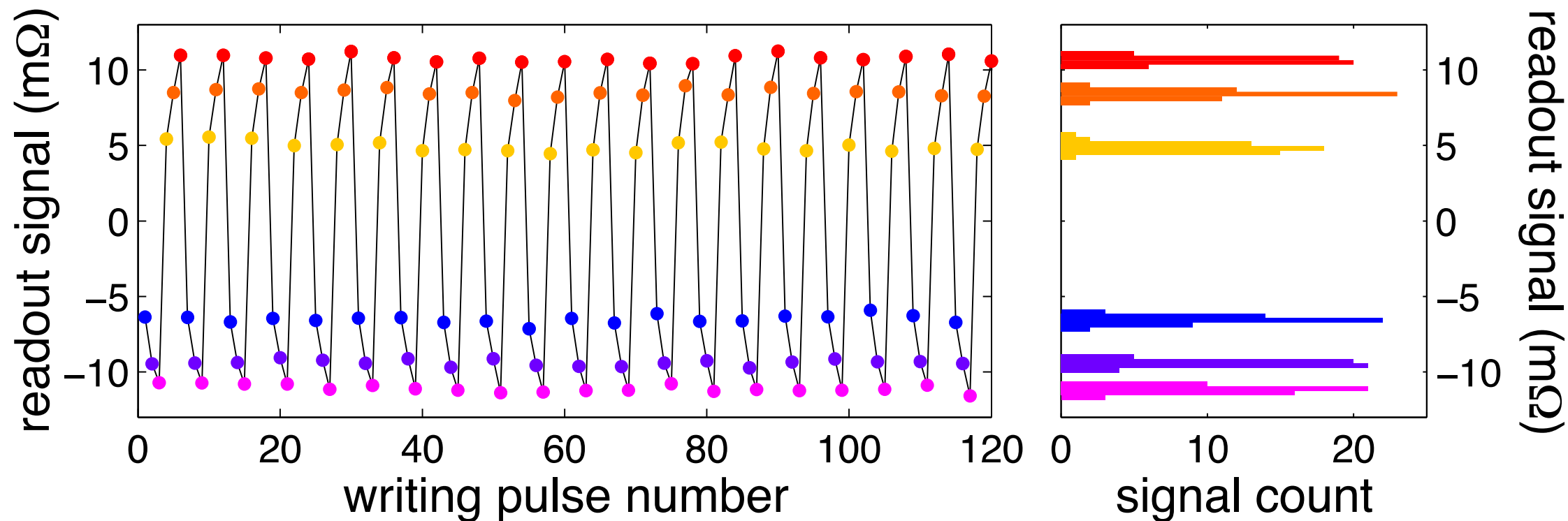
Il made in Italy scopre il grafene

L'Istituto italiano di tecnologia e la Fadel producono calzature hi-tech



You detect improvements when you use things

Remarkable features of antiferromagnetic spintronics

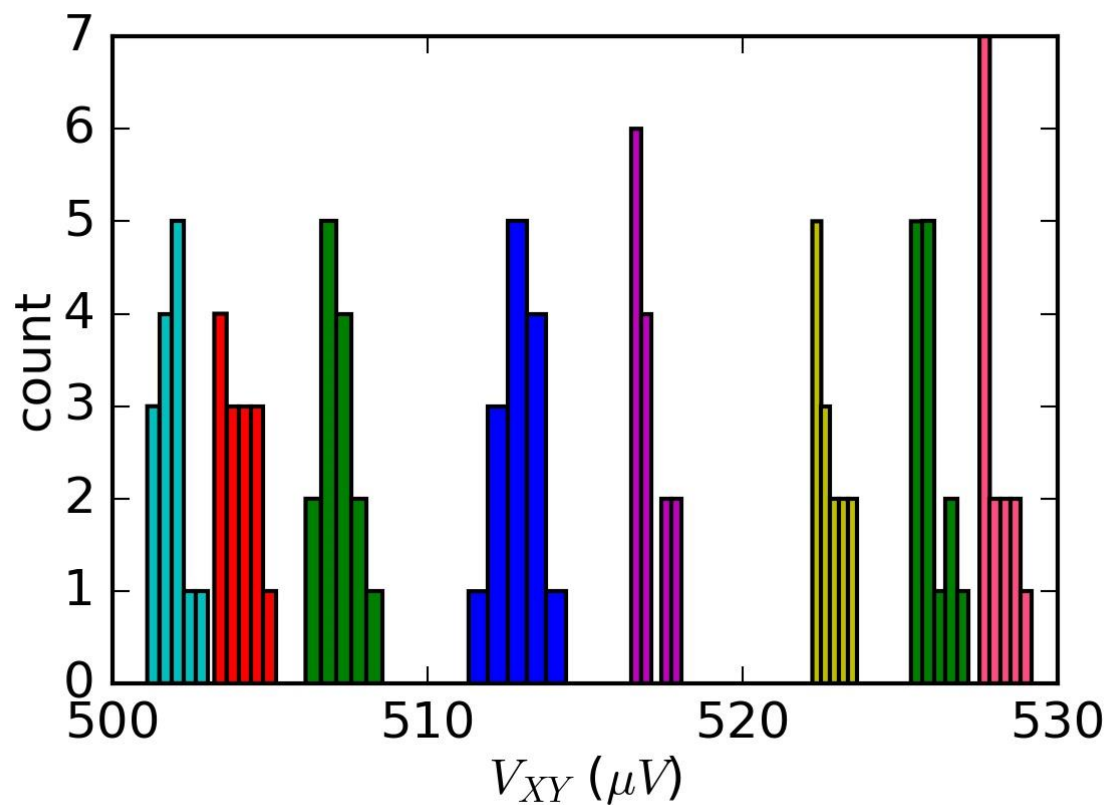


Current density was fixed at $2.7 \times 10^7 \text{ Acm}^{-2}$

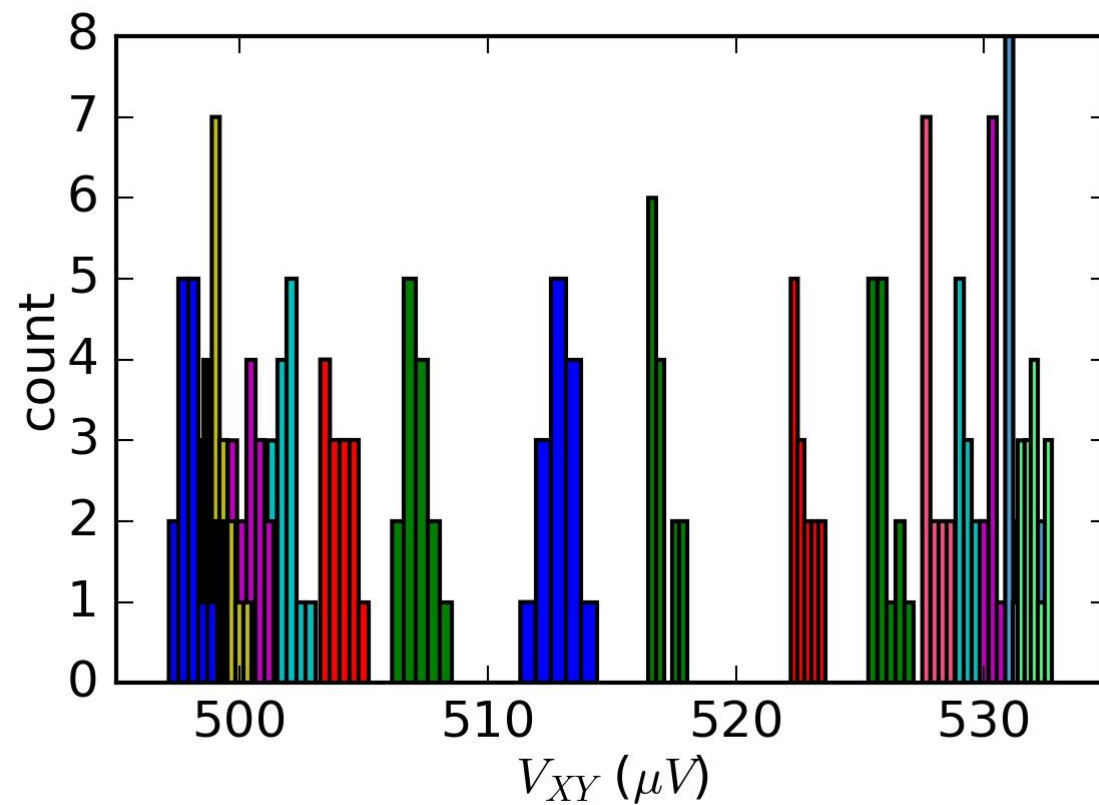
Pulse length: $200 \mu\text{s} - 1 \text{ ms}$

Multiple stable intermediate states

March 2016

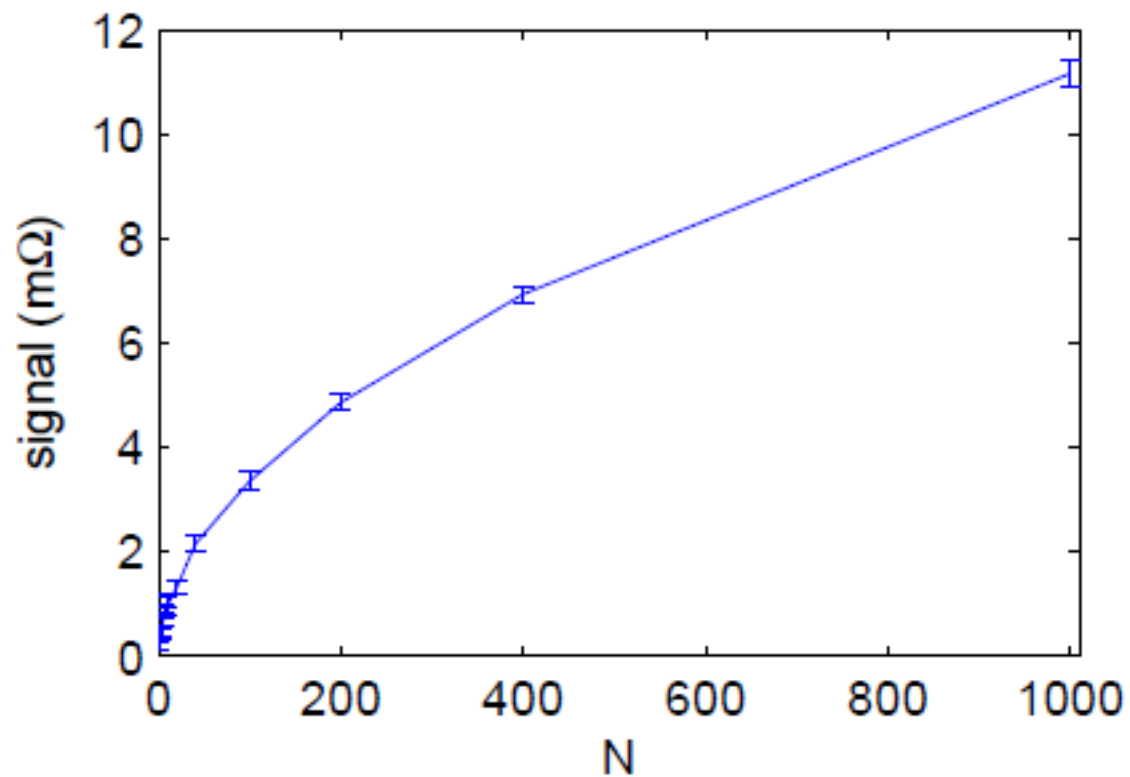


8 intermediate states



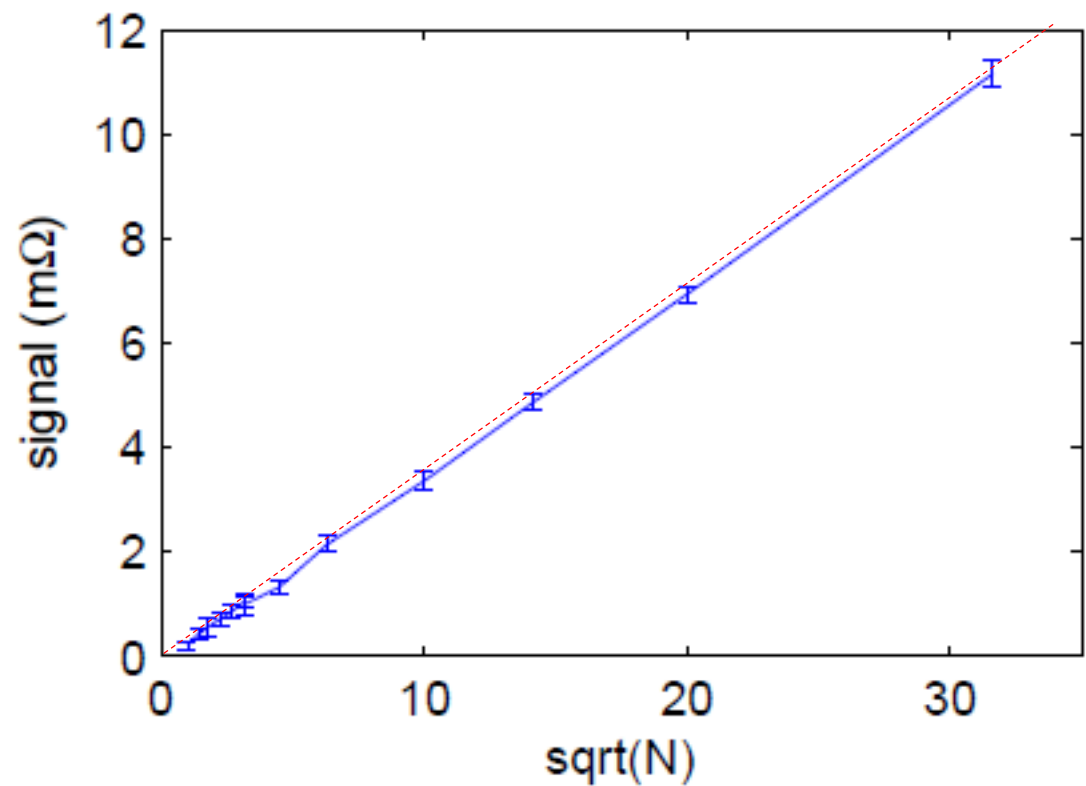
16 intermediate states

June 2016



1000+ intermediate states

Quickest pulse 250 ps



Easy to linearize output

September 2016

2

January 2016

6

March 2016

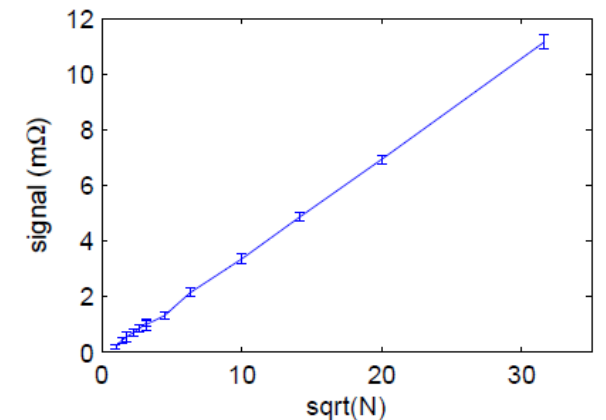
16

June 2016

1024

September 2016

250 ps pulses
Count over 2^{10}
Easy to linearize output

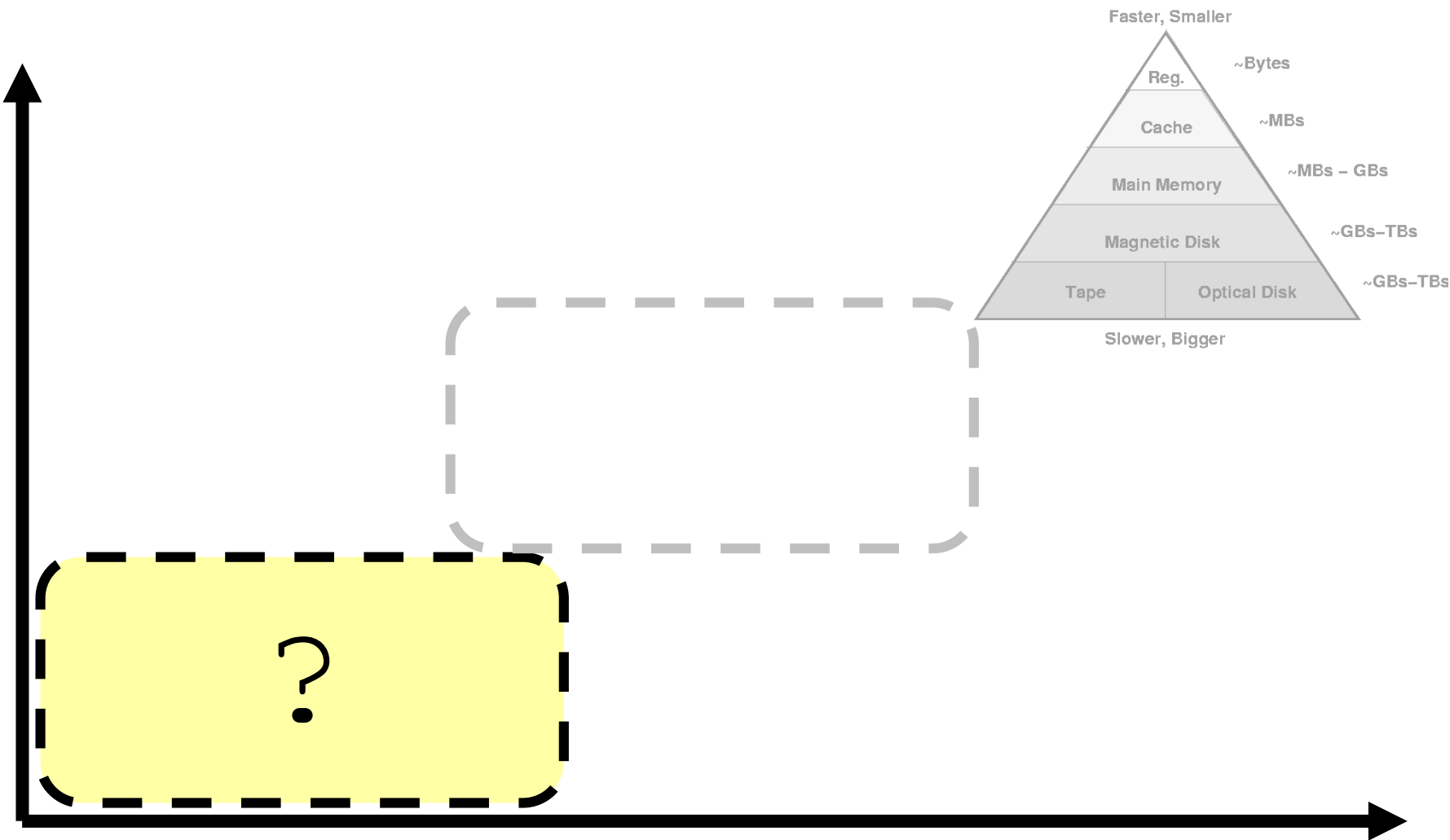


Vivien
Schuller
here

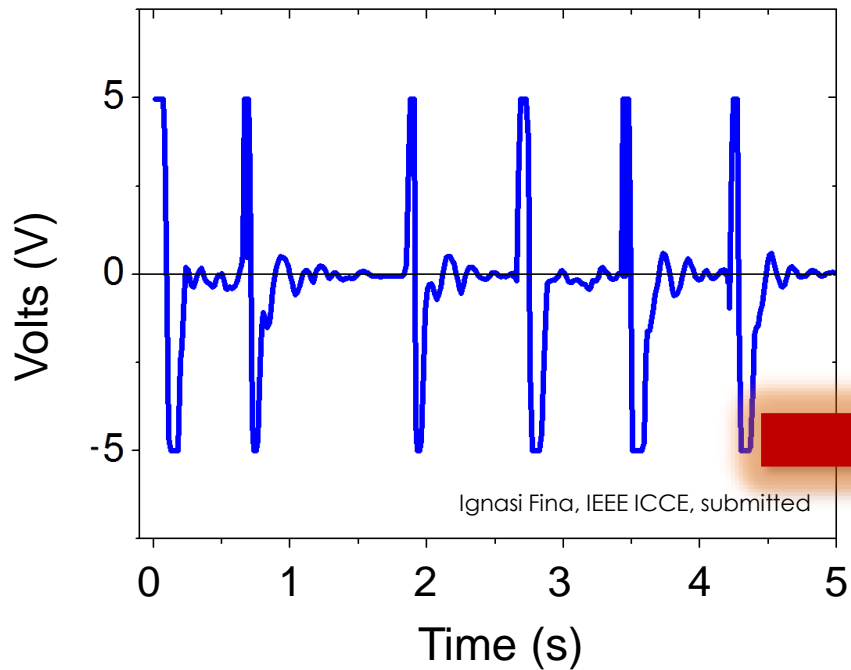
So what?

Costs

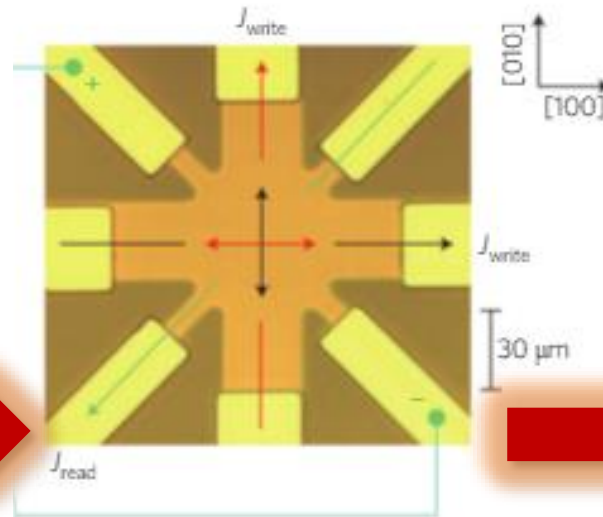
Time



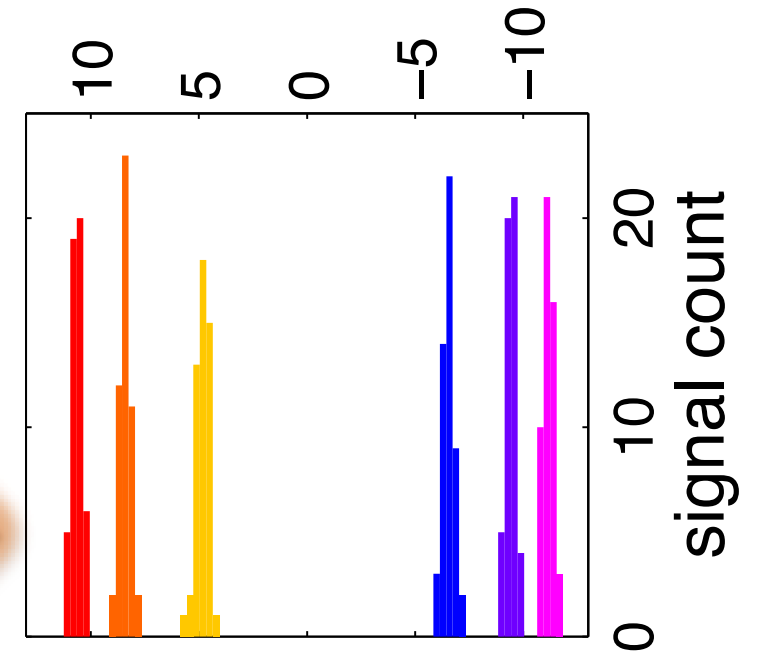
Pulse generator



AFMEM device

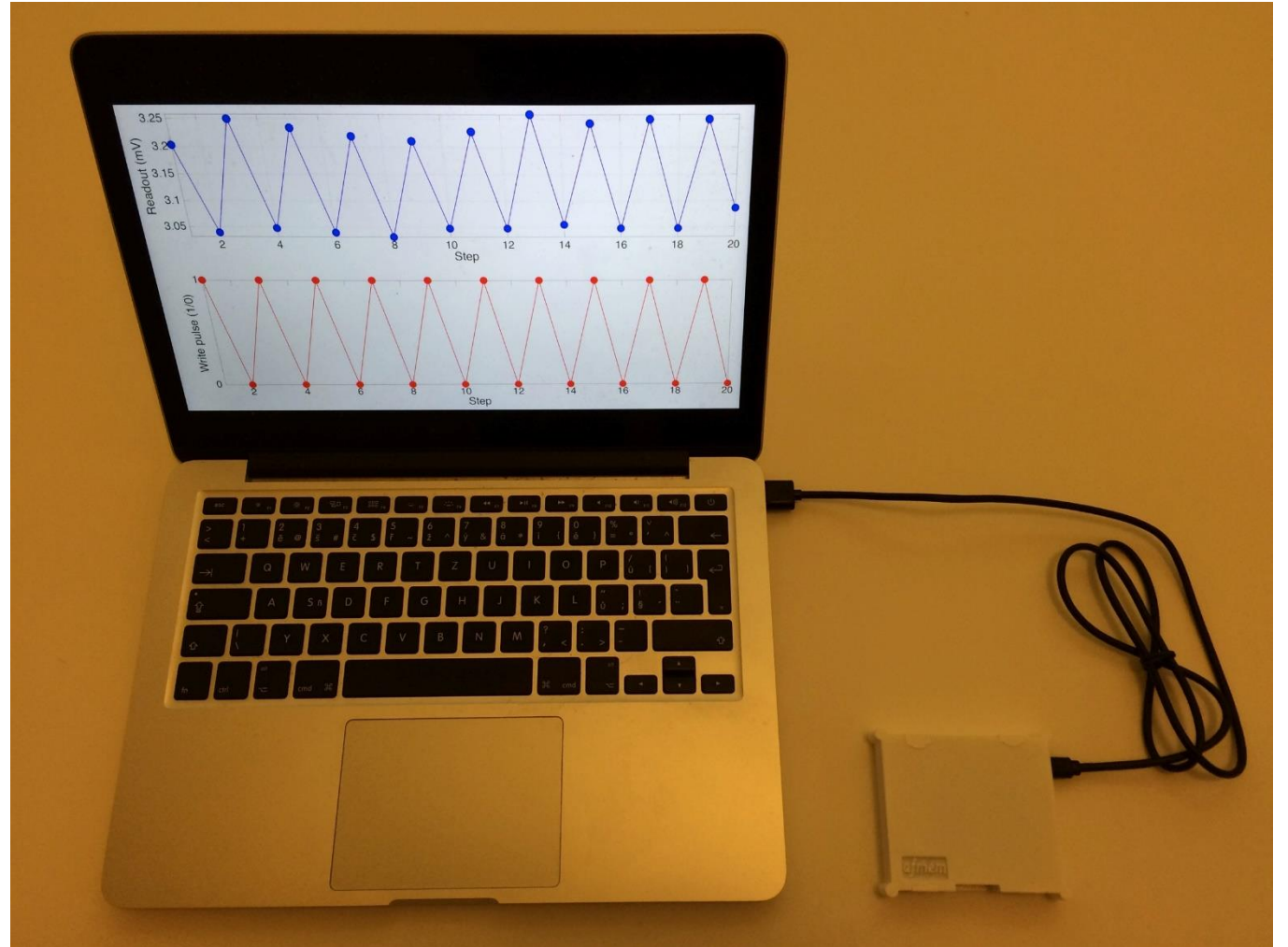


Number of pulses,
readout signal ($\text{m}\Omega$)

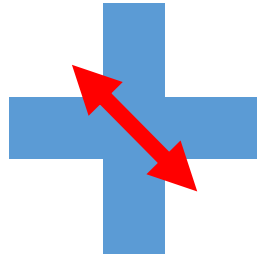


One AFM cell is an incremental counter

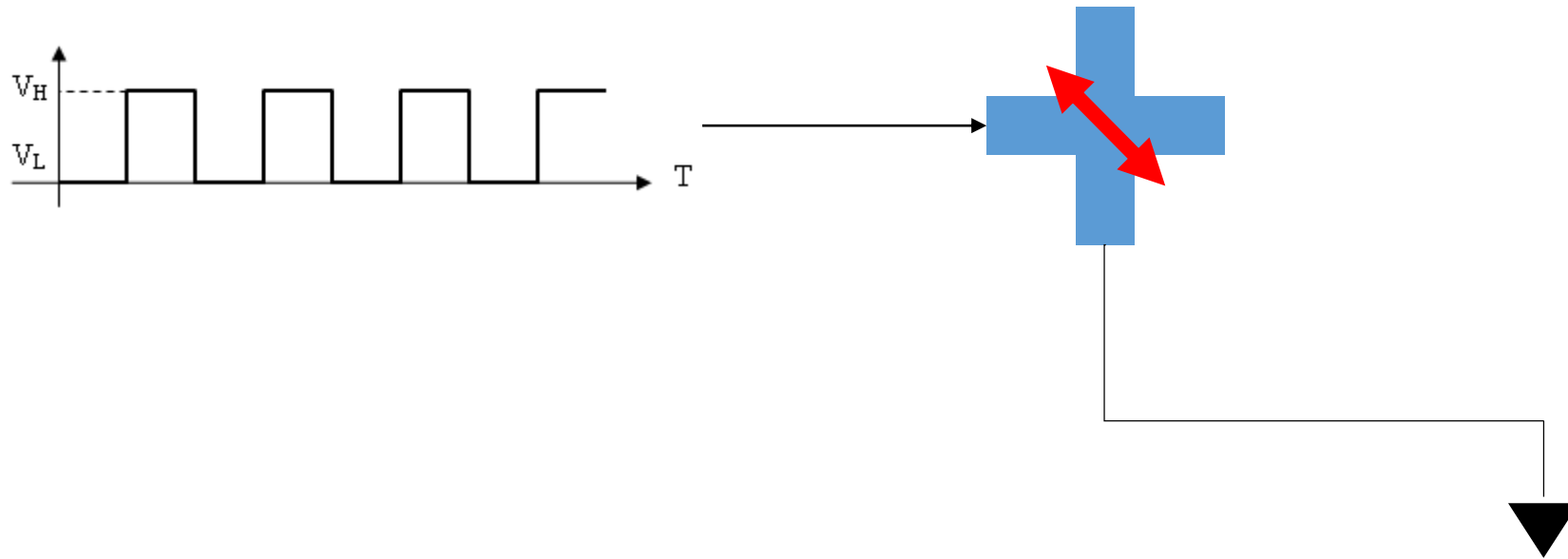
Packaging



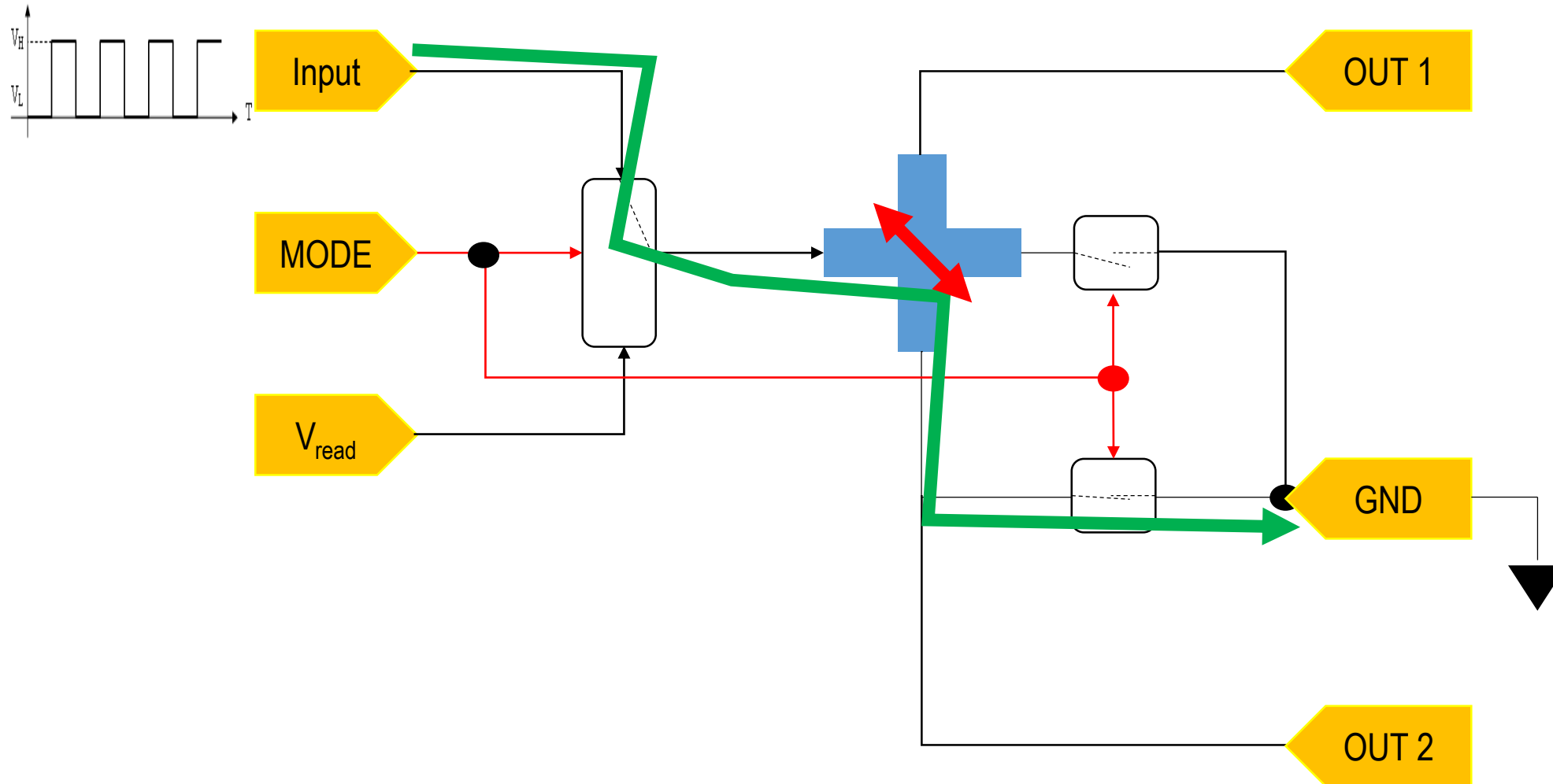
CuMnAs cross



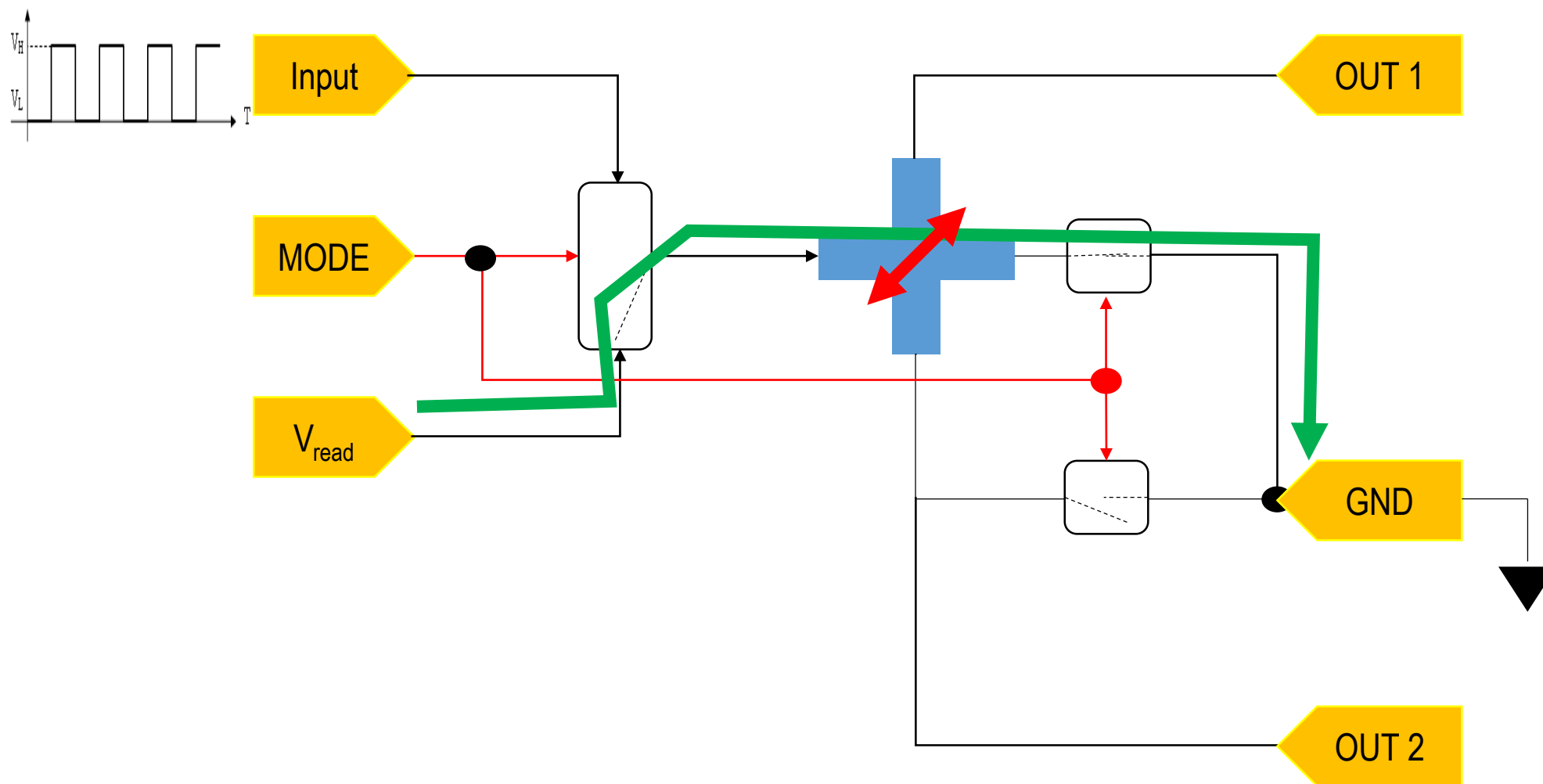
Principle of operation



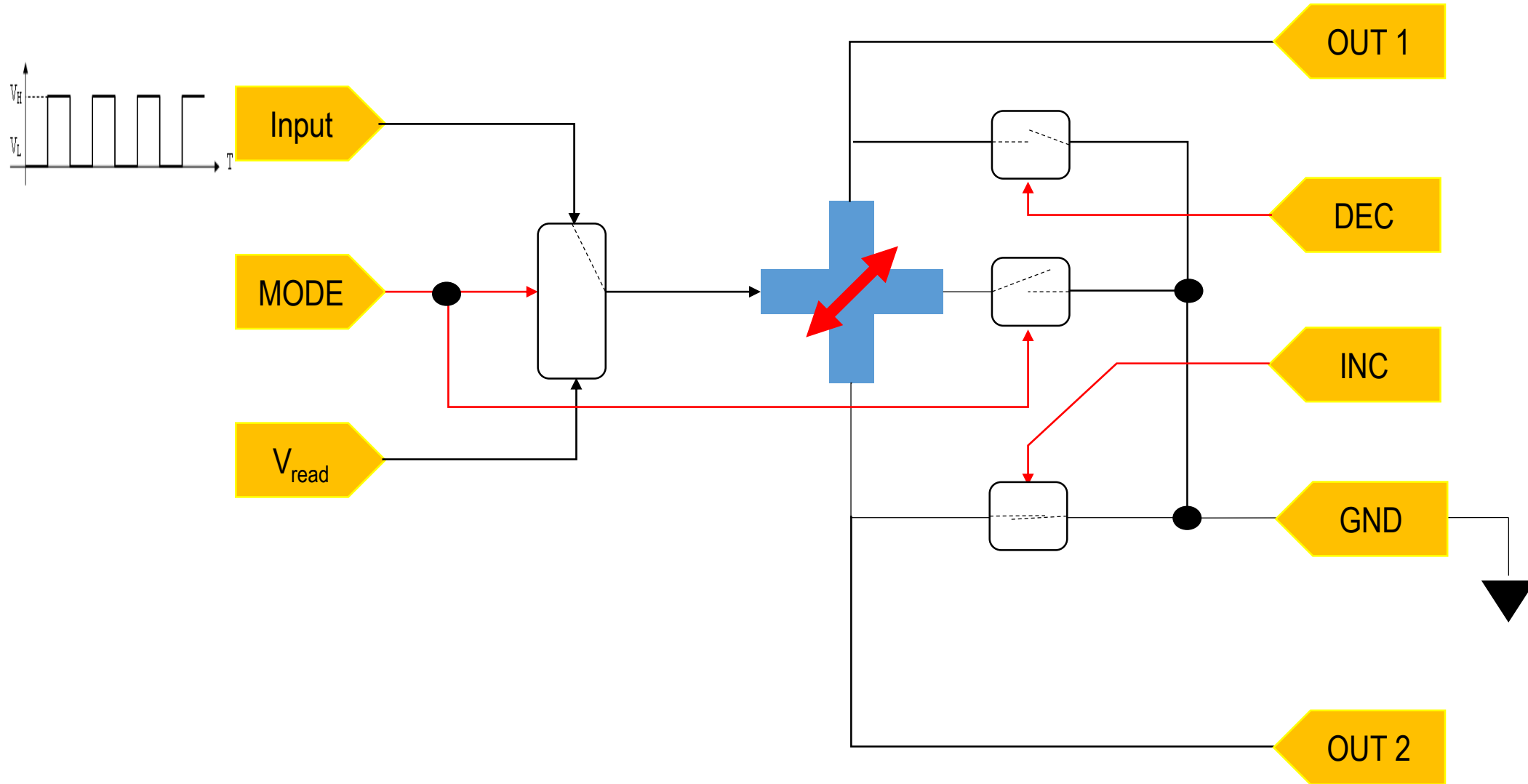
Counting mode



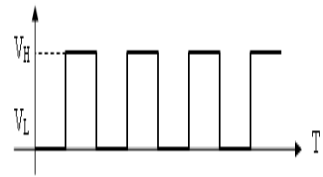
Reading mode



Increment/Decrement mode



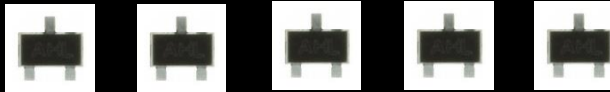
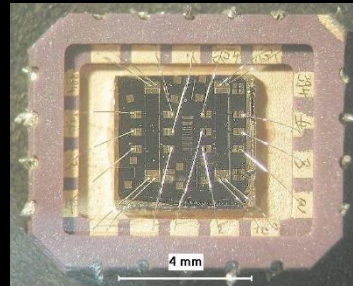
Hybrid encapsulation



Input

MODE

V_{read}



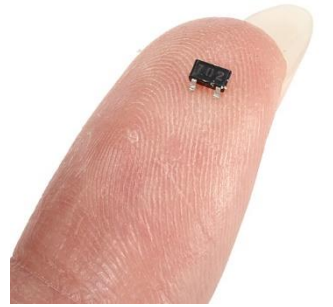
OUT 1

DEC

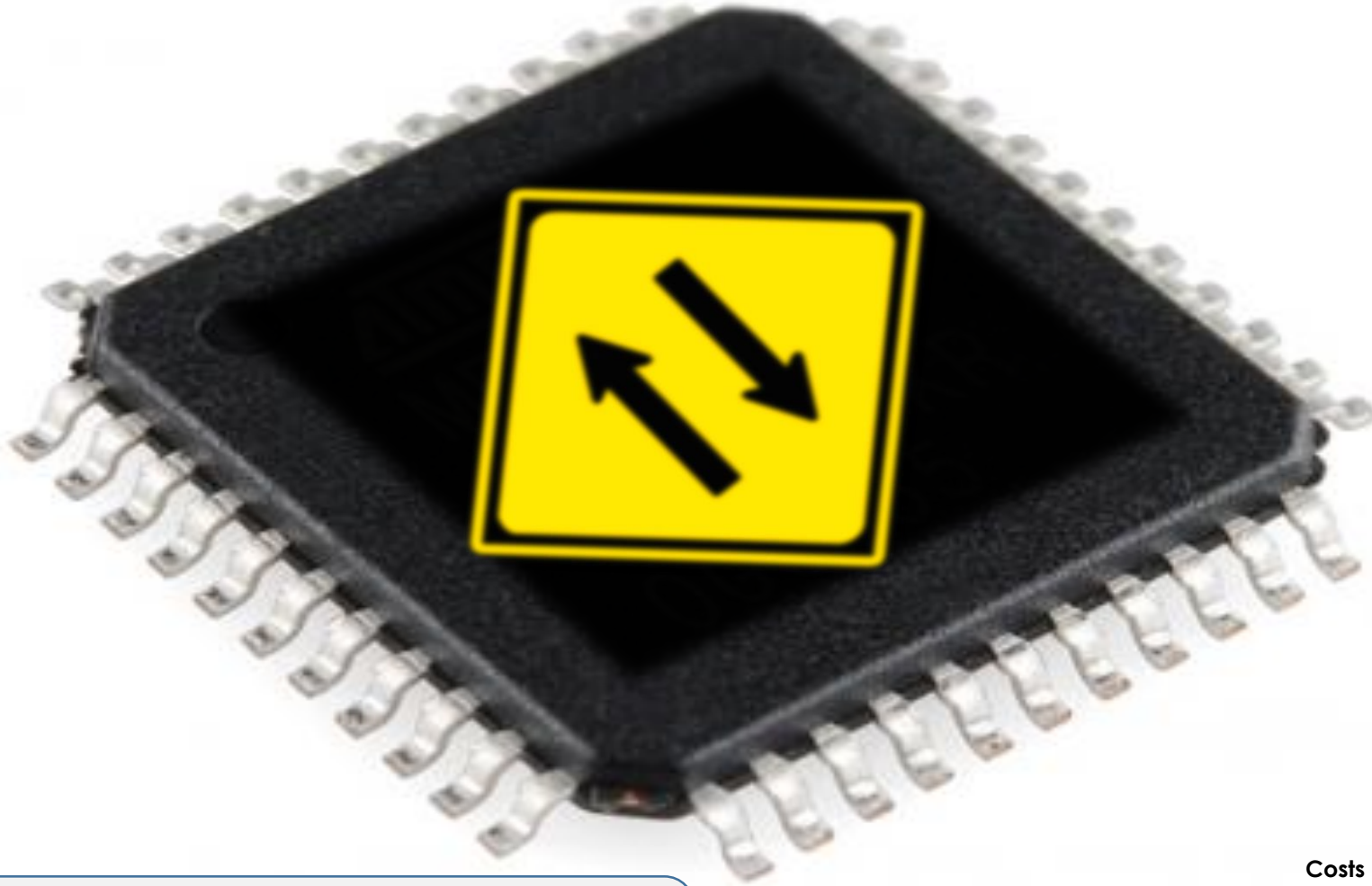
INC

GND

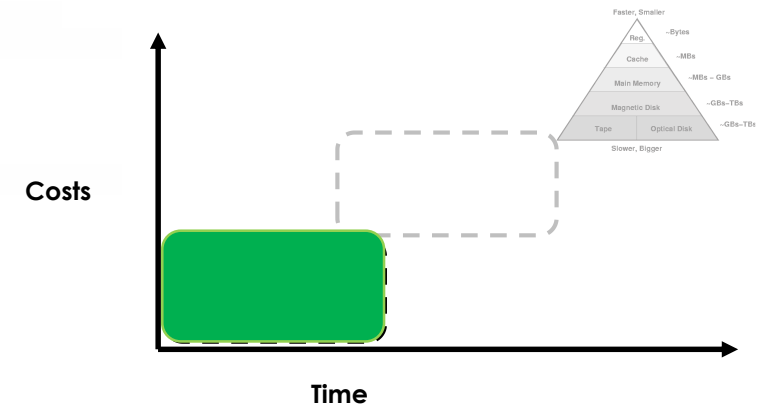
OUT 2

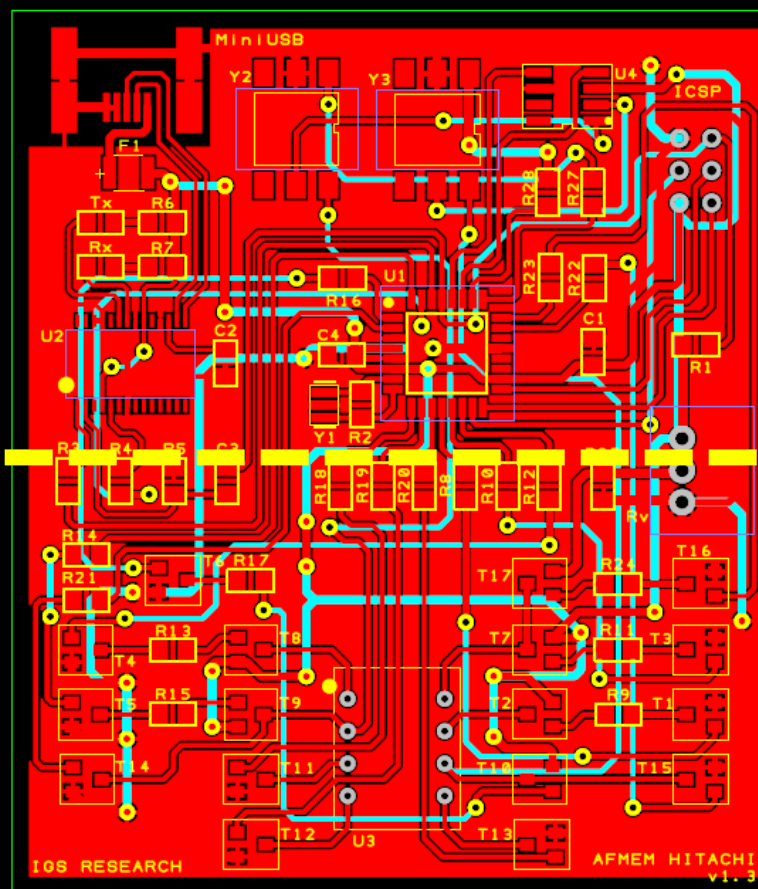
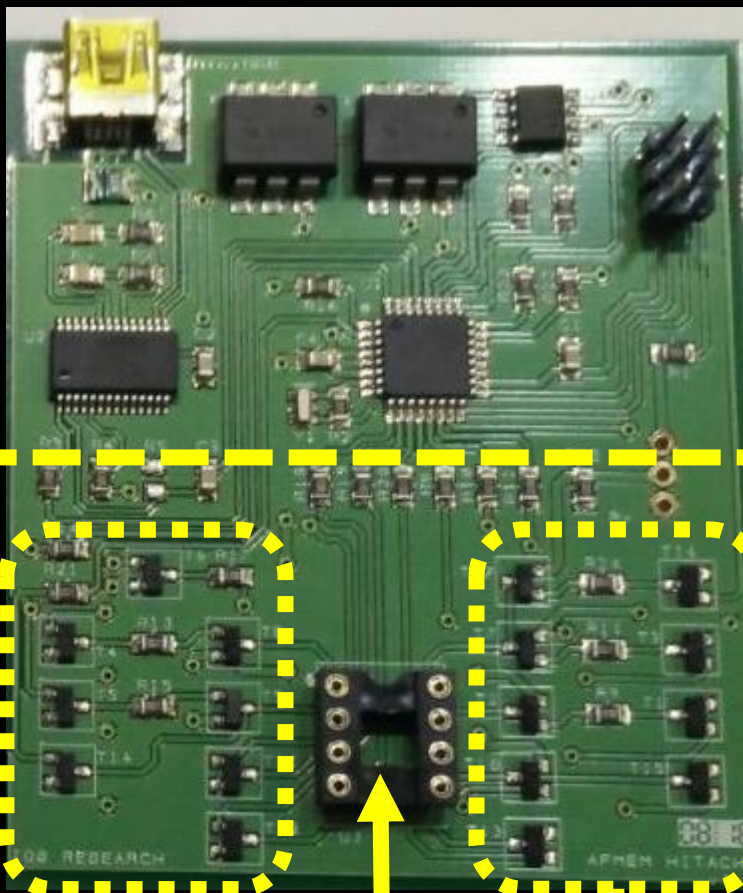


A stand-alone component that receives inputs
and reports an electrical voltage



If you wish, you could add **linearization**,
amplification, counter filing **flags**, ...

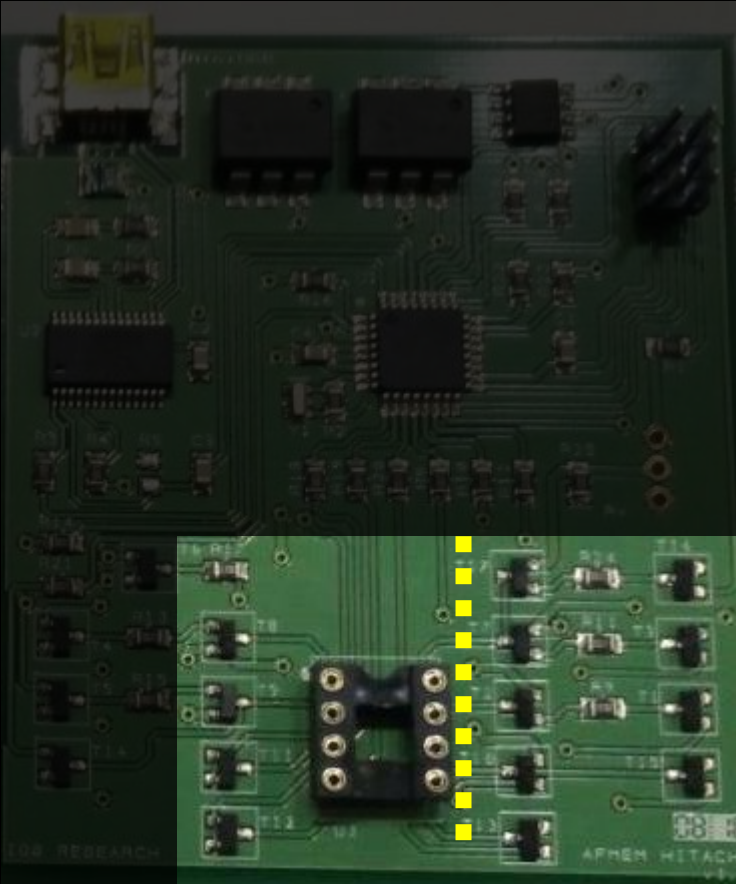




USB Comms
Voltmeter
Programming

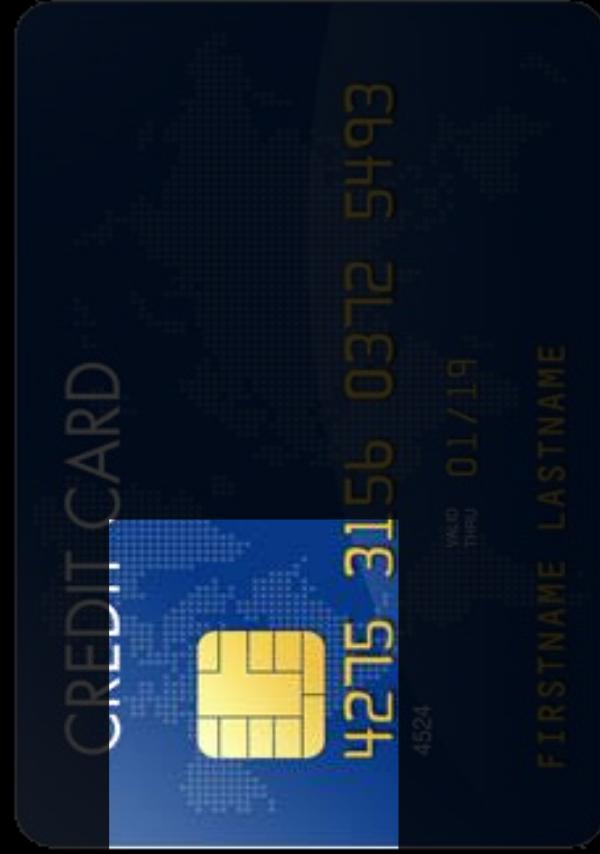
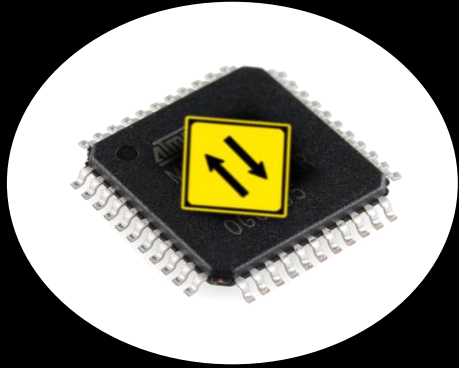
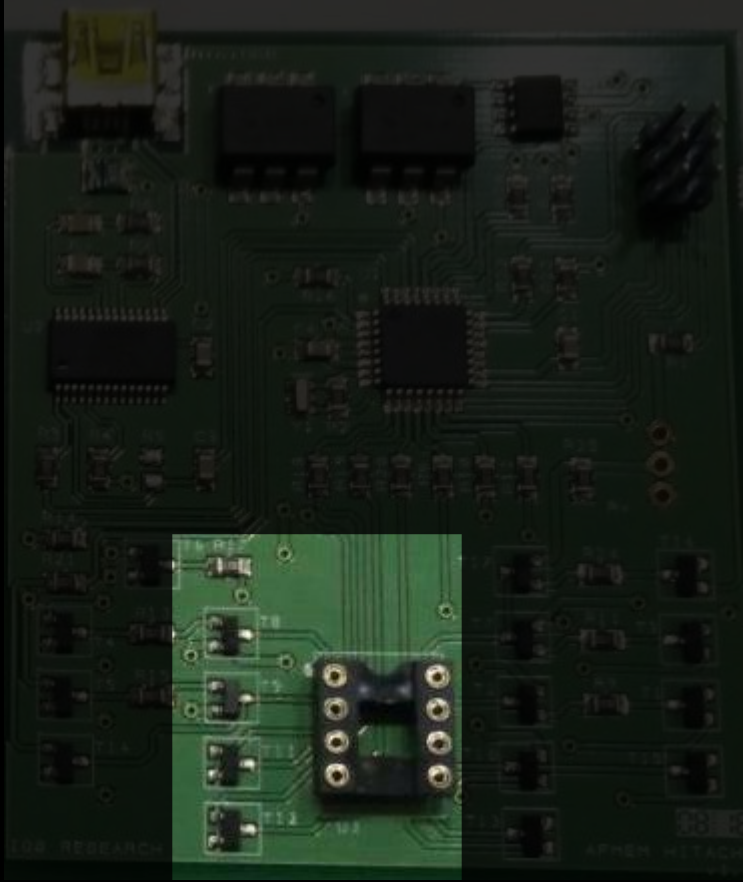
We had 13 transistors,
we need 10 for 2 AFMEM counters

8 pin chip carrier: could contain 2 AFMEM counters



We placed components only on one side

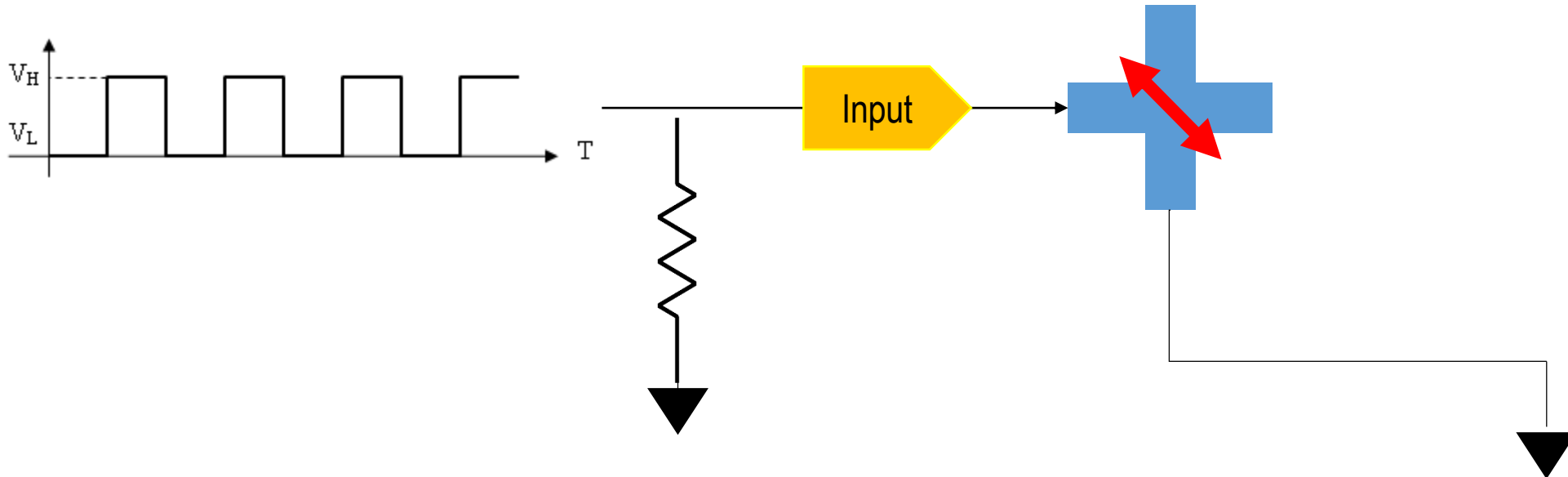
We used 2 layer routing



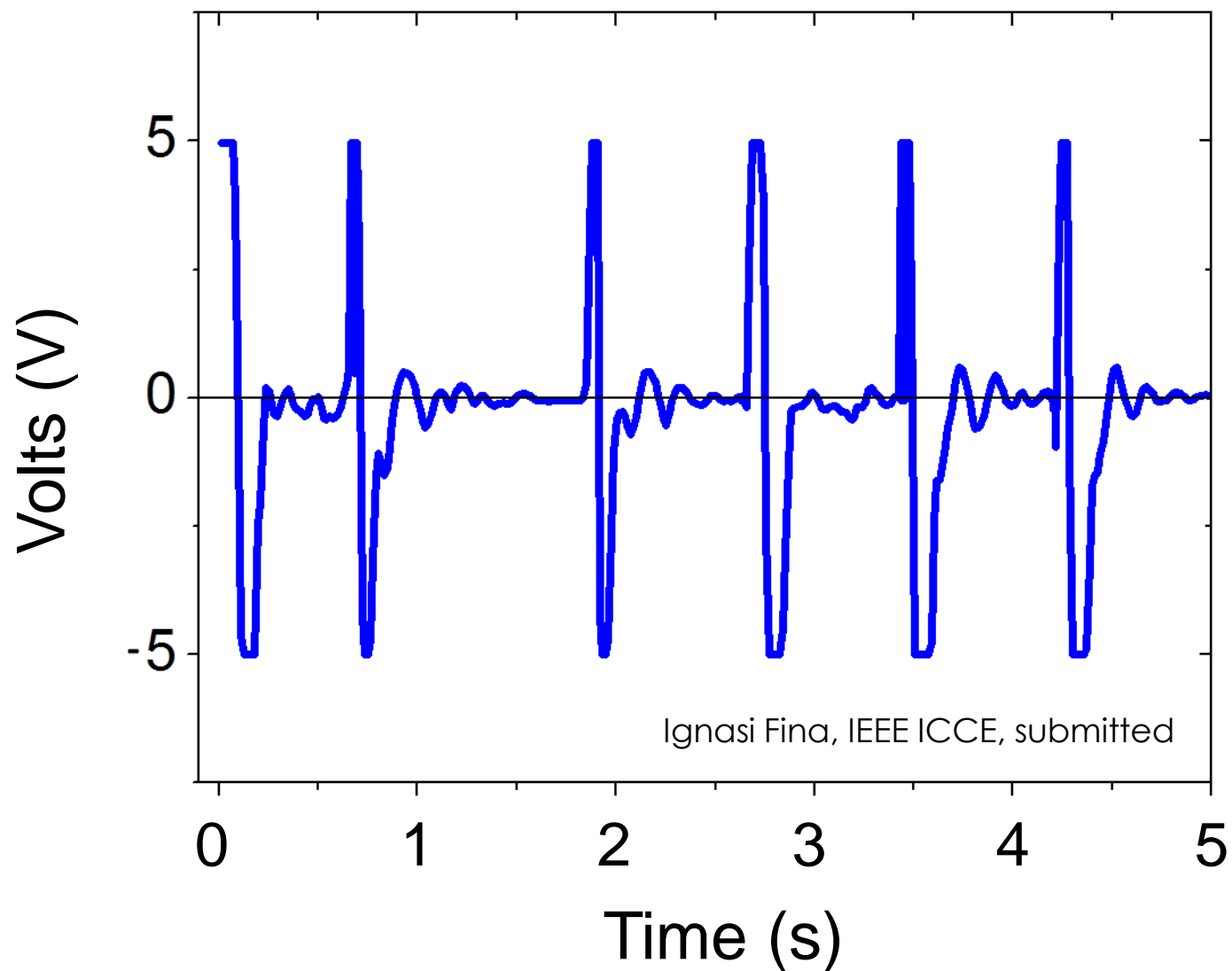
Subtle features

Non-volatile spin-based retention

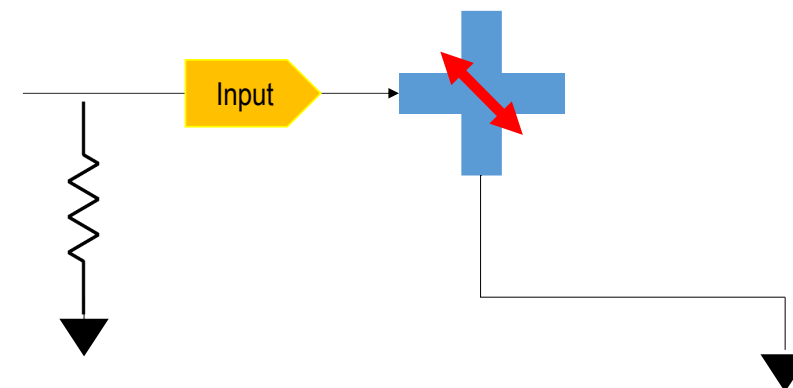
Small currents or a direct path to ground won't discharge



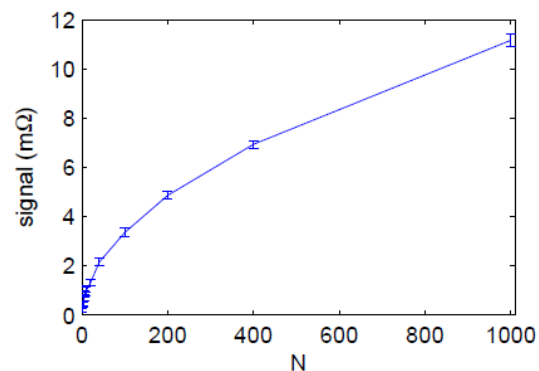
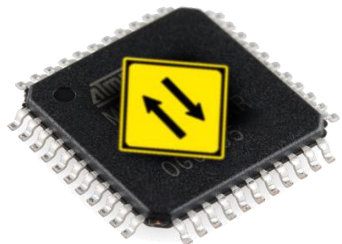
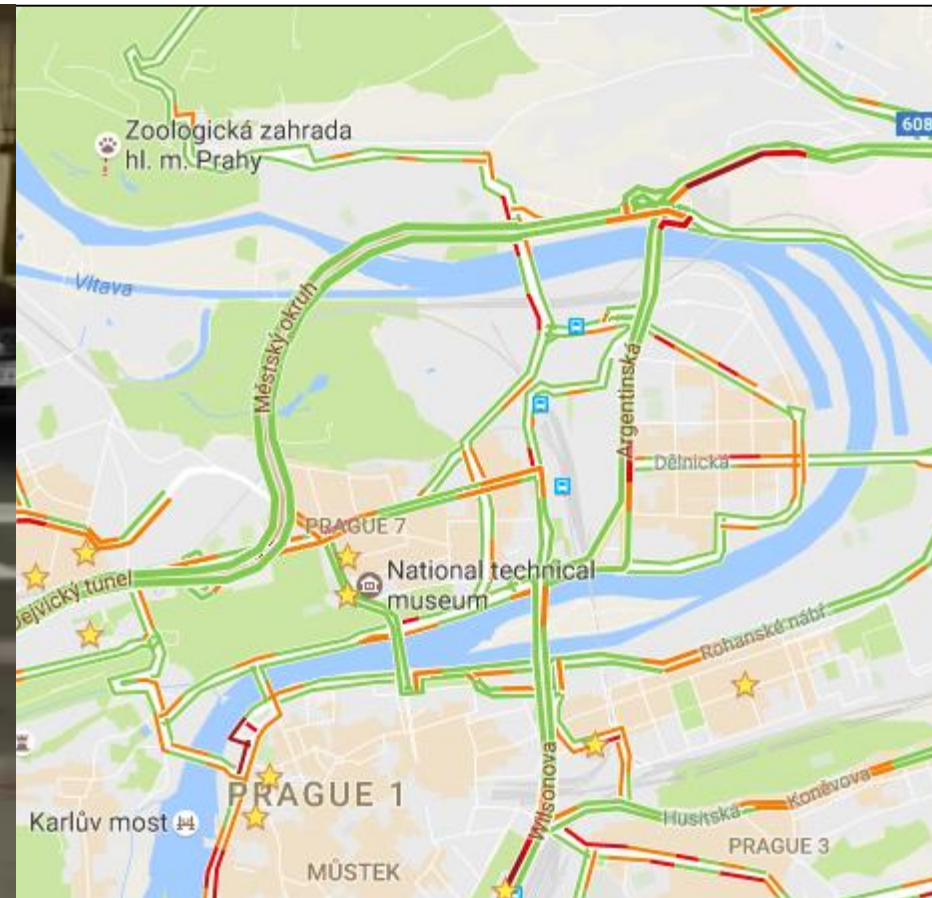
Piezoelectric impulses are oscillatory and leak to ground



These won't erase the information in AFMEM

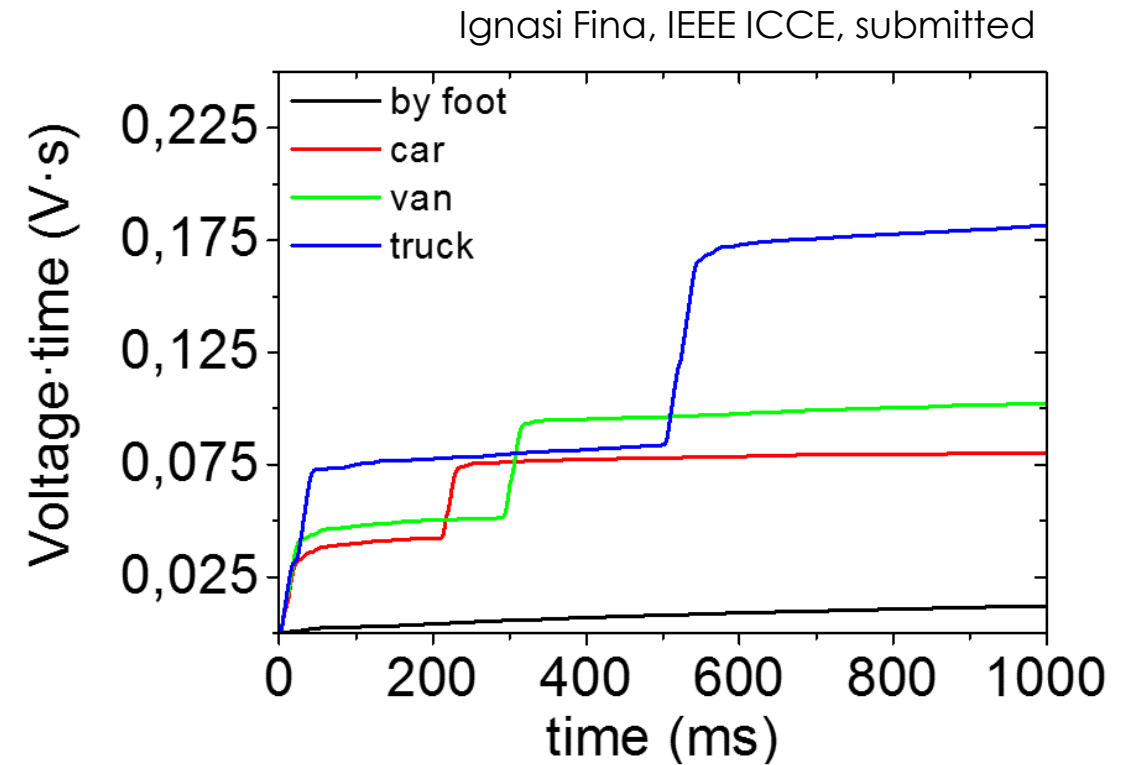


Passive traffic flow monitoring



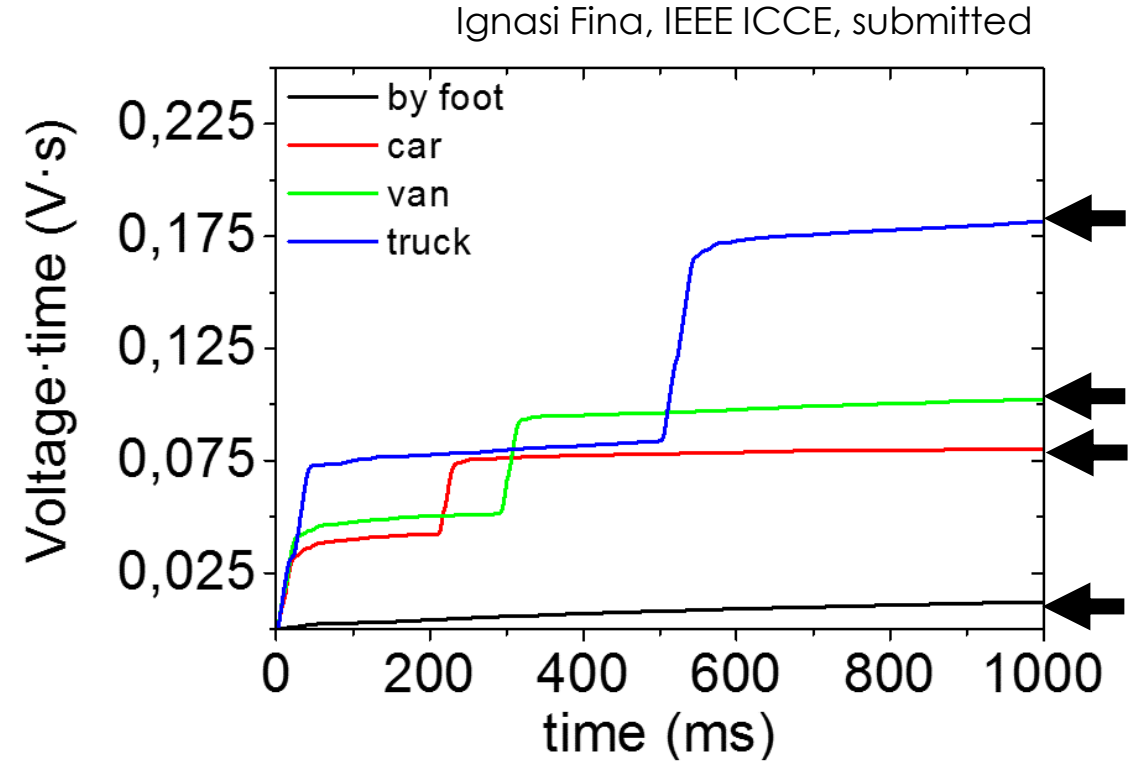
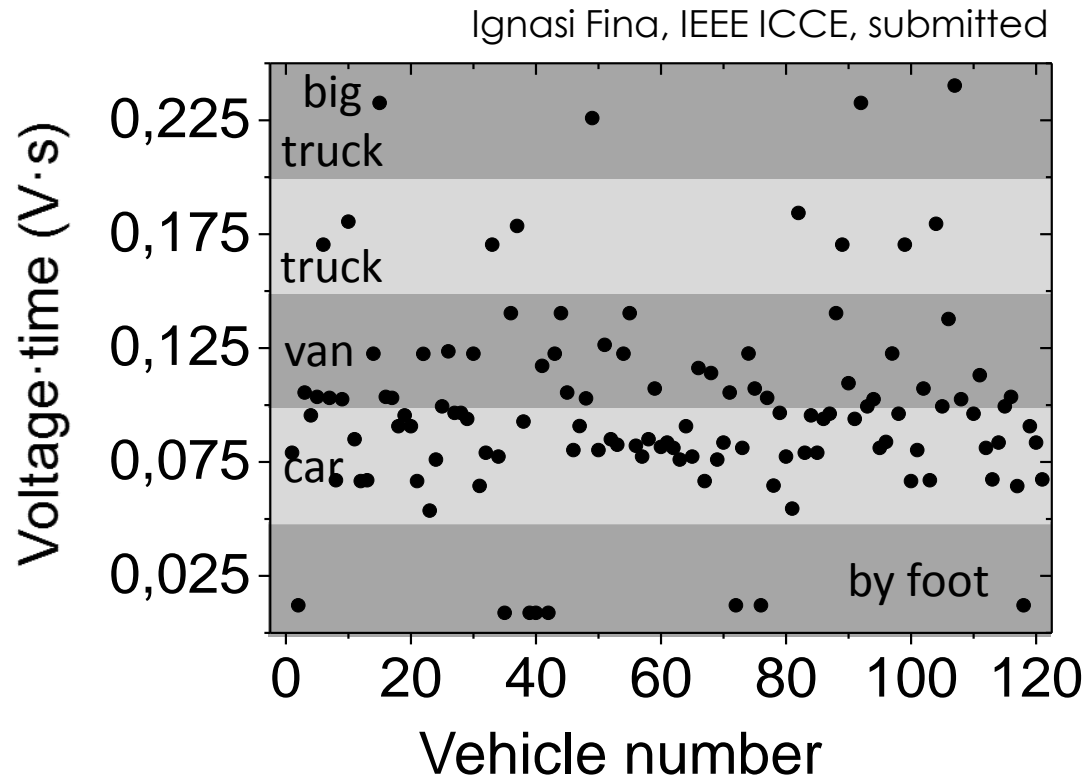
3 colors updated each 10 seconds.
(Let it be *inaccurate* and low-capacity!)

Passive vehicle classification



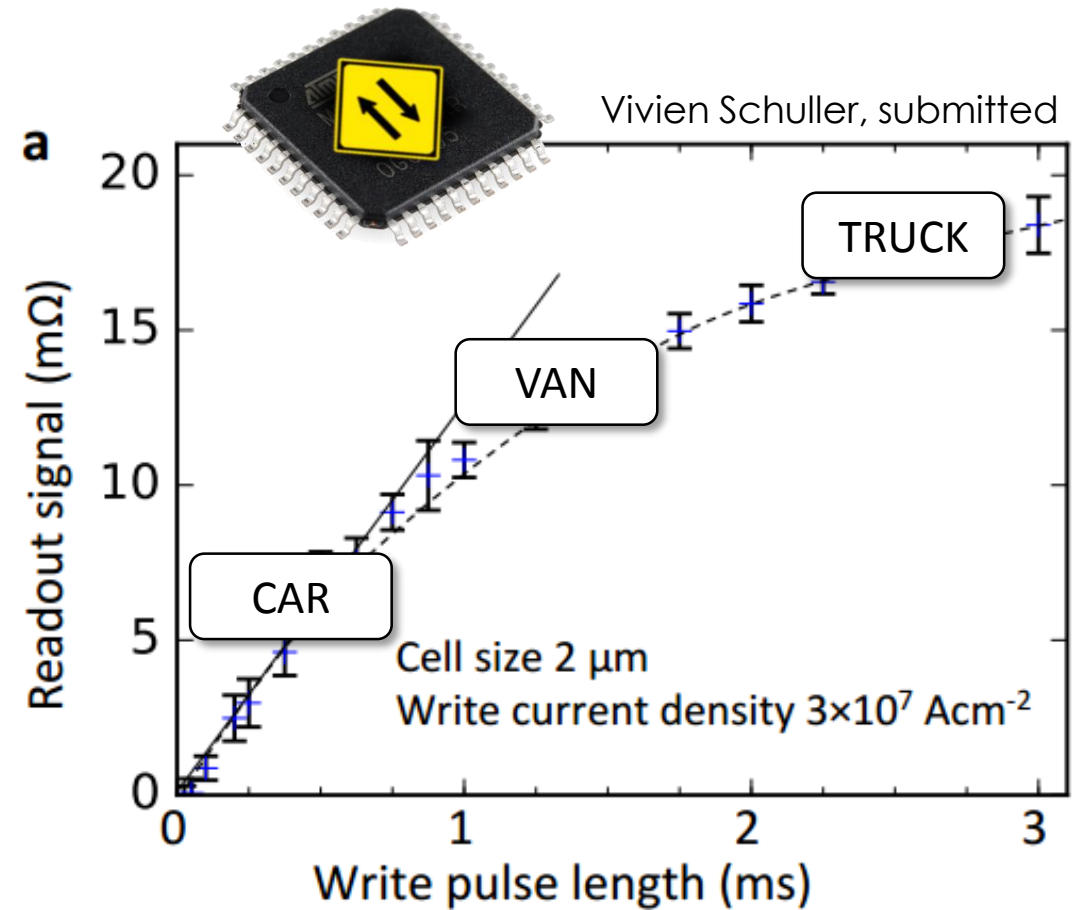
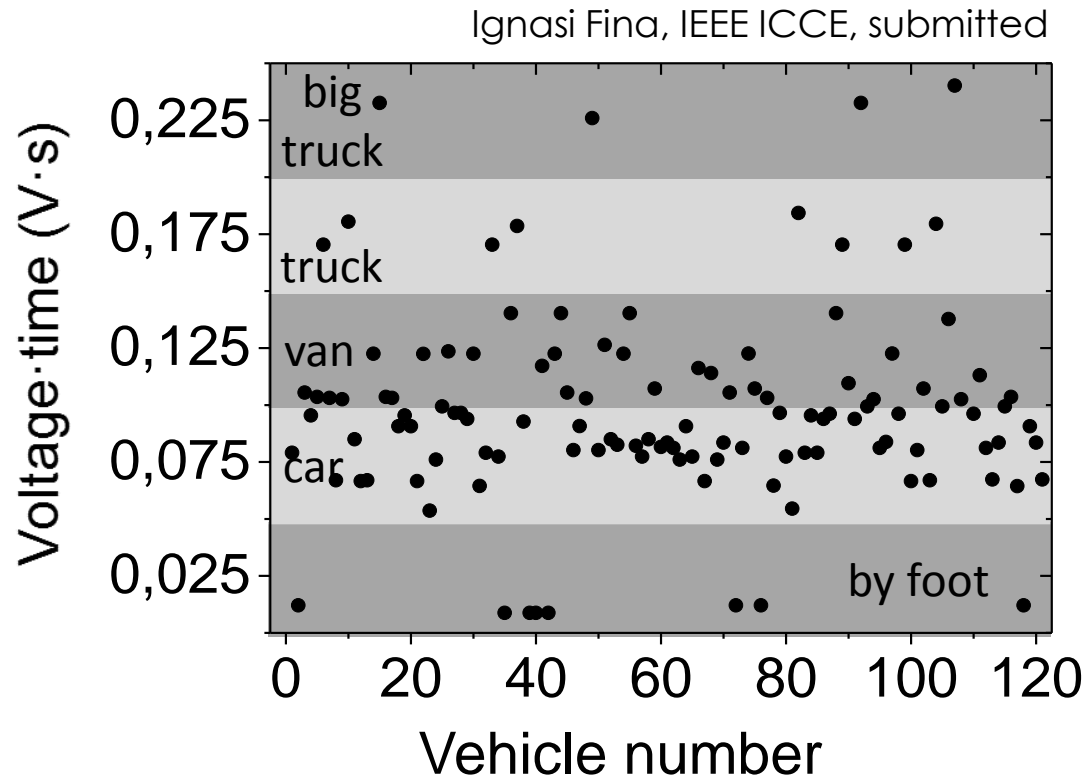
The integrated piezoelectric signal classifies the vehicles

Passive vehicle classification



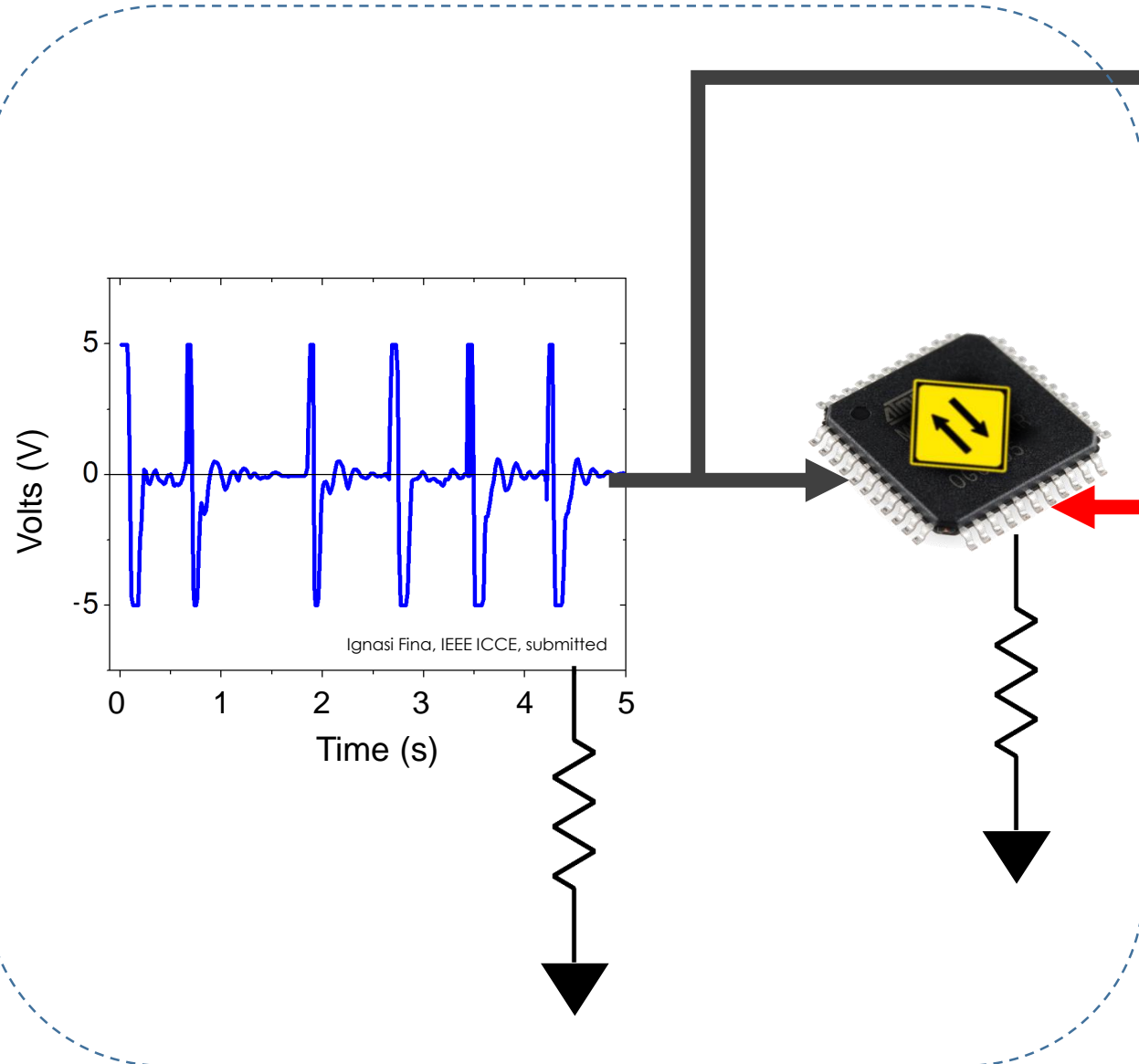
The integrated piezoelectric signal classifies the vehicles

Passive vehicle classification

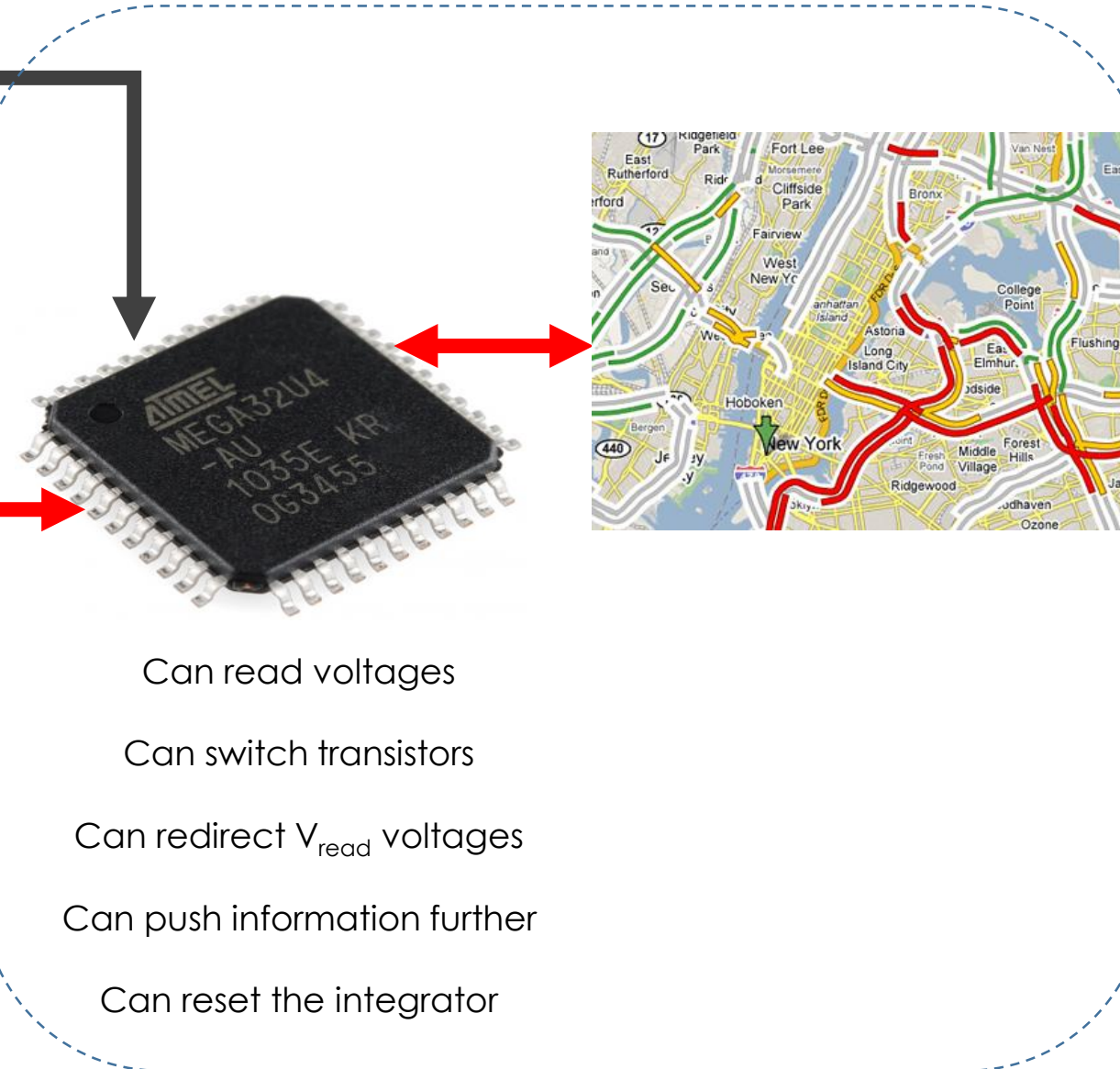


The AFMEM passively **integrates** (analyzes) the data

Electrically passive



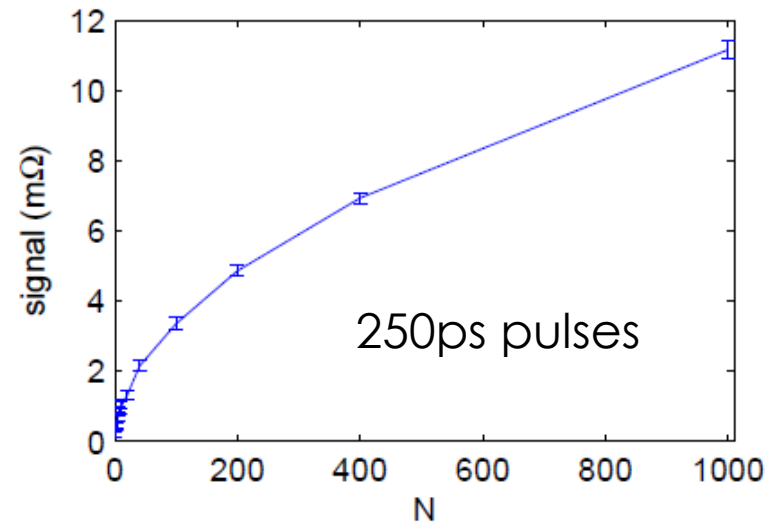
Switch on on-demand







What about high-frequencies?



Commercial pulse counters



Typically:

PRICE:

< 1 euro

RANGE:

one unit 8-16 bits



$(2^{10} = 1024)$

$(2^{16} = 65536)$

Easy to concatenate!

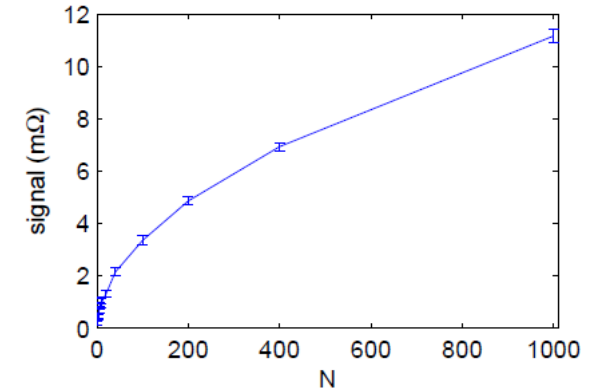
MAX FREQUENCY:

10 - 40 MHz

eu.mouser.com/Semiconductors/Counter-ICs/_/N-1he21?Keyword=4017B&FS=True								
Buy Selected Compare Selected Compare up to 20 parts.								
Select	Image	Mouser Part No	Mfr. Part No.	Mfr.	Description		Availability	Pricing (EUR)
<input type="checkbox"/>	 Enlarge	595-CD4017BM96 To purchase full reel, order in multiples of 2500:	CD4017BM96	Texas Instruments	Counter ICs CMOS Decade Counter	Datasheet	10.643 In Stock Alternative Packaging	Cut Tape 1: 0,362 € 10: 0,304 € 100: 0,186 € 1.000: 0,143 € Reel 2.500: 0,122 € 10.000: View MouseReel Available
<input type="checkbox"/>	 Enlarge	771-HEF4017BTD-T To purchase full reel, order in multiples of 2500:	HEF4017BT,653	NXP Semiconductors	Counter ICs 5-STAGE JOHNSON COUNTER	Datasheet	4.443 In Stock Alternative Packaging	Cut Tape 1: 0,52 € 10: 0,42 € 100: 0,264 € 1.000: 0,198 € Reel 2.500: 0,168 €

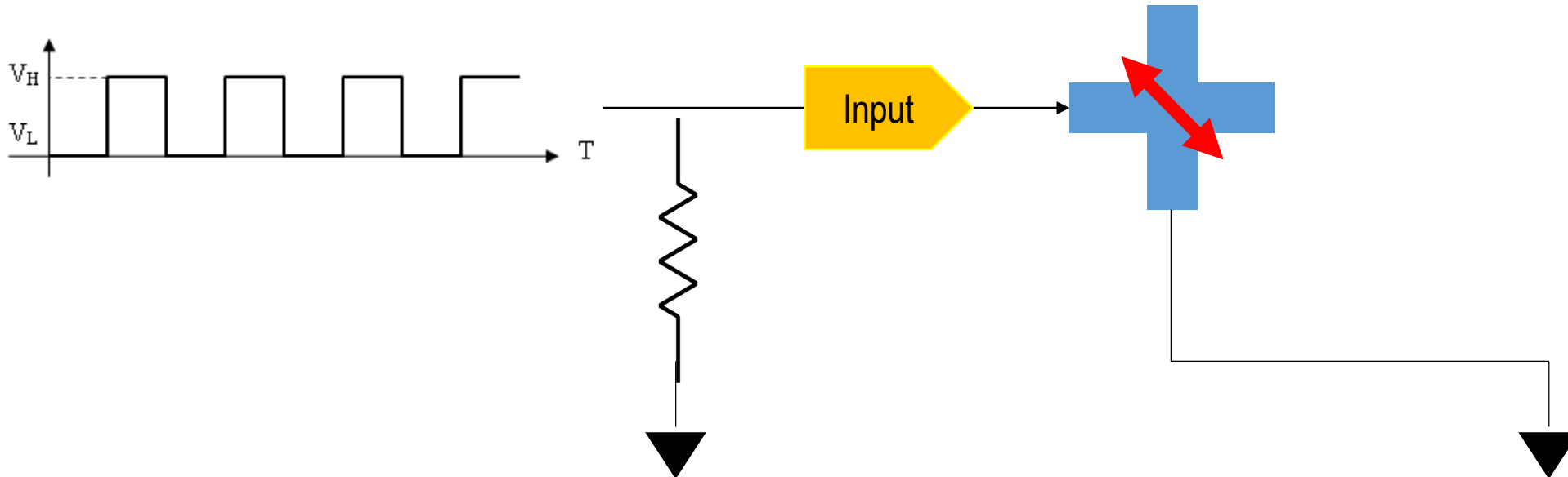
Can we do better than this?

AFM not even at its limits for 250 ps pulses



Bridge between THz and MHz

“Slow ” electronics can revisit each “1 ms”



Commercial pulse counters

Measuring **time**

Measuring **velocities!**

Measuring **distances** (time of flight)

Example: $D = c/2 * (\text{number of pulses})$

Consumer electronics,
Civil engineering and infrastructure risk,
Military and security.



SF02 Laser Rangefinder – 50 m



\$349.00

Product ID: **28043**

In Stock: **14**

Quantity

1

Add to cart



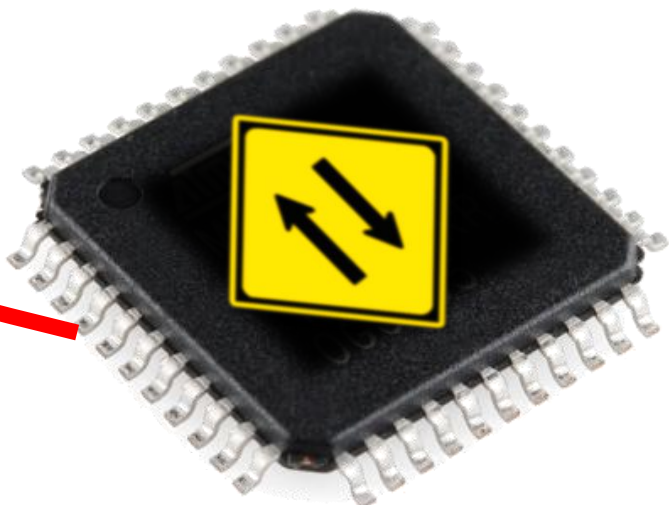
1-9

\$349.00

10+

\$314.10

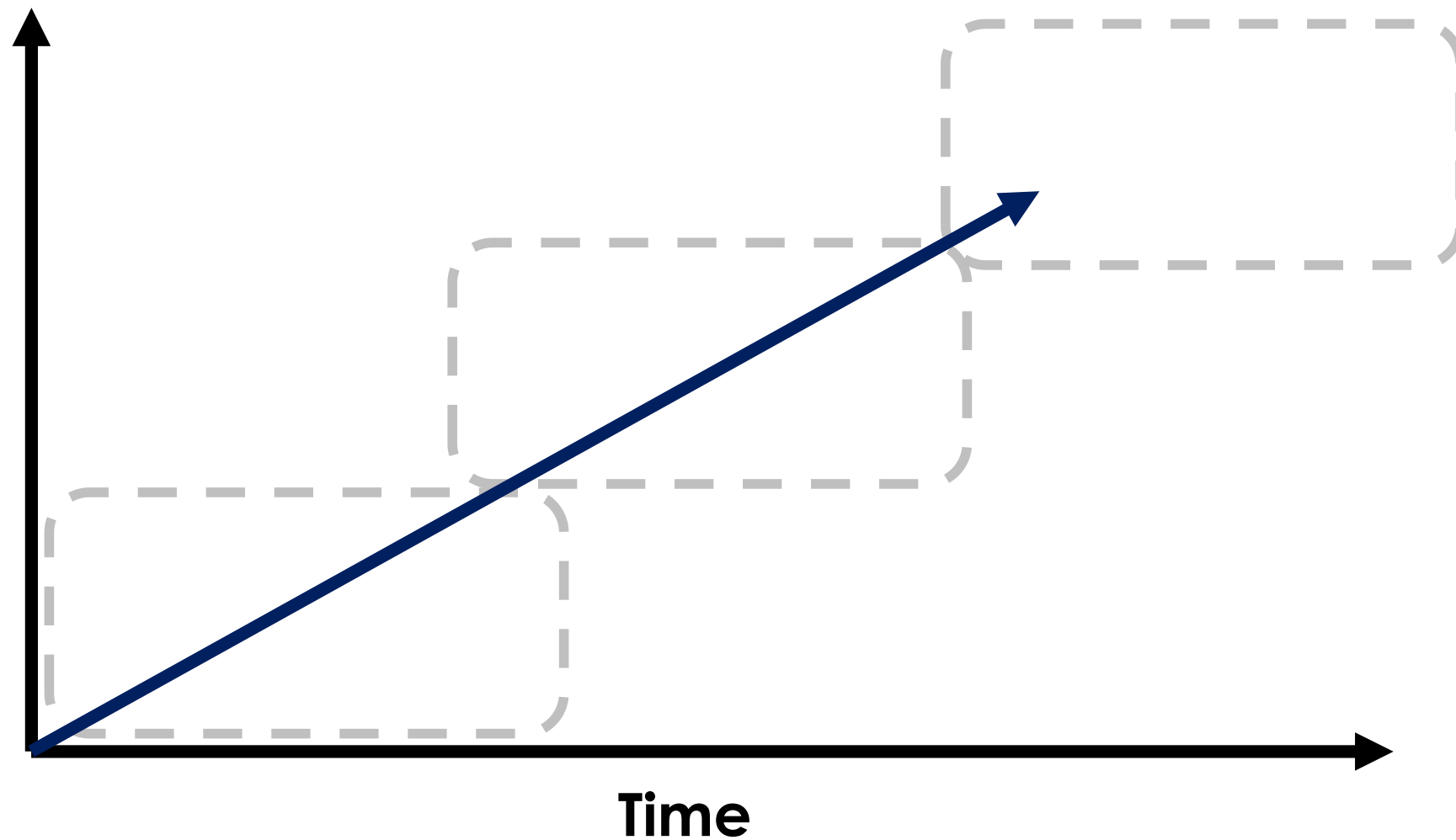
7 Downloads





How can we become competitive in the short-term?

Incremental progress in complexity



Getting closer to solutions

A thermometer component costs 1 EURO

“Adding an antenna” of €5 increases the value of the product by €50+ euros

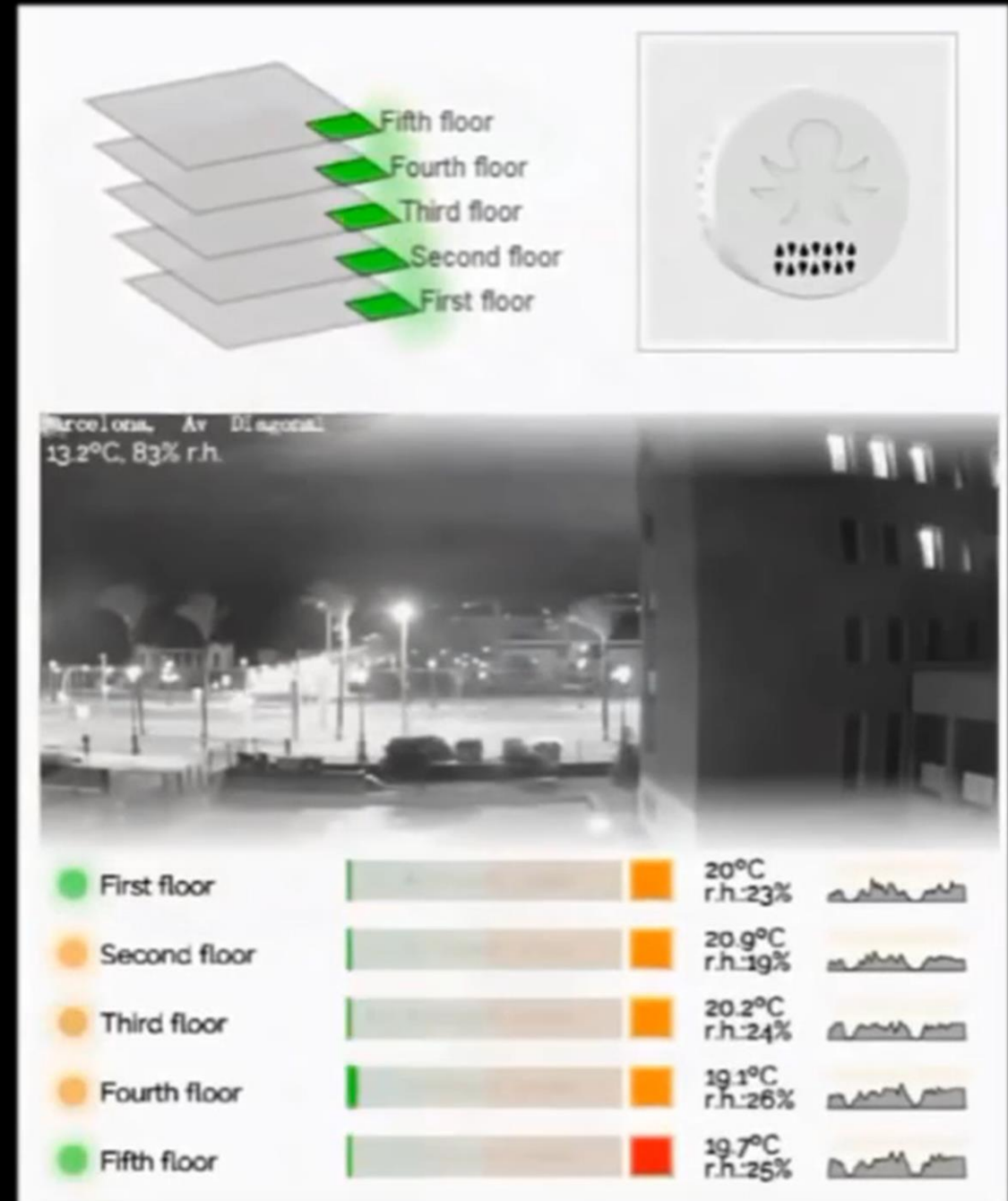
INTERNET = ADDED VALUE

LOW ACCESS FEE

COMPONENT

< DEVICE

< SOLUTION



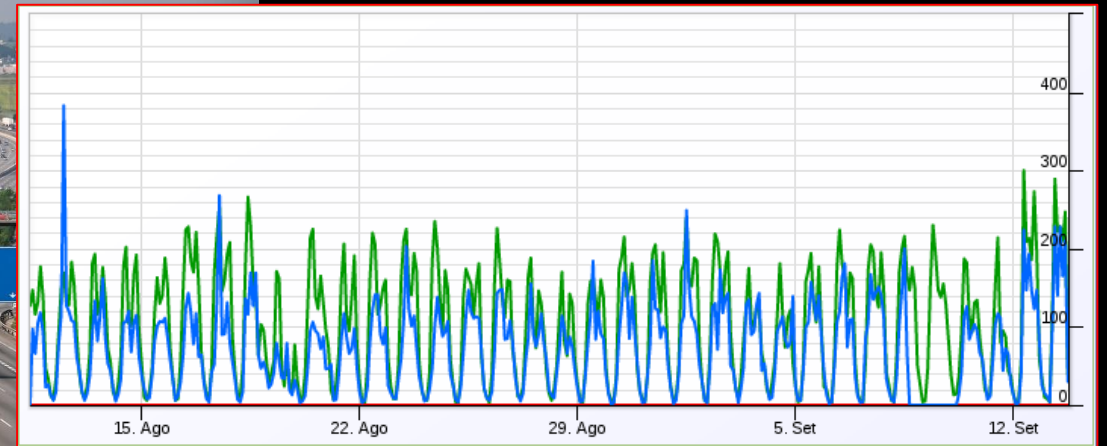
Recycle know-how



Technological
Know how



Market
know-how



AFM spintronics
won't be *perfect* the first day



**Not the
best
camera**



GoPRO® sold \$1.5 billion in 2015



AFM spintronics
won't be *perfect* the first day,
but we are moving.

Thanks for the view

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