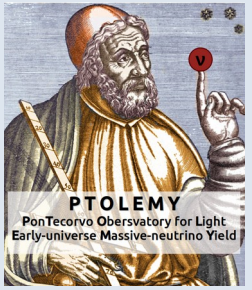
PTOLEMY
HV stabilization system

N. Rossi, A. Cocco, N. D'Ambrosio,
M. D'Incecco, G. Korga, M. Messina, F. Pofi
and F. Virzi (*LNGS Group*)



PTOLEMY Collaboration Meeting
Genova, 20-22 November 2024

Part I

Static voltage reference

Motivations and goals

Resolution $\Delta E \sim \Delta V$:

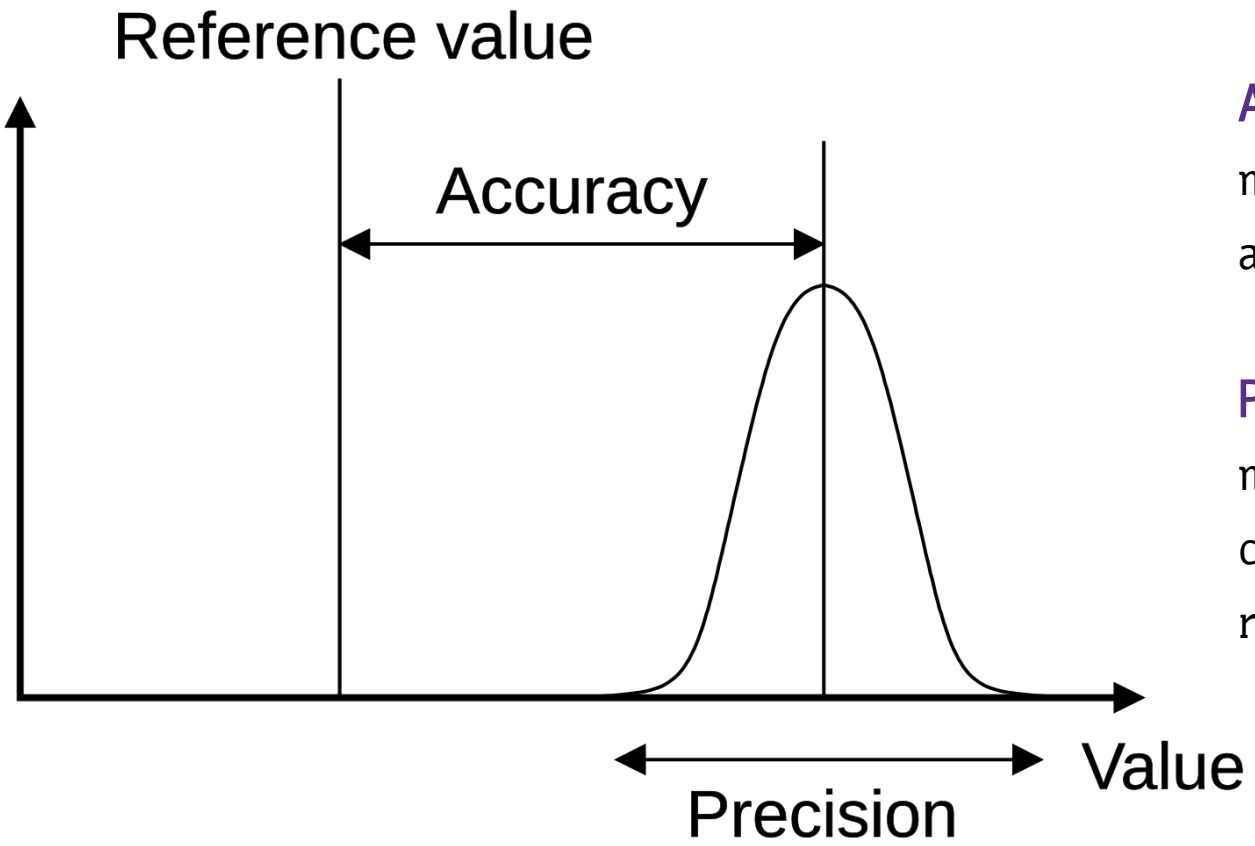
$\Delta E < 50$ mV at the tritium end point (18600 keV)

@ 20 kV → $\Delta V/V \sim 2.5$ ppm

High precision reference diode chain

Non invasive measurement with a field mill

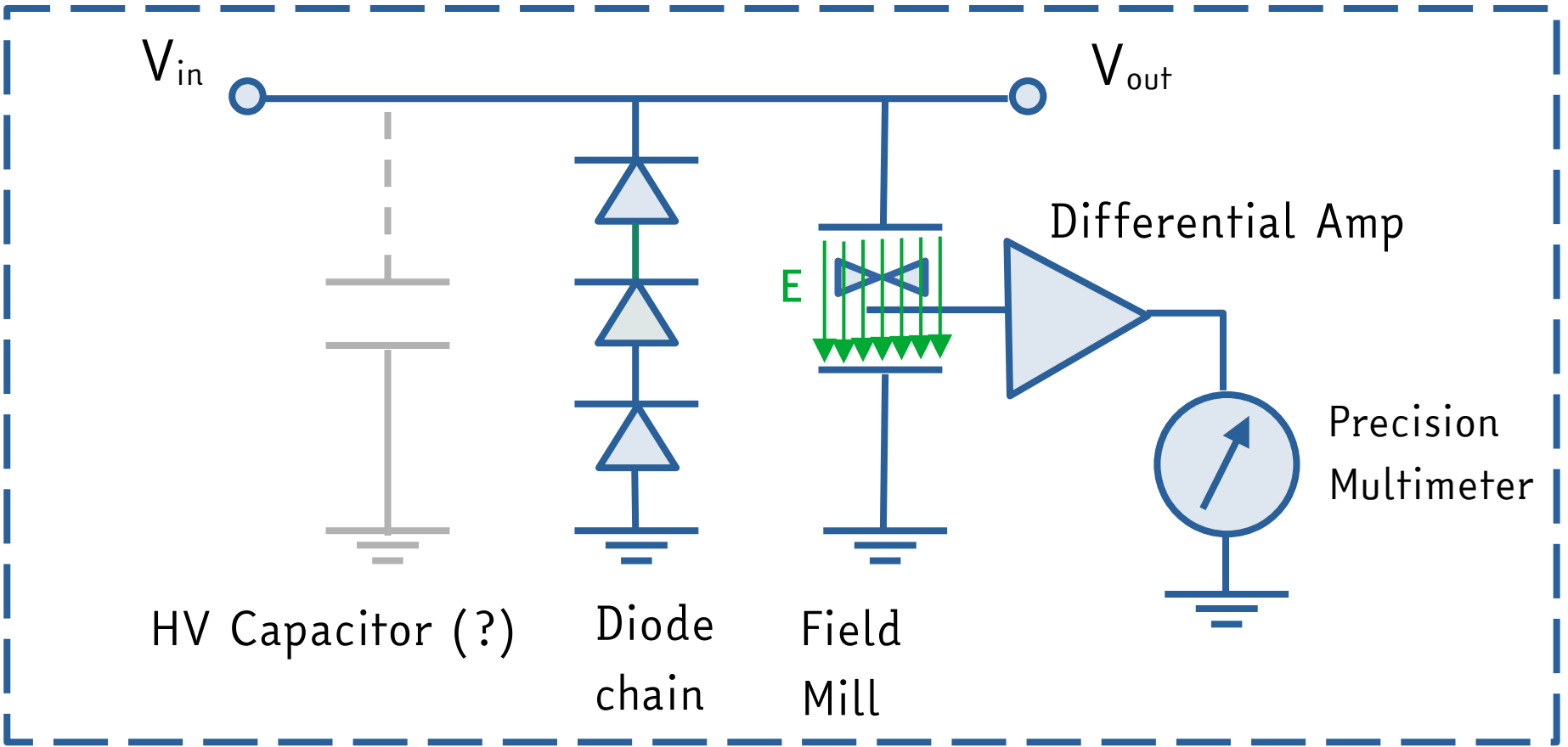
Accuracy and Precision



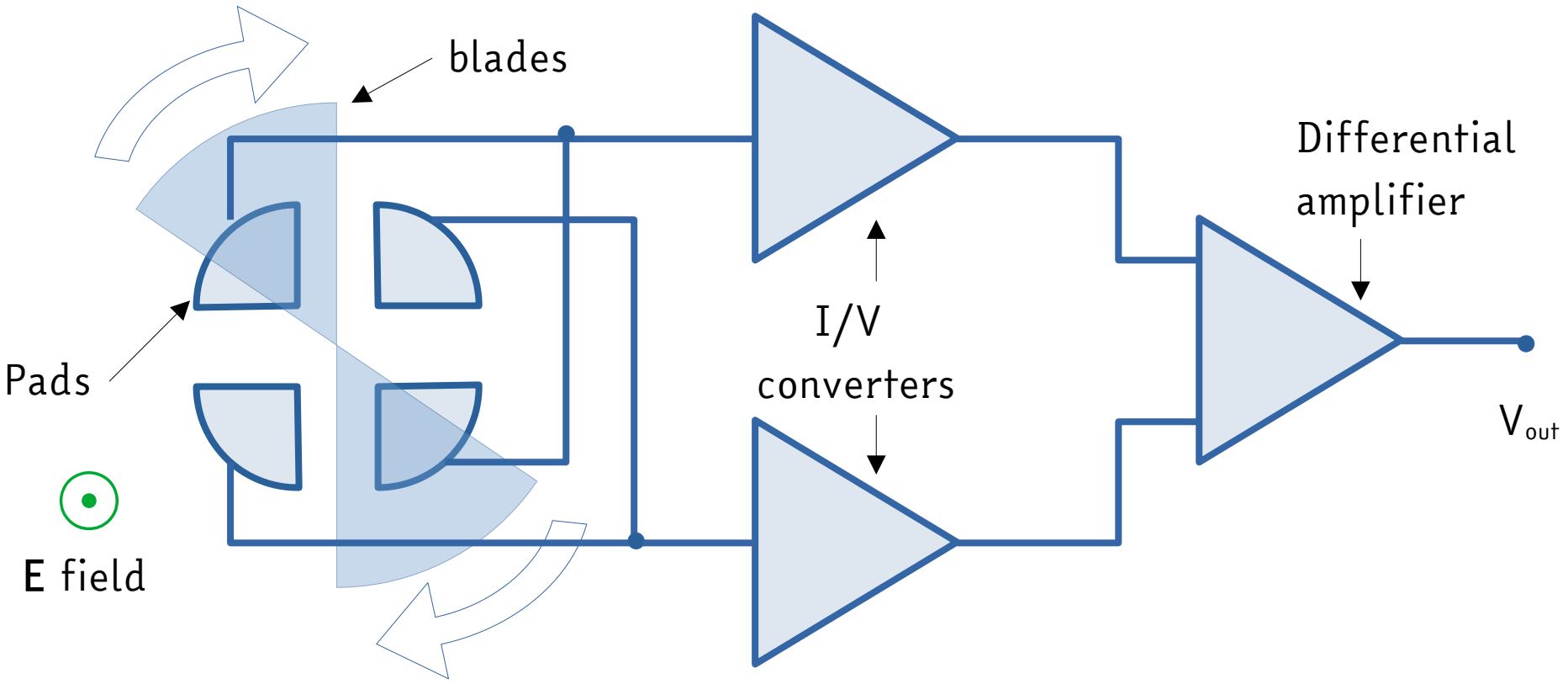
Accuracy: proximity of measurement results to the accepted value

Precision: degree to which measurements under unchanged conditions show the same results.

Setup scheme (baseline)



Amplification chain



High precision reference voltage regulators (slang *diode*) - REF50xx

V_0 = 10V

V_{in} = 10.2 – 18 V

I_q = 0.8 mA

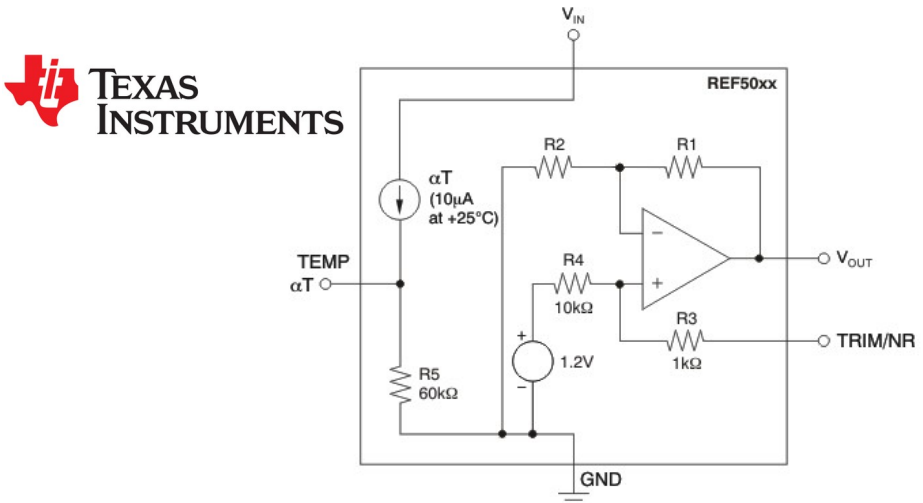
Low temperature drift: 2.5 ppm/°C

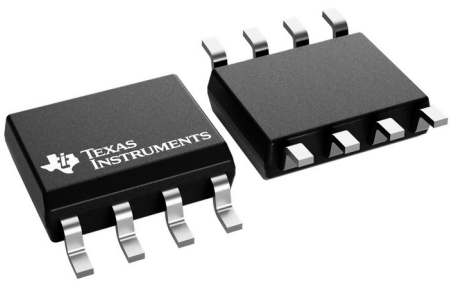
High accuracy: 0.025%

Low noise: 0.5 $\mu V_{pp}/V$

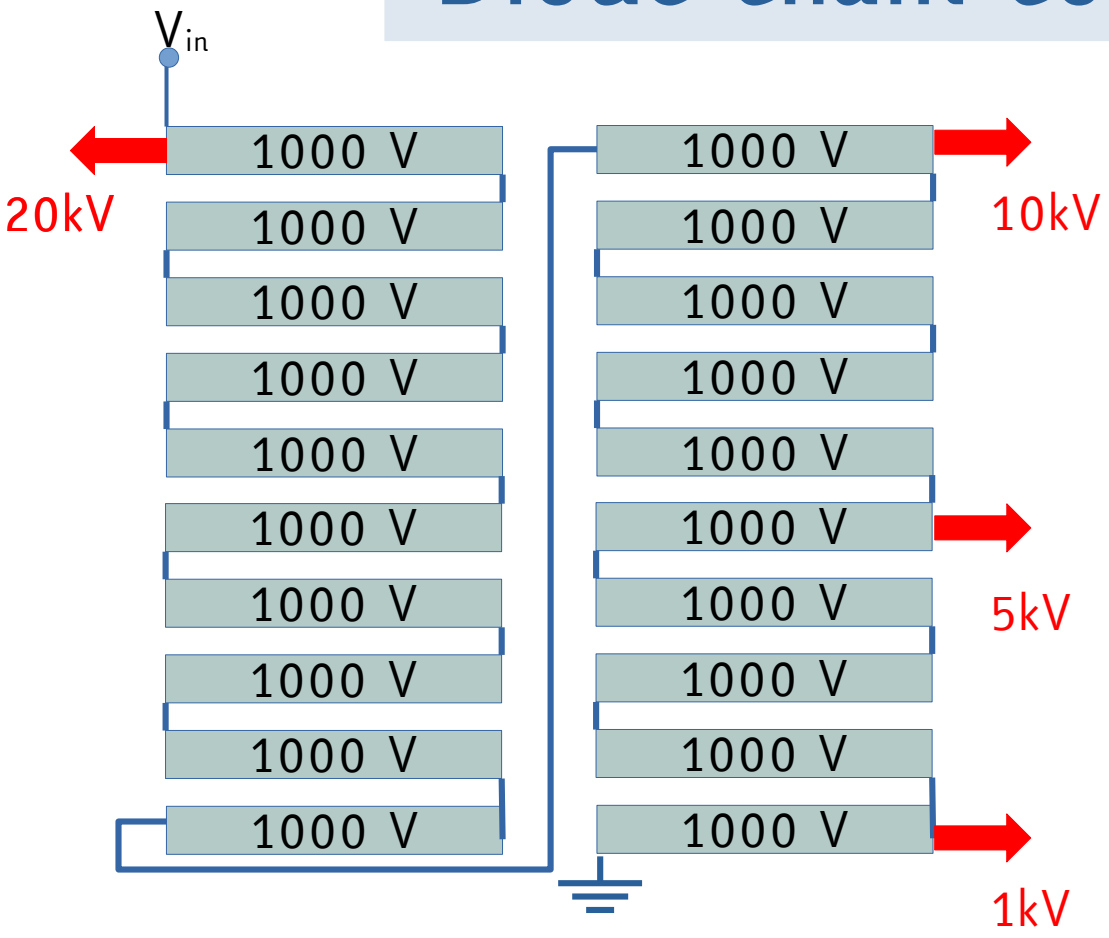
Eccellent long term stability: 22 ppm/1000h

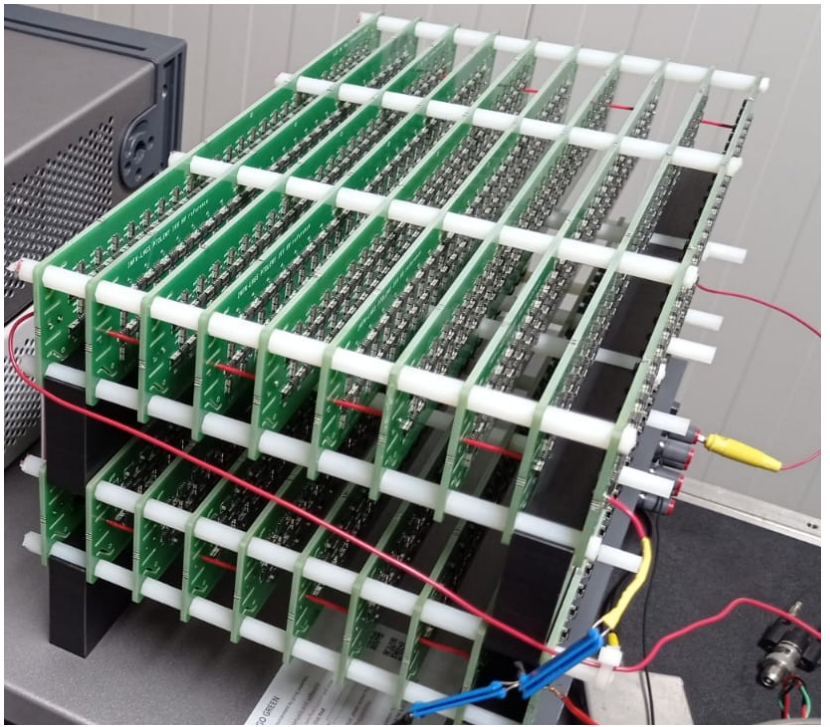
Temperature range: -40 ÷ 125°C





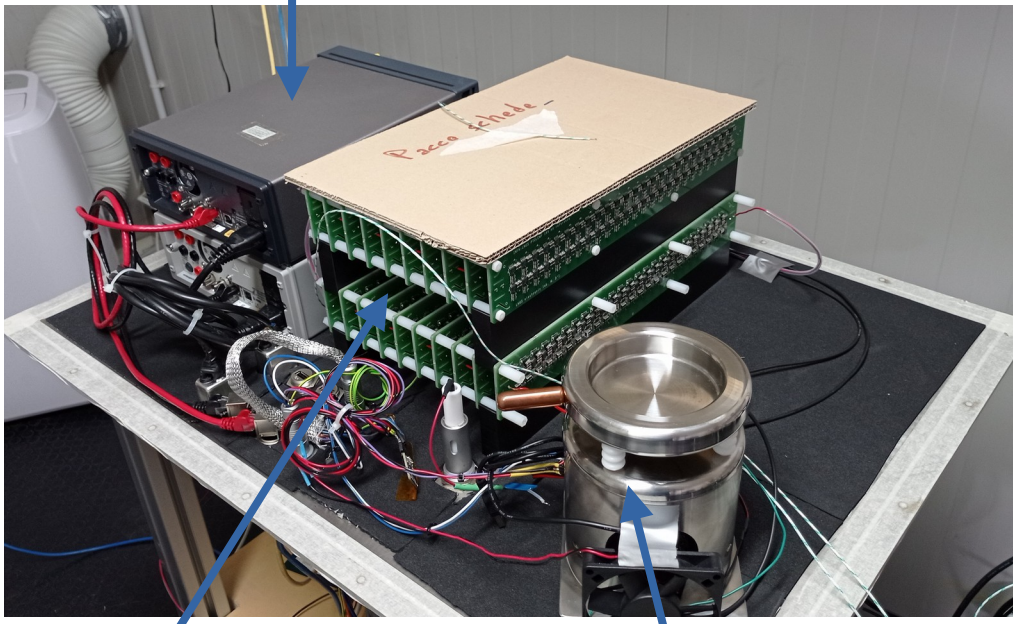
Diode chain configuration

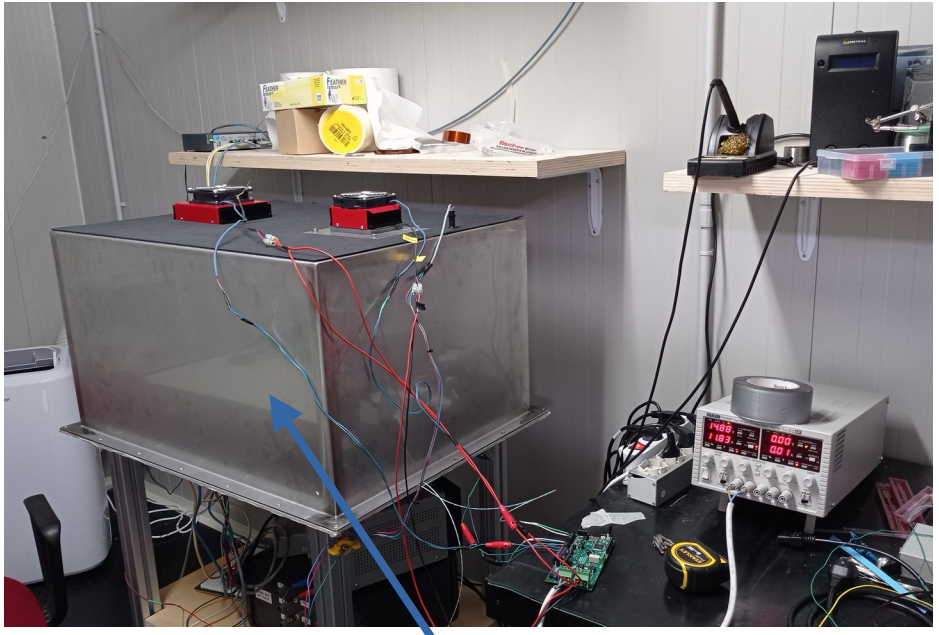




Old set-up

Precision
Multimeters
6.5 and 7.5 digits



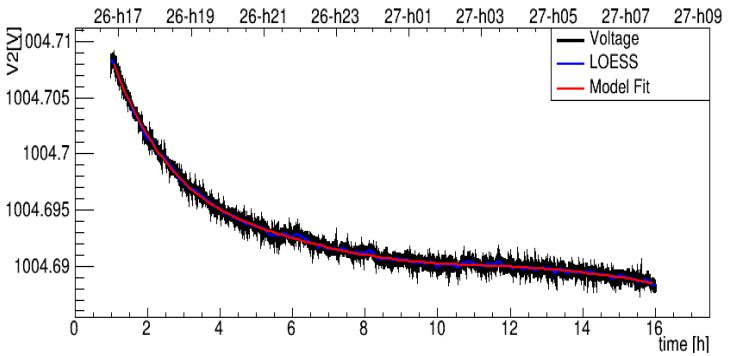


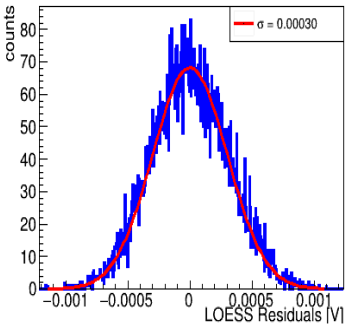
Diode chain

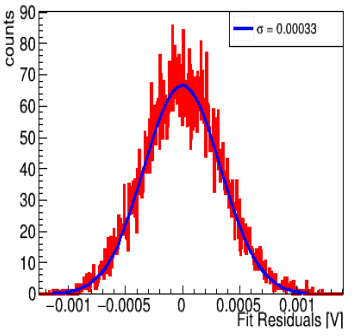
Field mill

Climatic chamber

Old results (baseline)

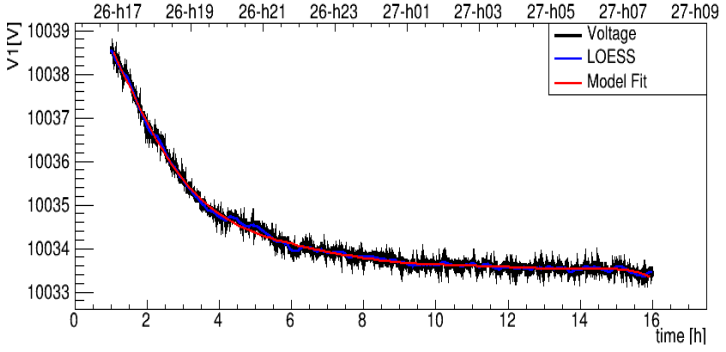


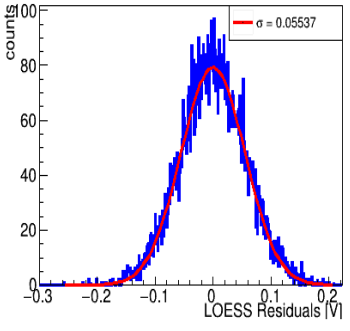


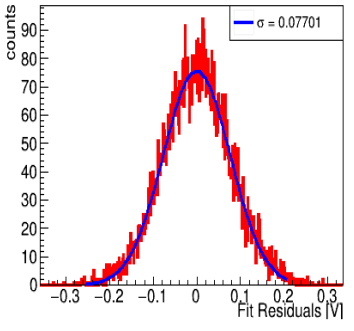


Single board (1 kV)

σ = 0.3 mV







10 board series (10 kV)

σ = 55 mV

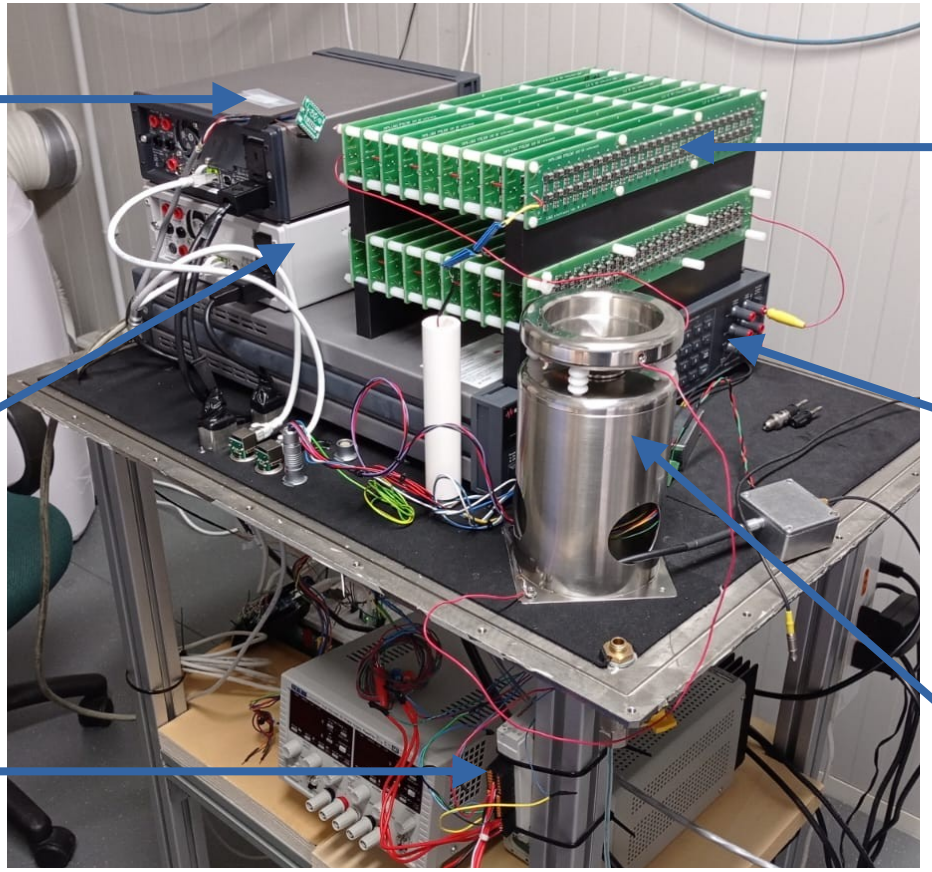
σ(intrisic, 10kV) = sqrt(10) x 0.3 ~ 1 mV (<<55 mV !!!)

σ(intrisic, 20kV) = sqrt(20) x 0.3 ~ 1.4 mV [I wish!!!]

New set-up

- New climatic chamber ✅
- New motor ❌⚠️
- New mill blade ✅
- New motor driver ⚠️
- Modified differential amplifier ⚠️
- Additional precision multimeter ✅
  (8.5 digits)
- HV slow switch ✅

New set-up



Multimeter
7.5 digits
(Field mill)

Multimeter
6.5 digits
Temp. board

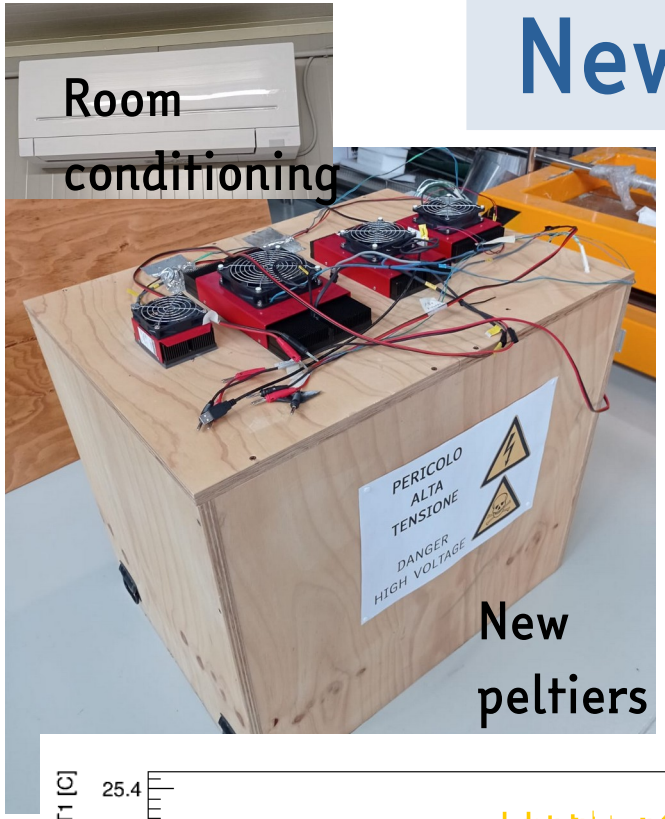
Motor driver

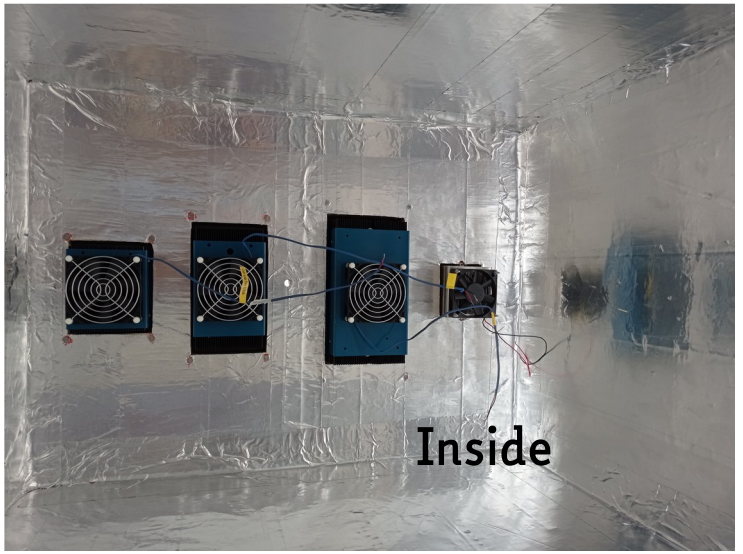
Diode
chain

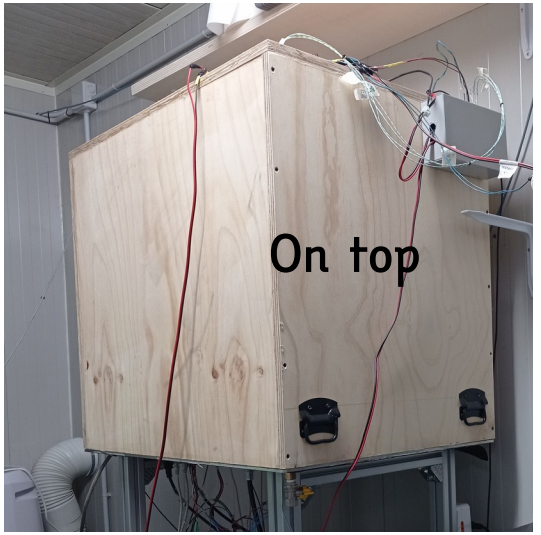
Multimeter
8.5 digits
(1kV board)

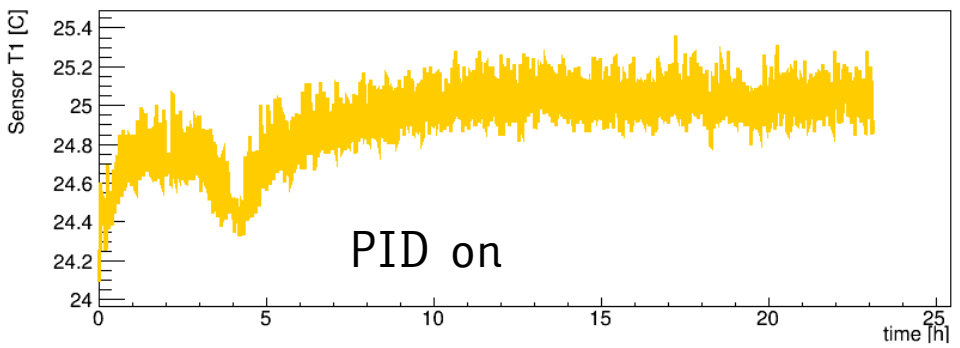
Field mill

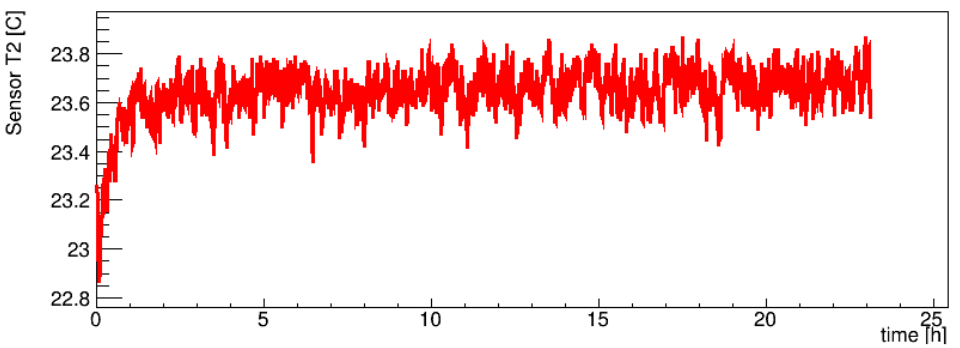
New climatic chamber



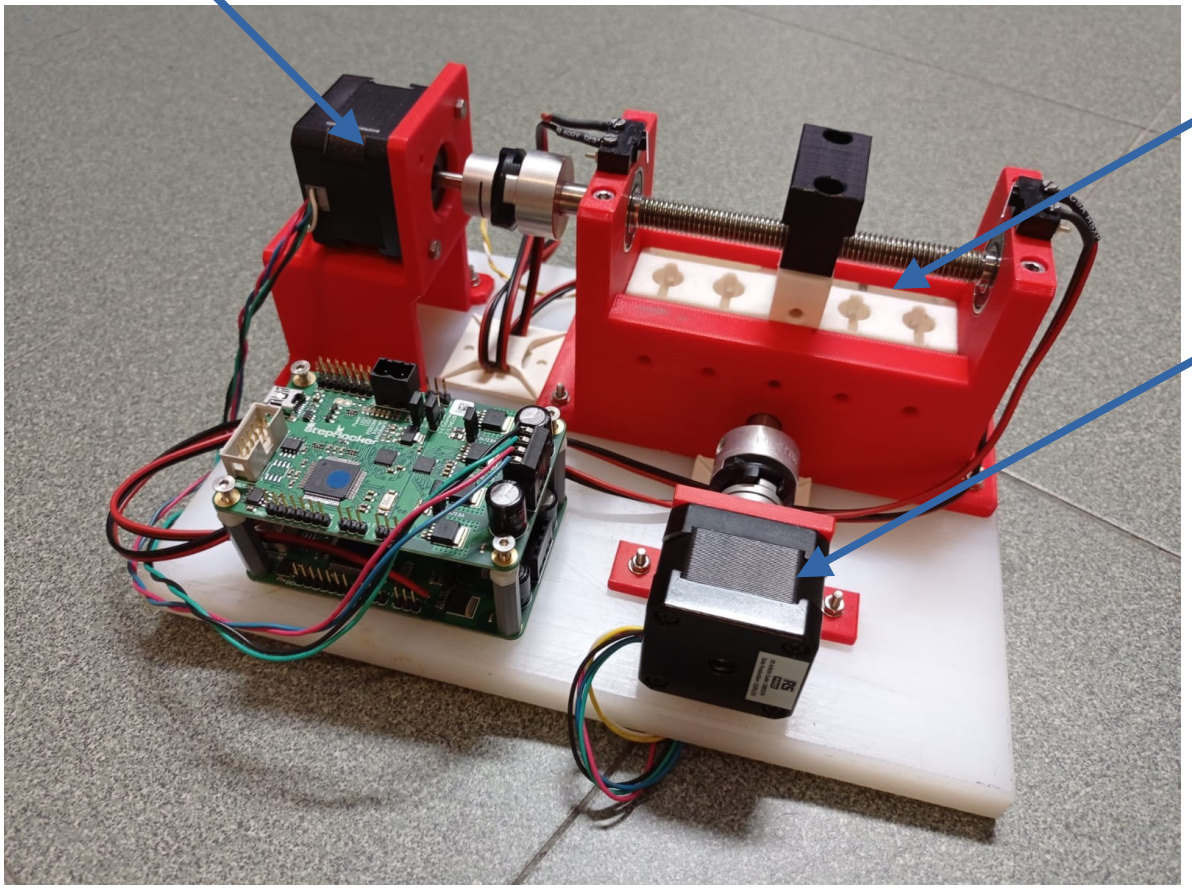








HV slow switch



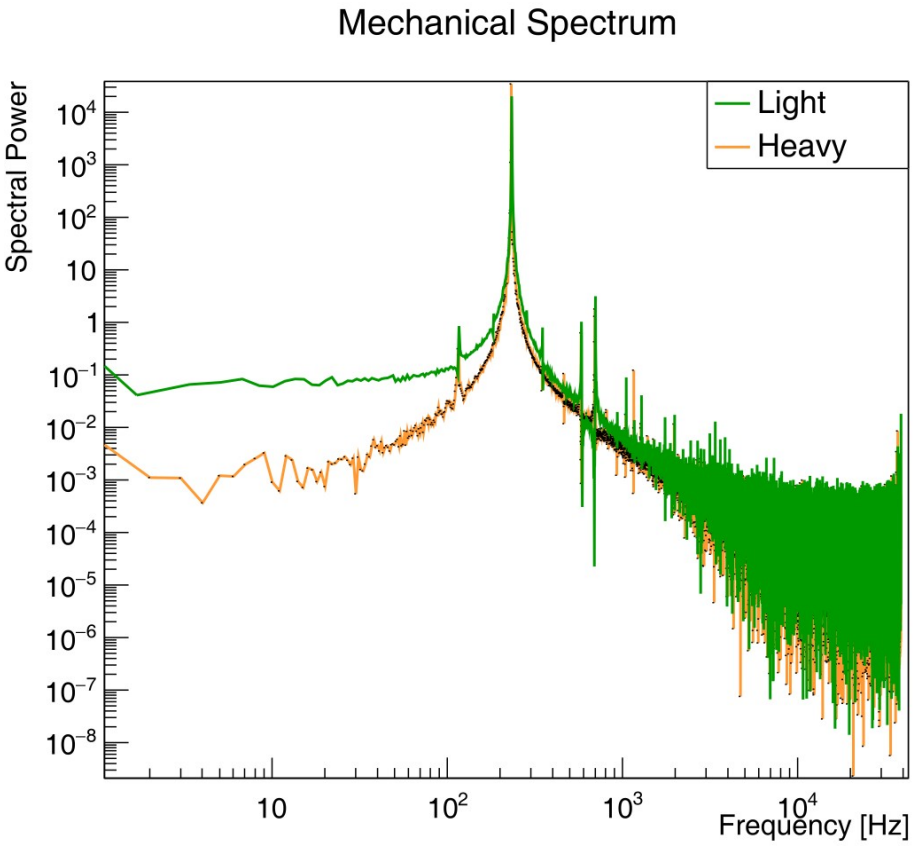
Switching between different partition of the diode chain without opening the climatic chamber

Ready to be tested

New mill blade

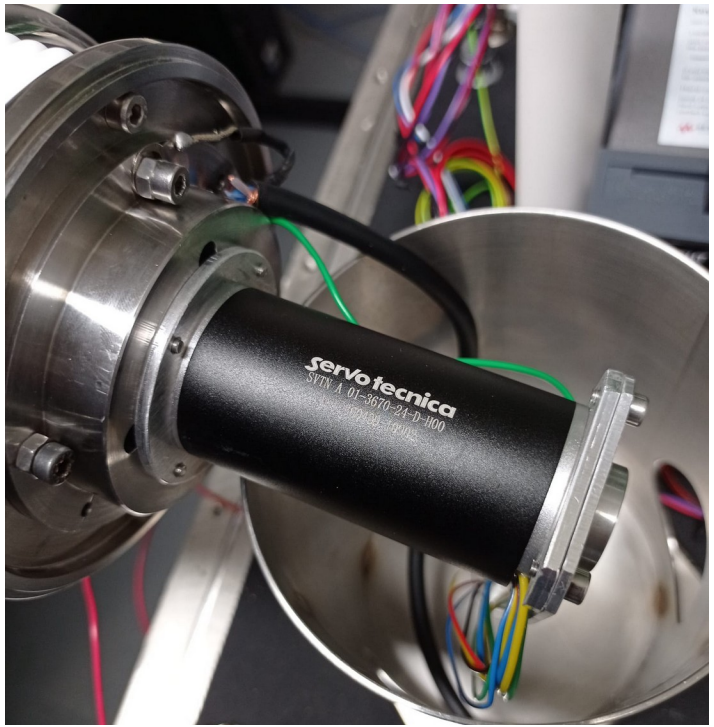
New mill blade LIGHT (height adjustable)

New mill blade HEAVY

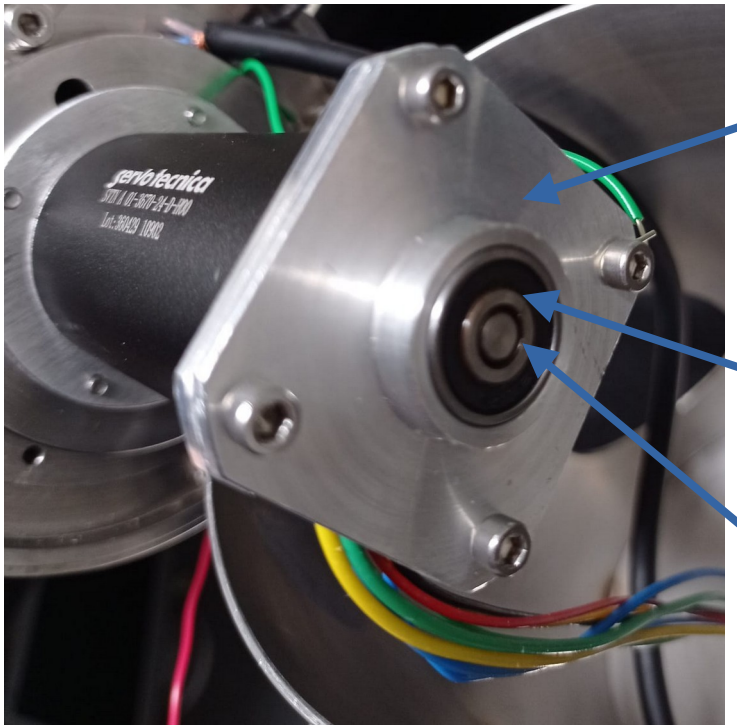


High stability in frequency

New motor

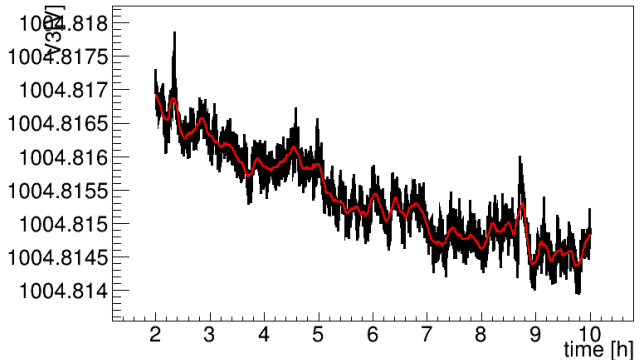


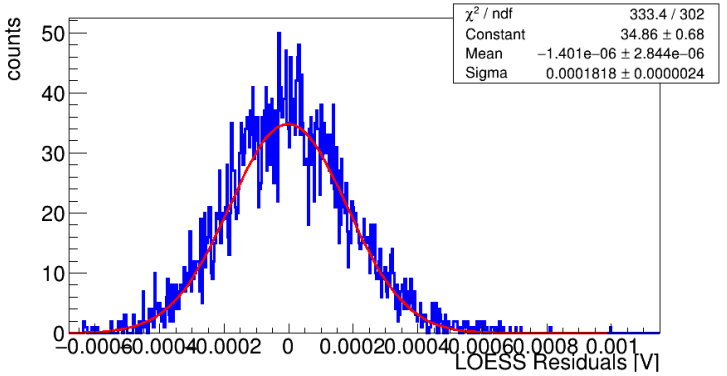
New brush-less motor



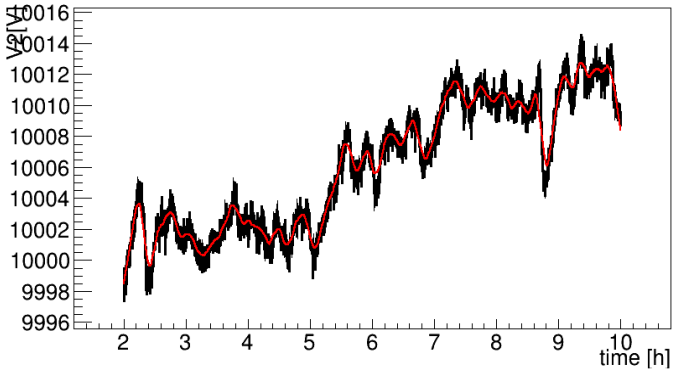
Grounding problem between the axis and the aluminum plate (> 10 kΩ)

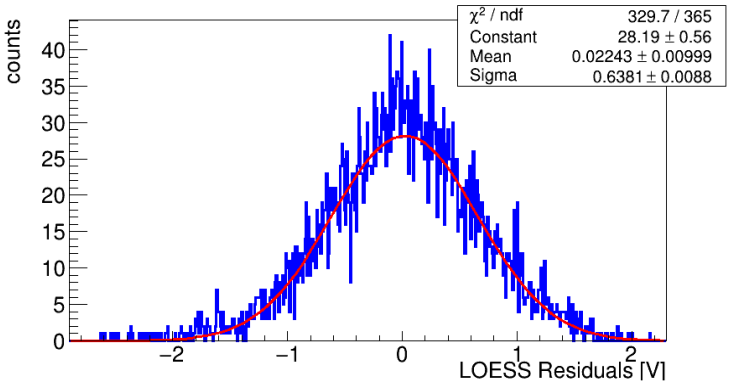
New results





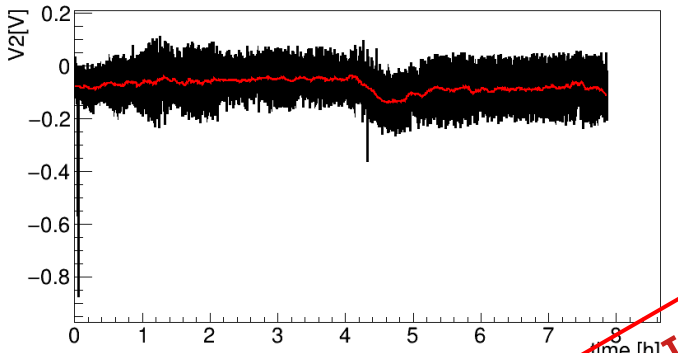
Single board
(1 kV)
σ = 0.18 mV
[IMPROVED]
ΔV/V = 0.18 ppm

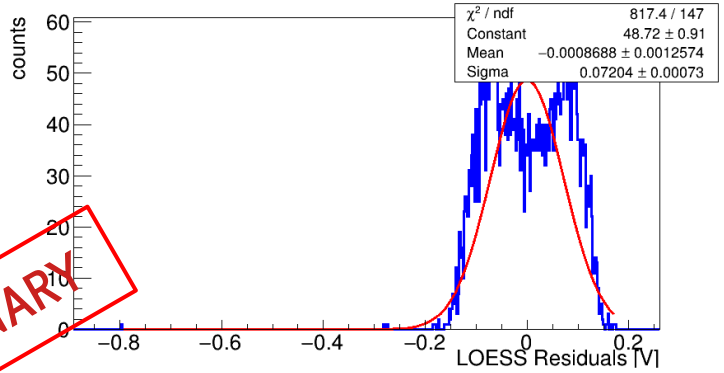




10 board series
(10 kV)
σ = 638 mV

Origin of the noise

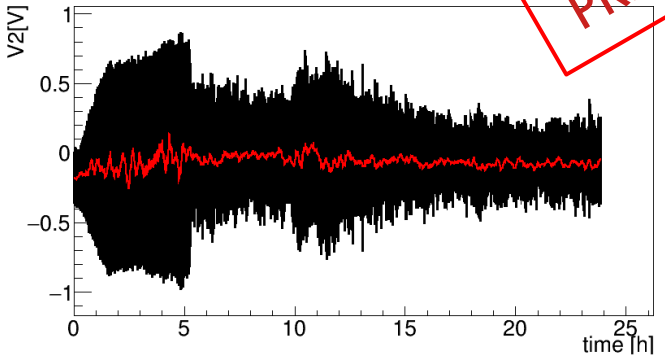


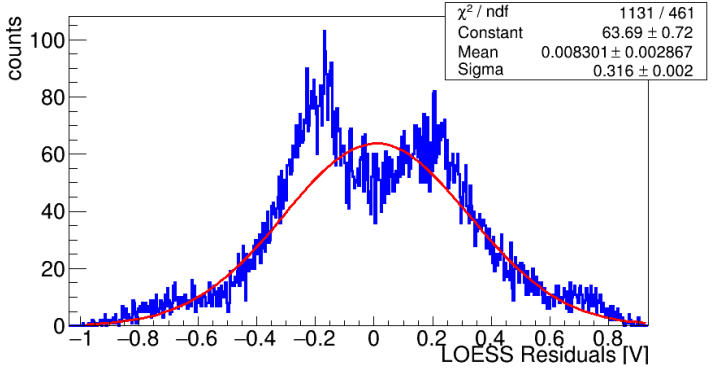


PRELIMINARY

Field mill off
Plate grounded

σ = 72 mV (10 kV eq.)





Field mill on
Plate grounded

σ = 300 mV (10kV eq.)

Next actions

- Motor **grounding** fix
- Optimization of the field mill signal **amplifier**
- Test on **mechanical stability**
- Tests with the new motor **driver**

Publication of preliminary results [in preparation]
- 0.18 ppm precision on the single board 1kV and extrapolation at 0.8 ppm
- Preliminary 5.5 ppm on 10kV and field mill technology

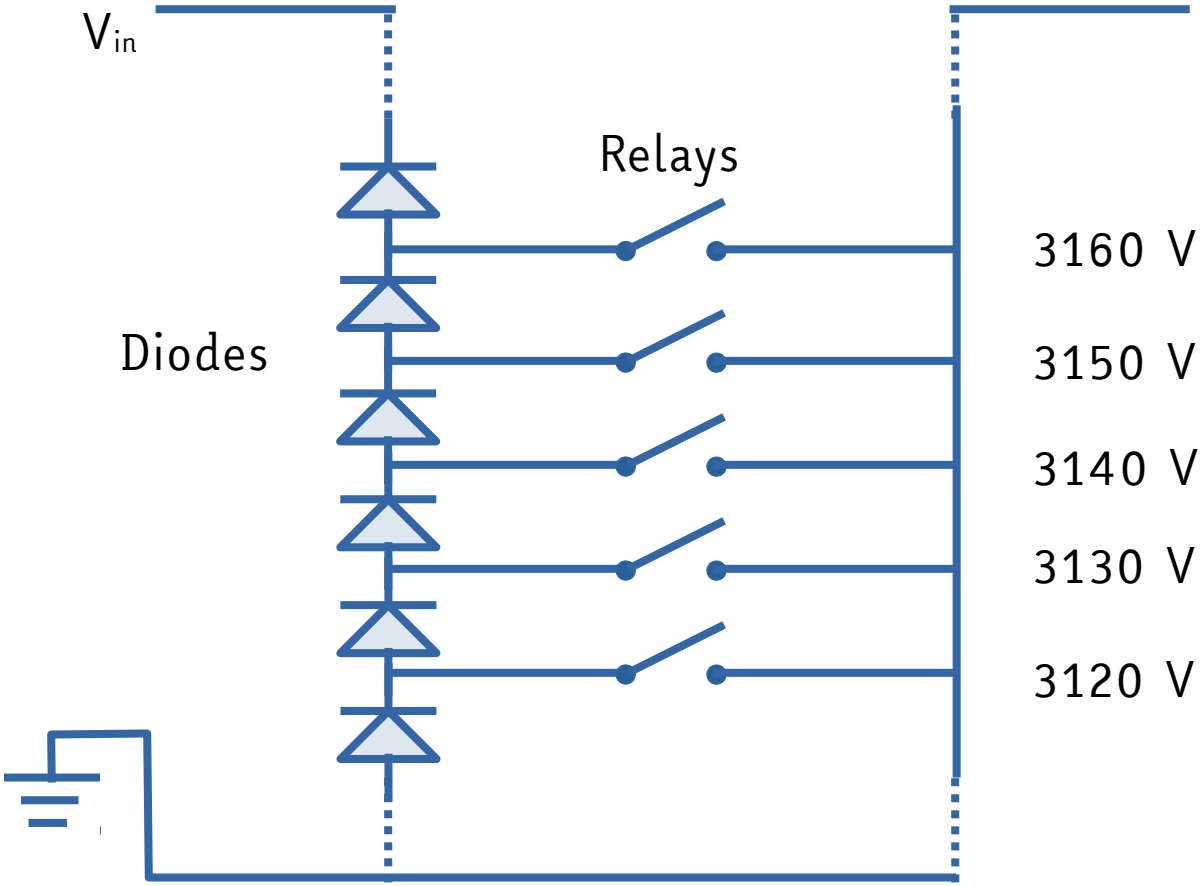
Part. II

Dynamic voltage reference

Dynamic filter electrode switch

- Change the reference voltage over a **wide range** from 0 to 20 kV
- Change in a **very short time** (~ 1ms)
- Avoid **electromagnetic noise emission**
- Avoid **leakage current** in switches
- Minimize the **reference diode divider** complexity

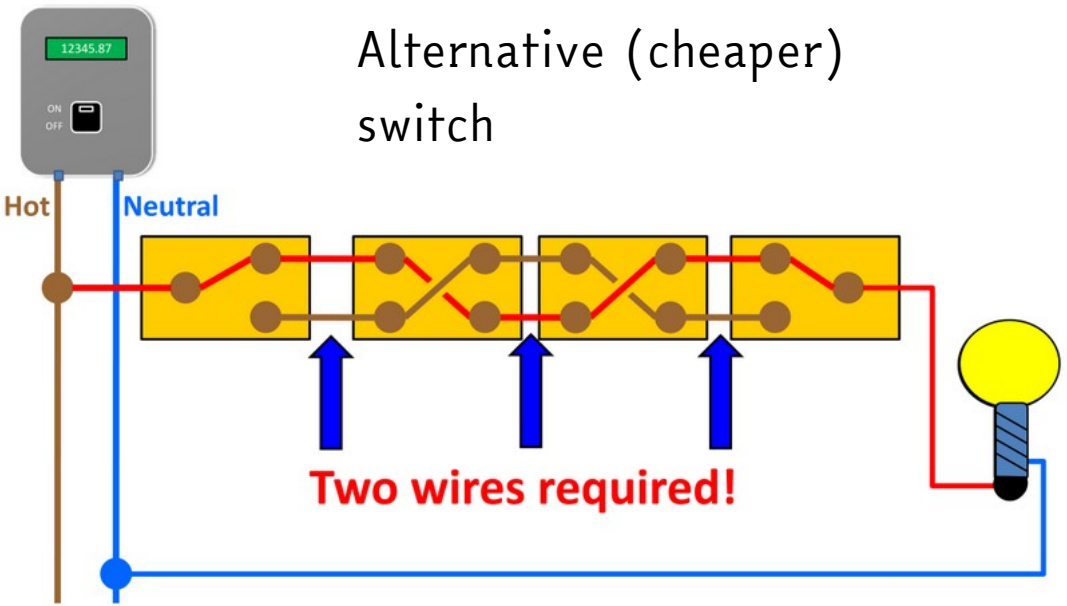
Zero level switch



Millipede
N-way switch

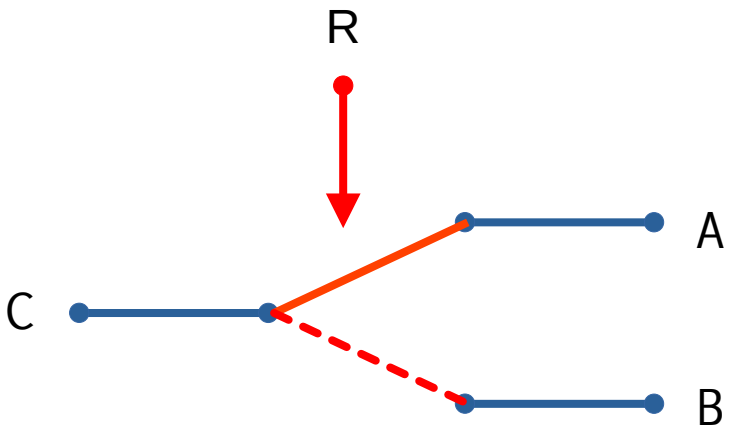
Issues:
- Complex system
- Too many components

Multiple switch problem

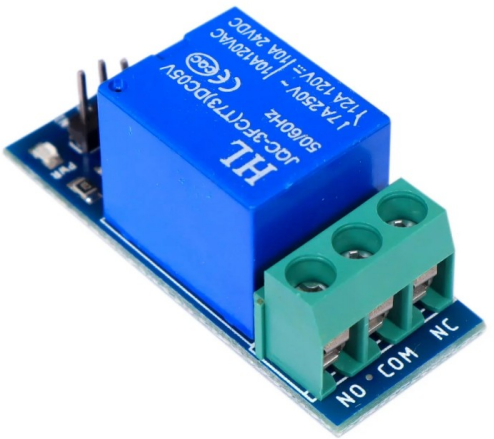


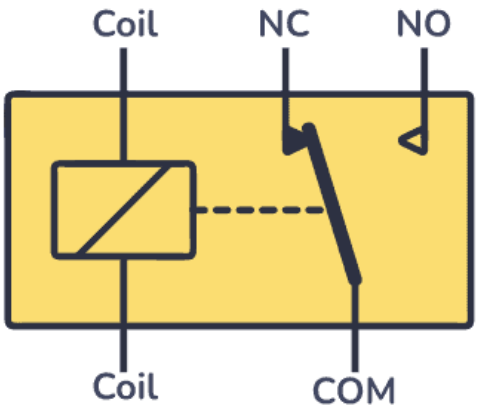
Alternative (cheaper) switch

Diverter (3 ways)



Three way witch



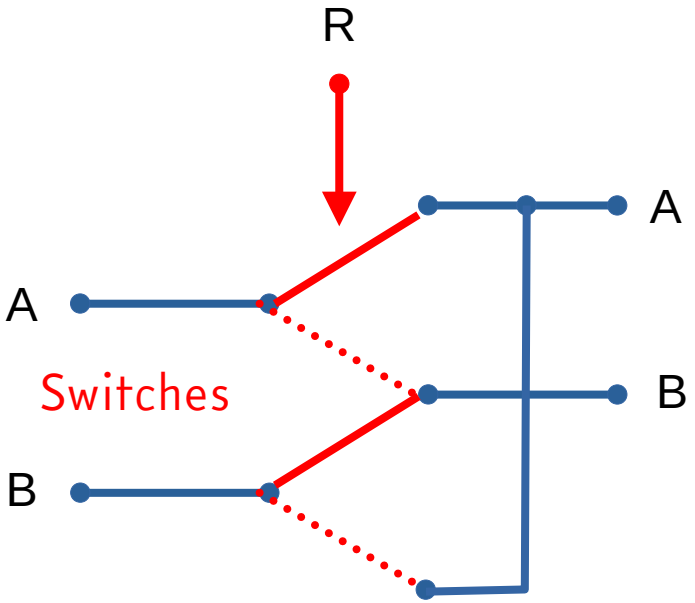


Common coil relay

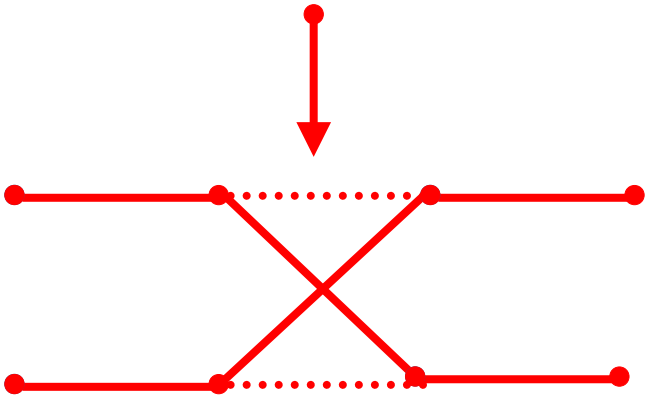
NC = normally closed

NO = Normally open

Inverter (4 ways)



Made of two relays switching Simultaneously



Simplified scheme

I. parallel (direct)
II. Crossed (inverted)

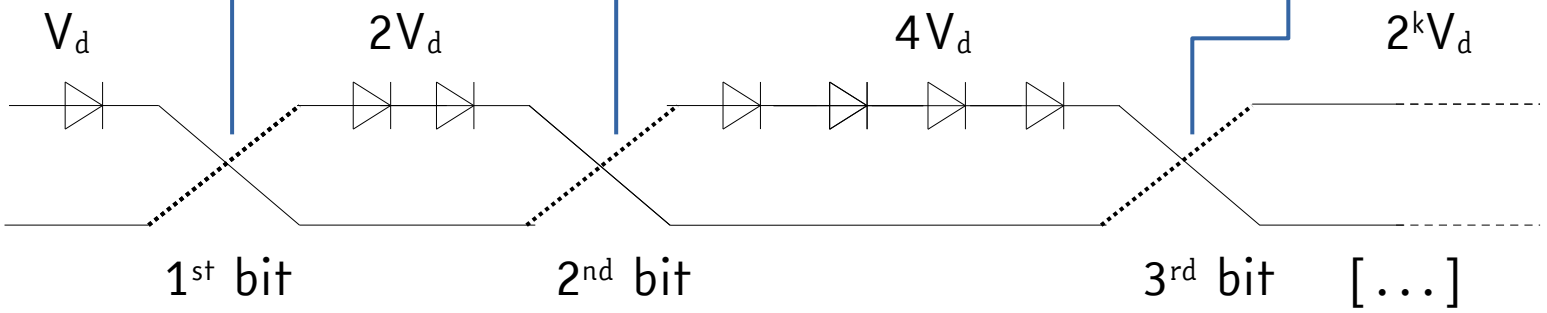
Encoding

0-20000 V
(in steps of V_d = 10 V)
Ex: 3142 V

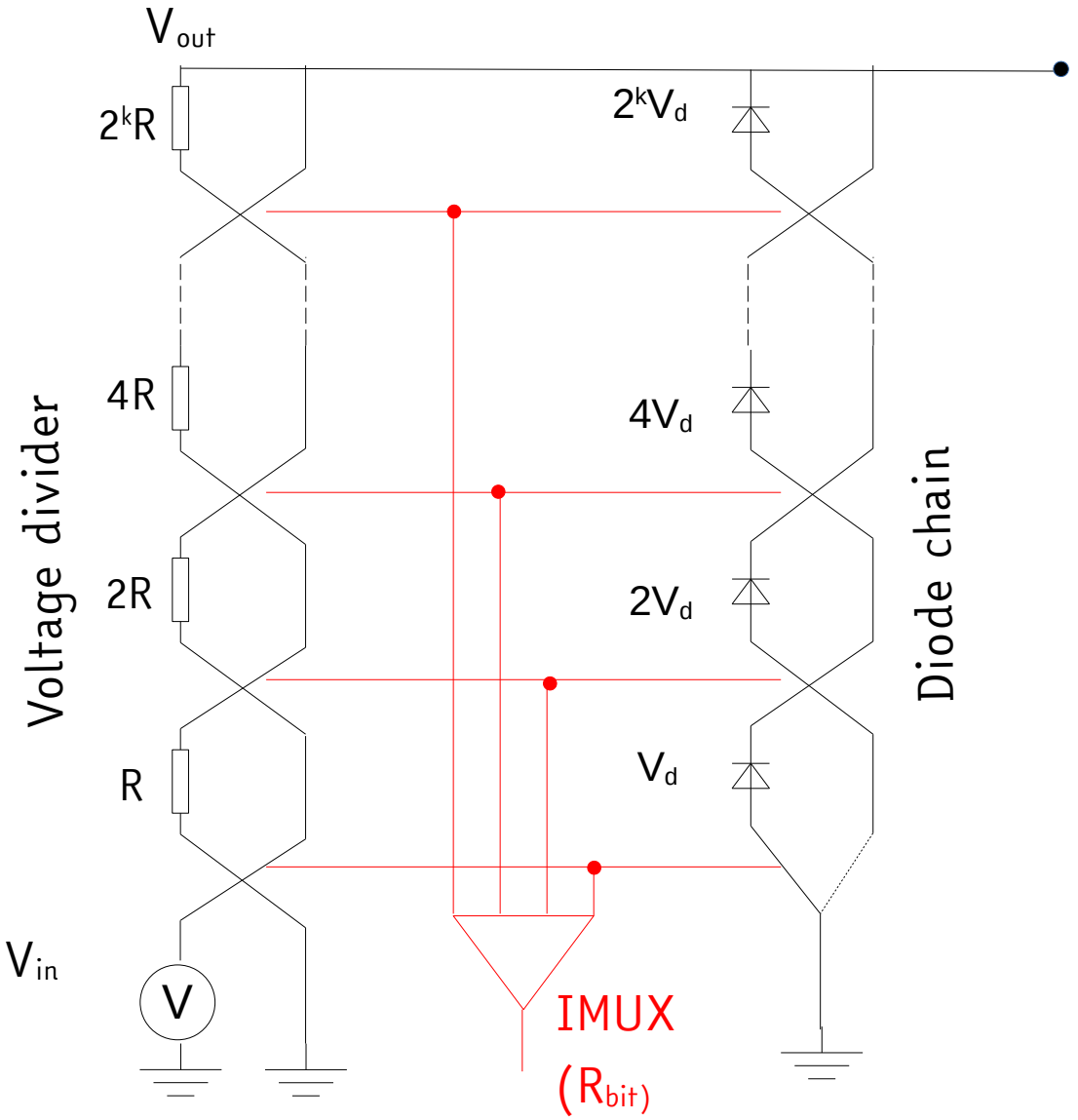
0-2000
11 bit (2048)
Ex: 314

Inverse MUX
Ex:
00100111010

IMUX

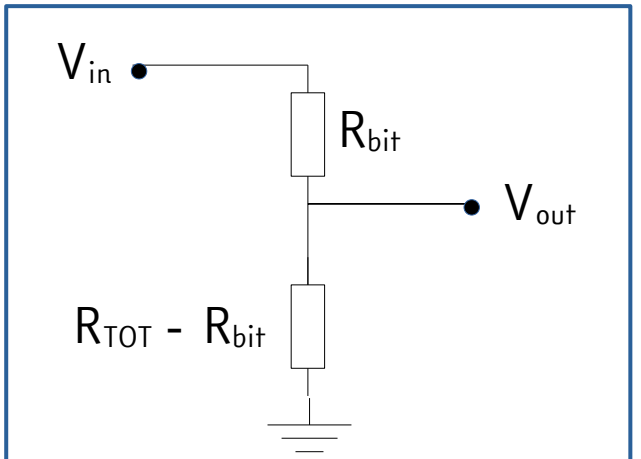


Divider



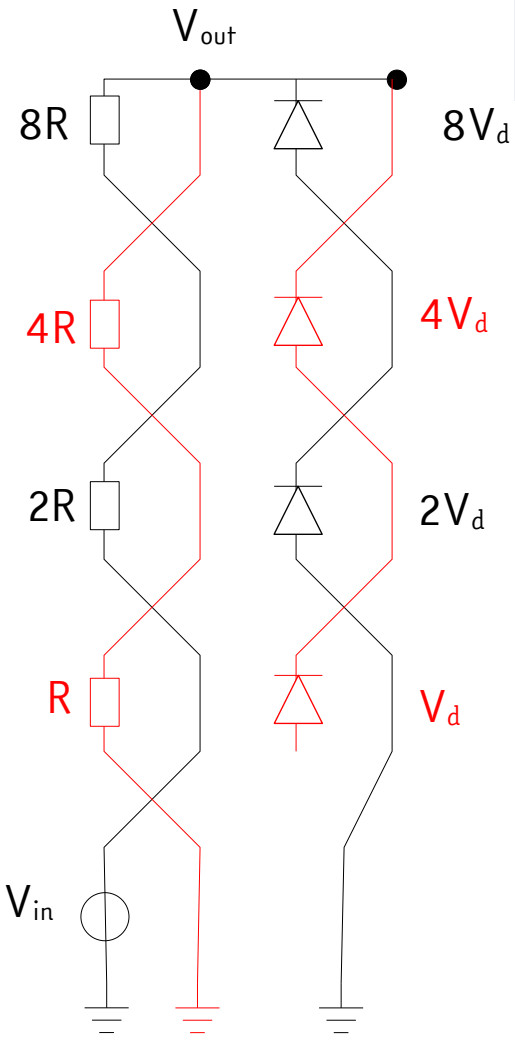
Vout (stable)

Voltage divider equivalent



$$V_{out} = V_{in}(R_{bit}/R_{tot})$$

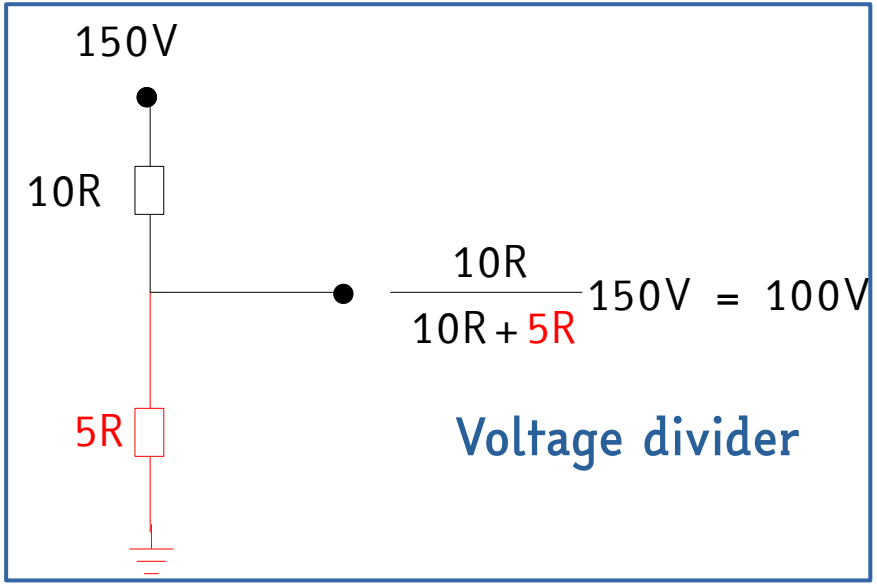
"4 bit" example



$1+2+4+8 = 15 \rightarrow V_{in} = 150$ V

Ex: $V_{out} = 100$ V

$100 \rightarrow N = 10 \rightarrow bit = 1010$

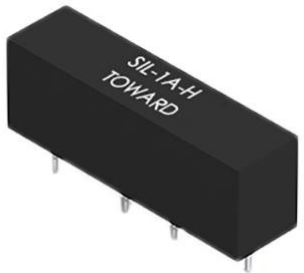


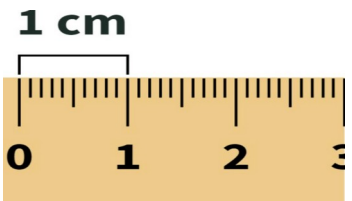
Diode Chain

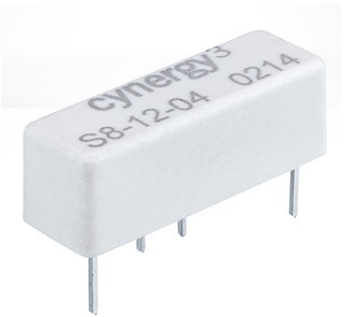
$8V_d + 2V_d \rightarrow 100$ V

High Voltage Relay

On the market…







A. Low noise

Solid-state relay (SSR)

(up to 2 kV)

B. Low noise

Reed switch relay

(up to tens of kV)

Next actions

Problem to face

- Fast output
- Leakage current
- Electromagnetic emission
- Field mill inertia

Test bench

- Realization of a small prototype < 1 kV with SSR
- Preliminary test with precision multimeter

Thank you very much!