Ambient Sensing and Processing Group

Politecnico di Torino

DRIFT REJECTION FRONT-END FOR LONG-RANGE CAPACITIVE SENSORS FOR HUMAN INDOOR LOCALIZATION

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INDOOR LOCALIZATION

- Monitor human activities to detect the early onset of diseases
- Assisted living for elderly people
- Detect unauthorized intrusions
- Home automation
- Reduce energy consumption

CAPACITIVE SENSORS - PRIMER

Capacitive sensors working in load mode:

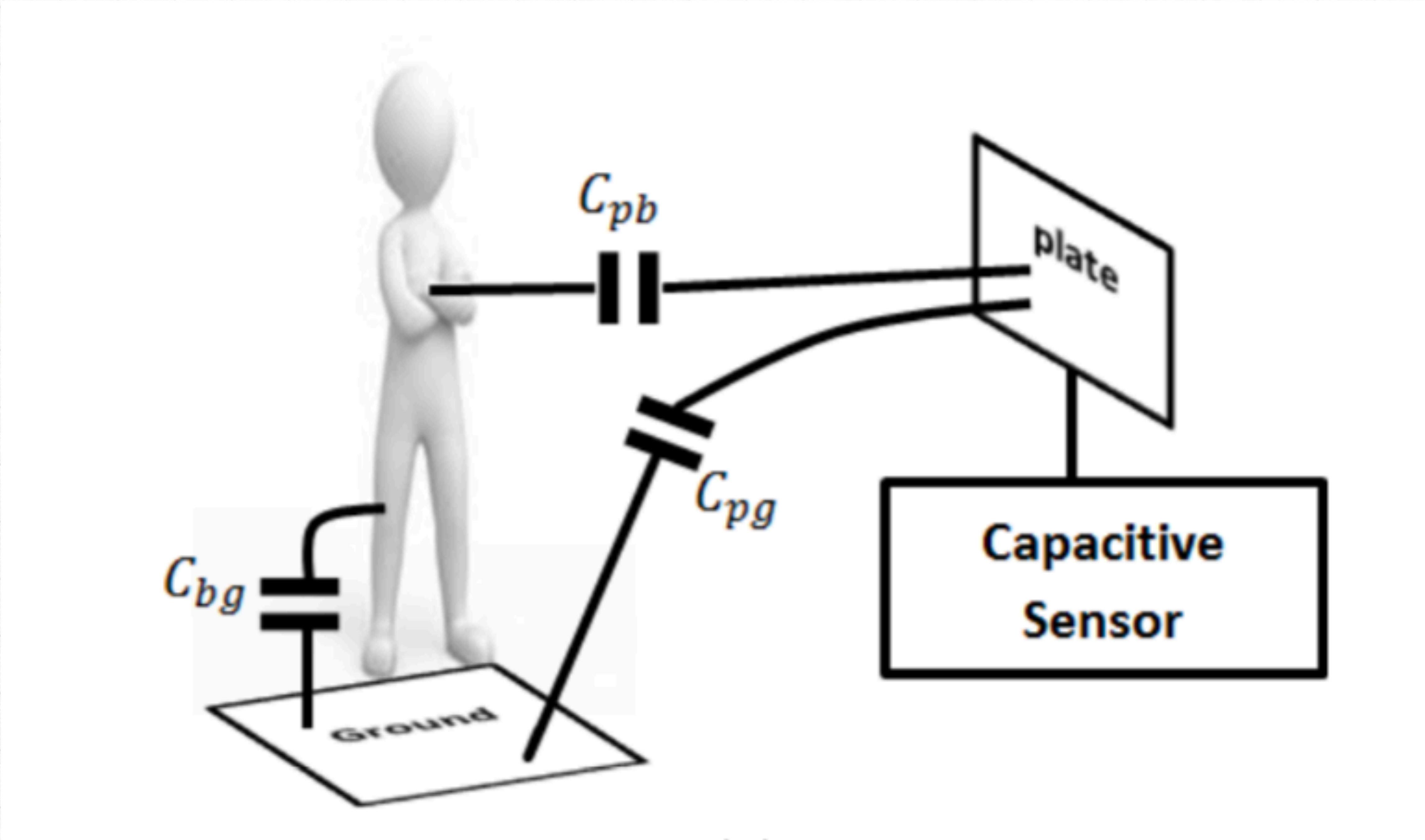
- One-plate transducer
- Human body as a constant-potential plate

PROs

1. Privacy-aware
2. Low power
3. Low cost of installation
4. Tagless
5. Detection of conductive and non-conductive objects

CONs

1. Short sensing range
2. Electric and electromagnetic noise can limit accuracy



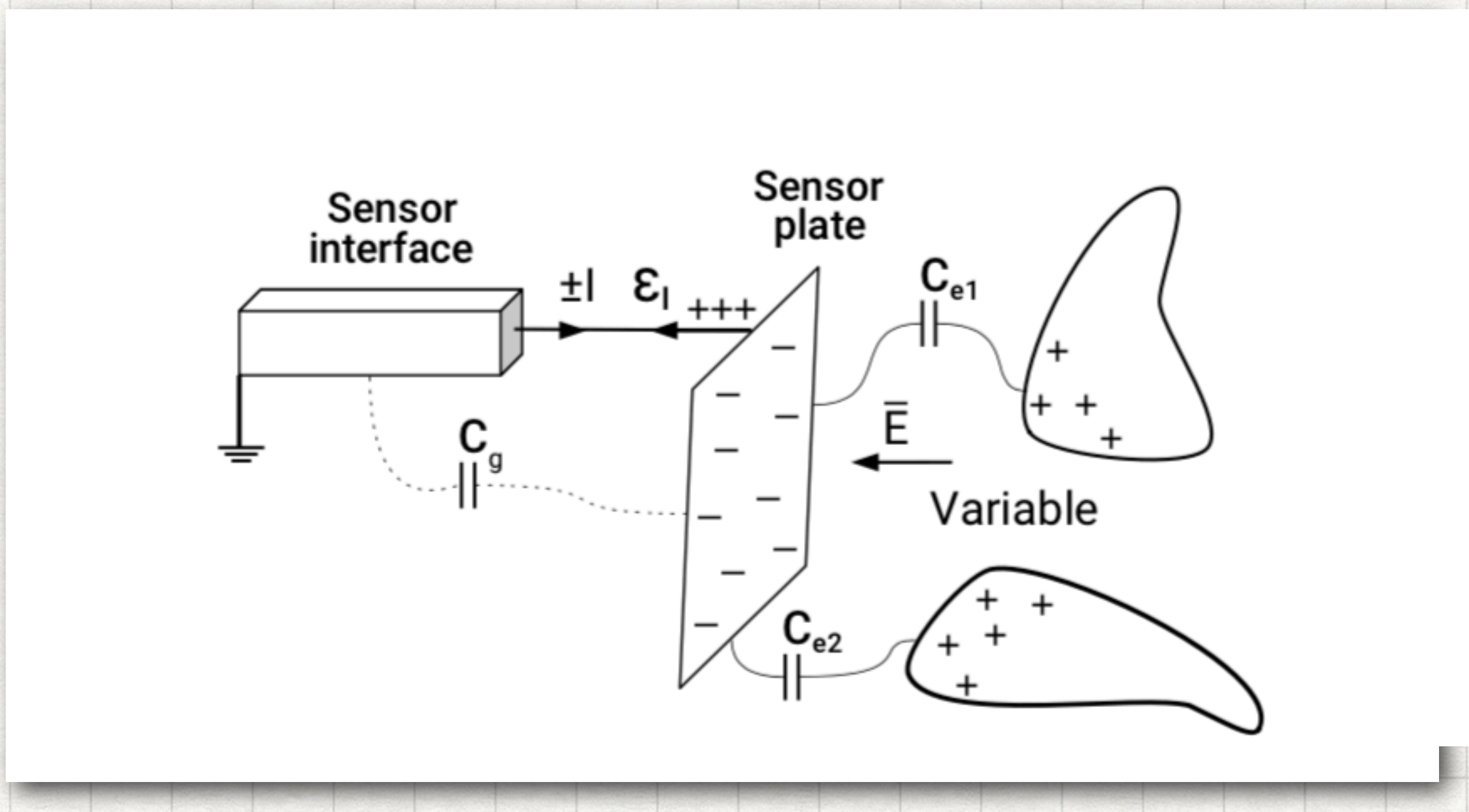
MAIN SOURCES OF NOISE

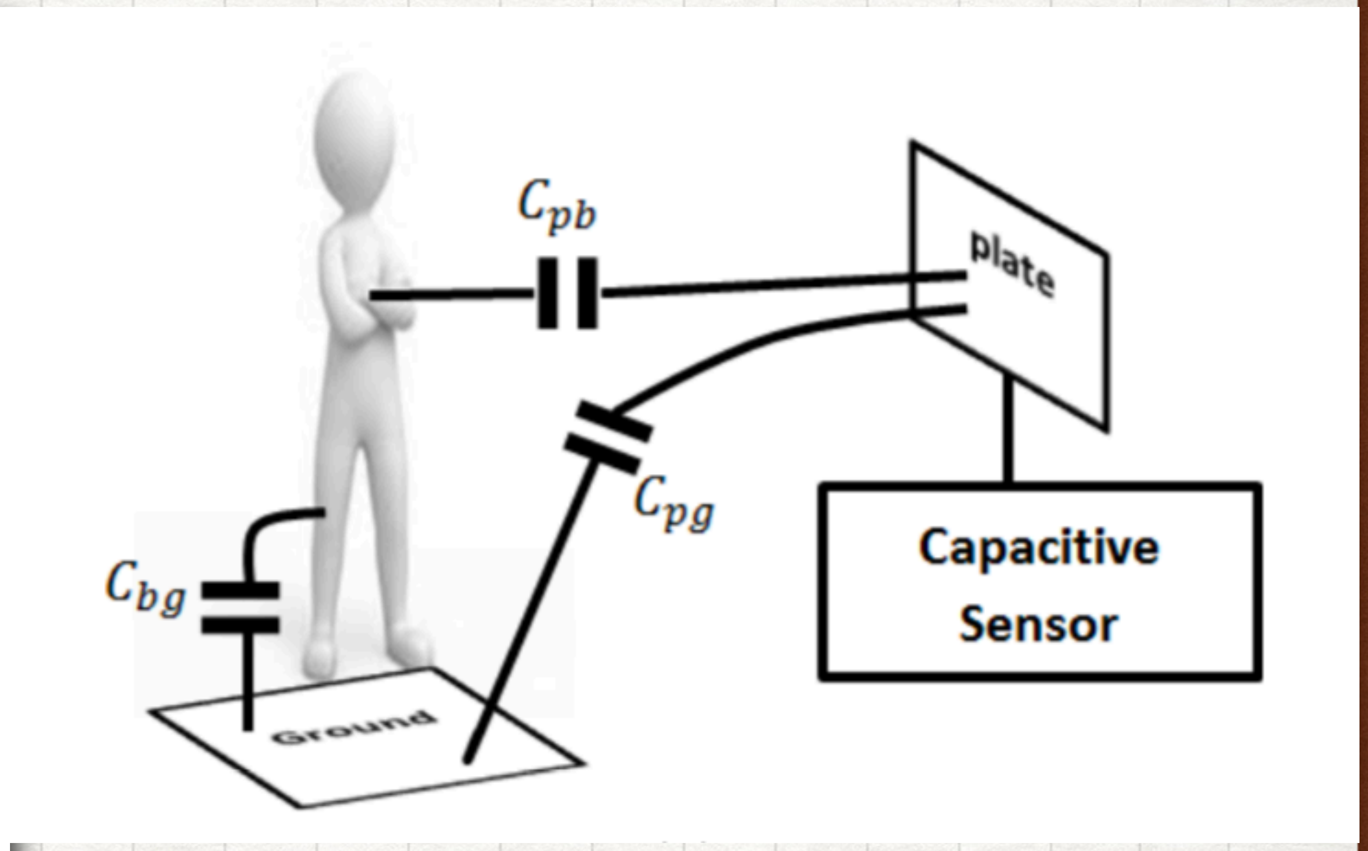
★ Low Frequency —> Measurement Drift

- Environmental charge buildups —> E variation —> induced drift current εi —> influence sensor interface parameters without a real change in sensor capacitance

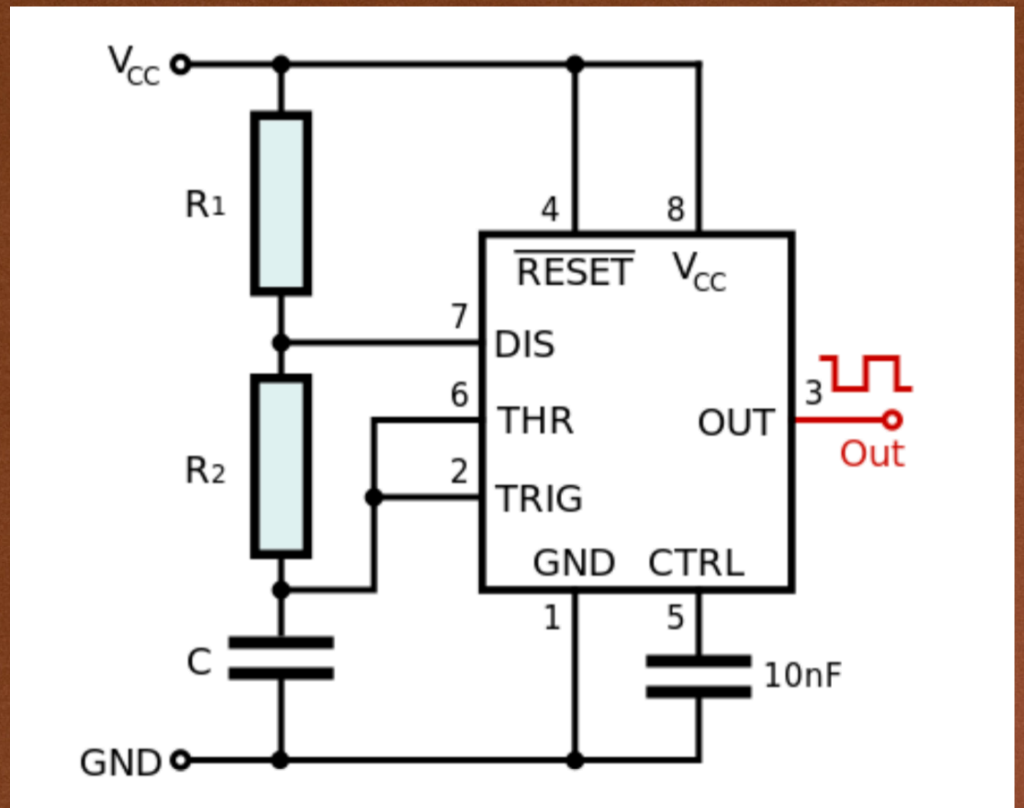
- Actual capacitance changes —> e.g variable air humidity

★ High Frequency —> Measurement Jitter

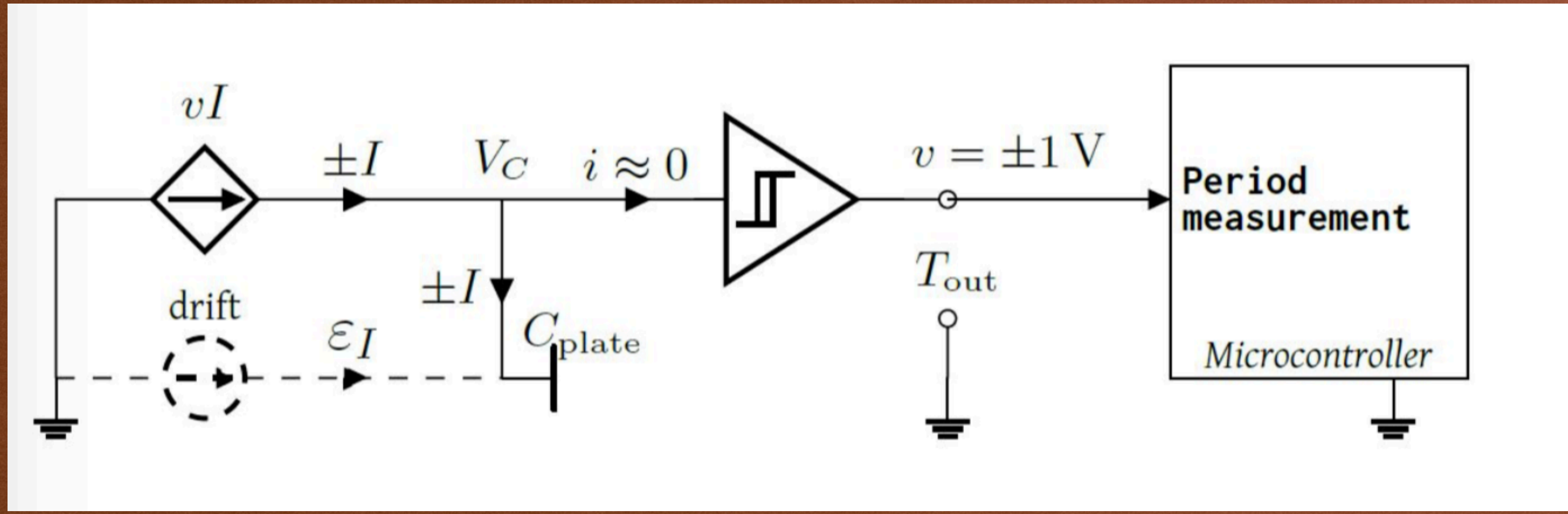




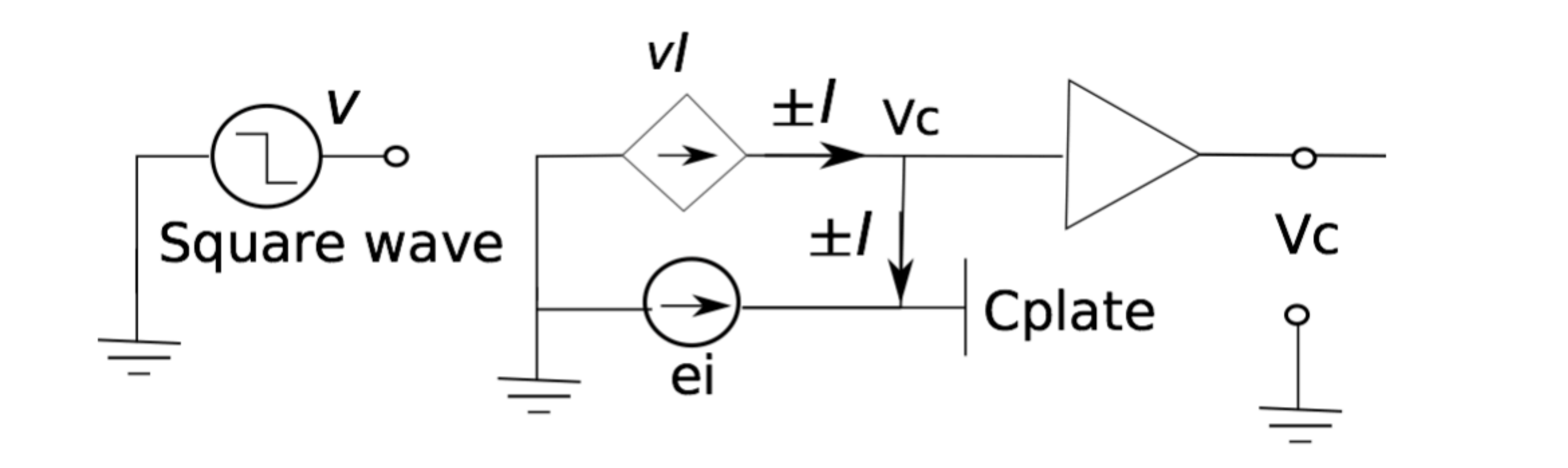
THREE ANALOG SIGNAL CONDITIONING CIRCUITRY



- RC-FE: period modulator, based on astable multivibrator



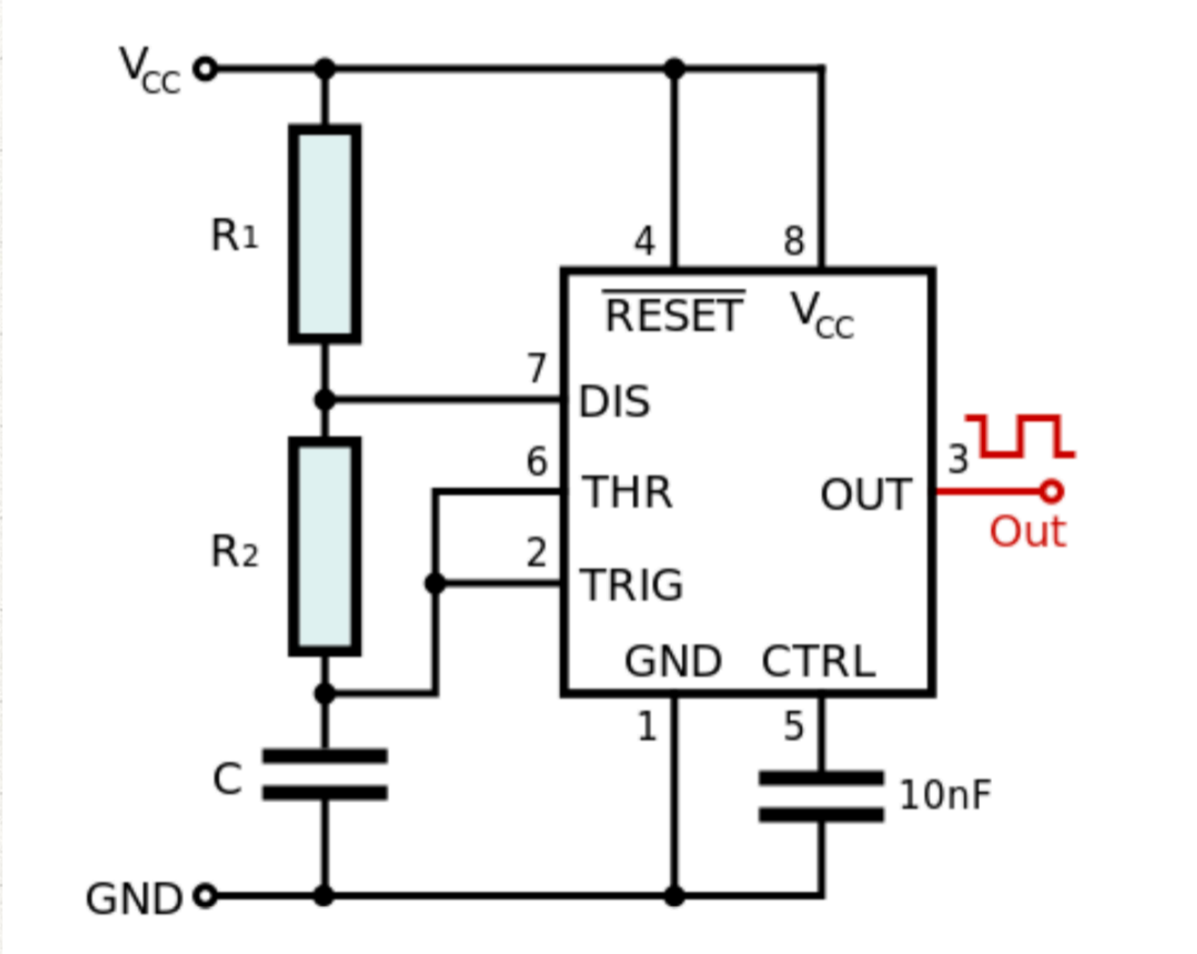
- IC-FE: period modulator, based on constant current charge-discharge



- IC-FE: slope modulator, based on constant current charge-discharge

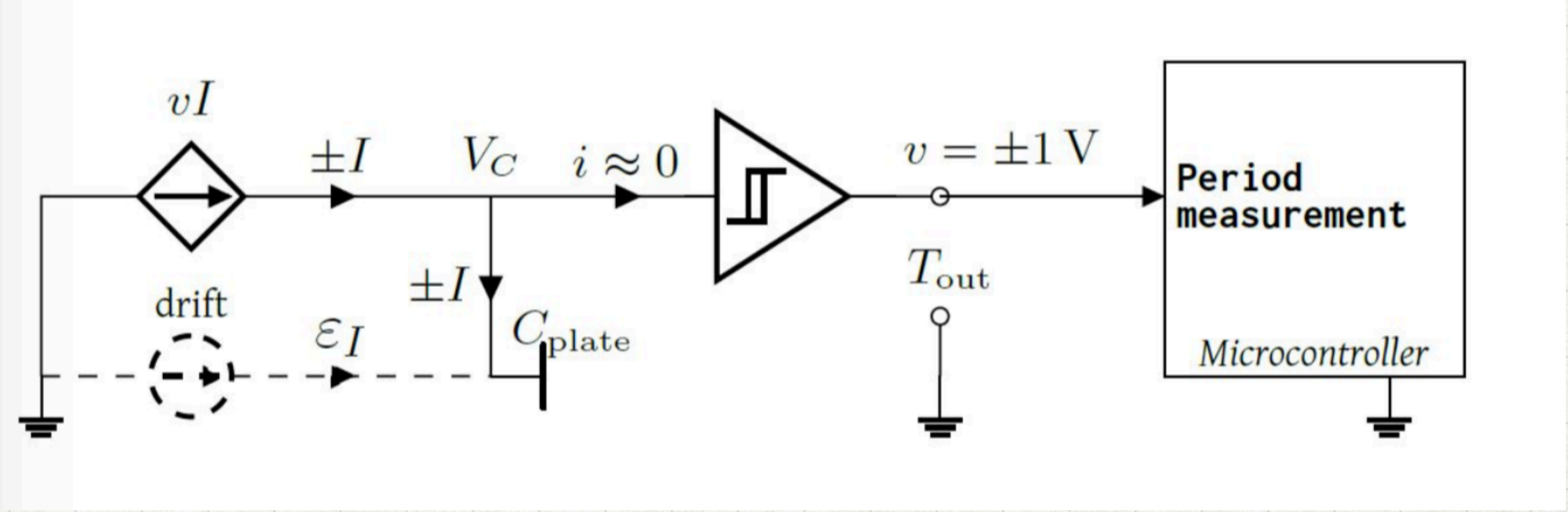
RC PERIOD MODULATOR

- astable oscillator
- RC-FE output is a square wave
- The period of the square wave depends on resistances value and capacitance value
- The two resistors are fixed



IC PERIOD MODULATOR

- It cyclically charges and discharges the plate using a voltage-controlled current source with constant current
- It uses a trigger of Schmitt with hysteresis thresholds
- As soon as the voltage triangular wave reaches one of the thresholds, the output of the trigger swings, consequently, the current source changes sign



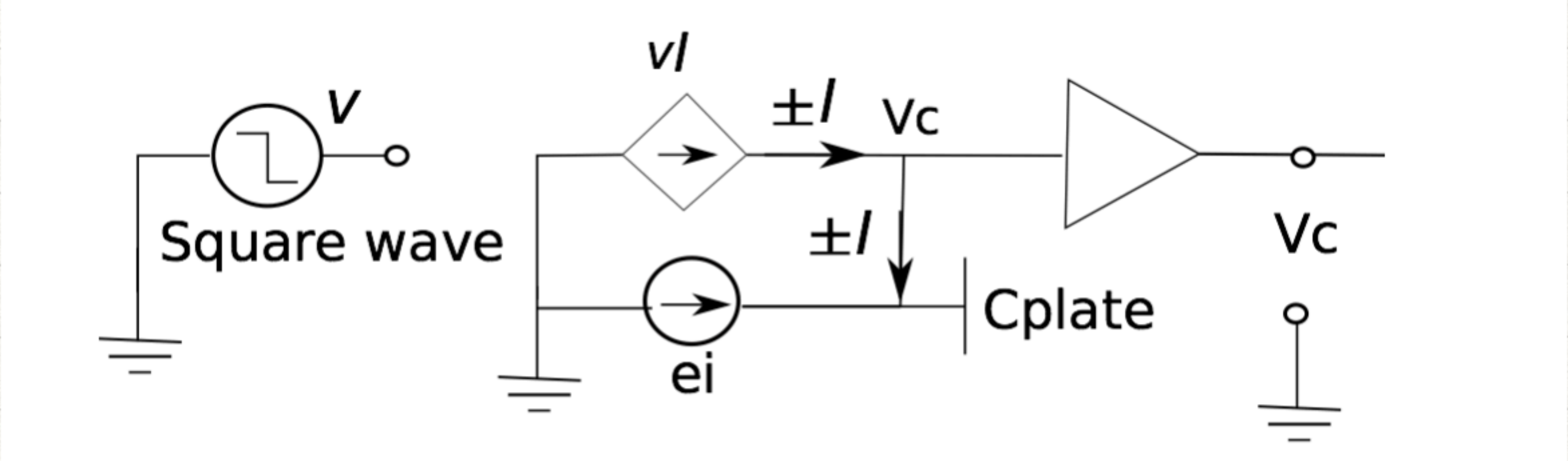
SLOPE MODULATOR

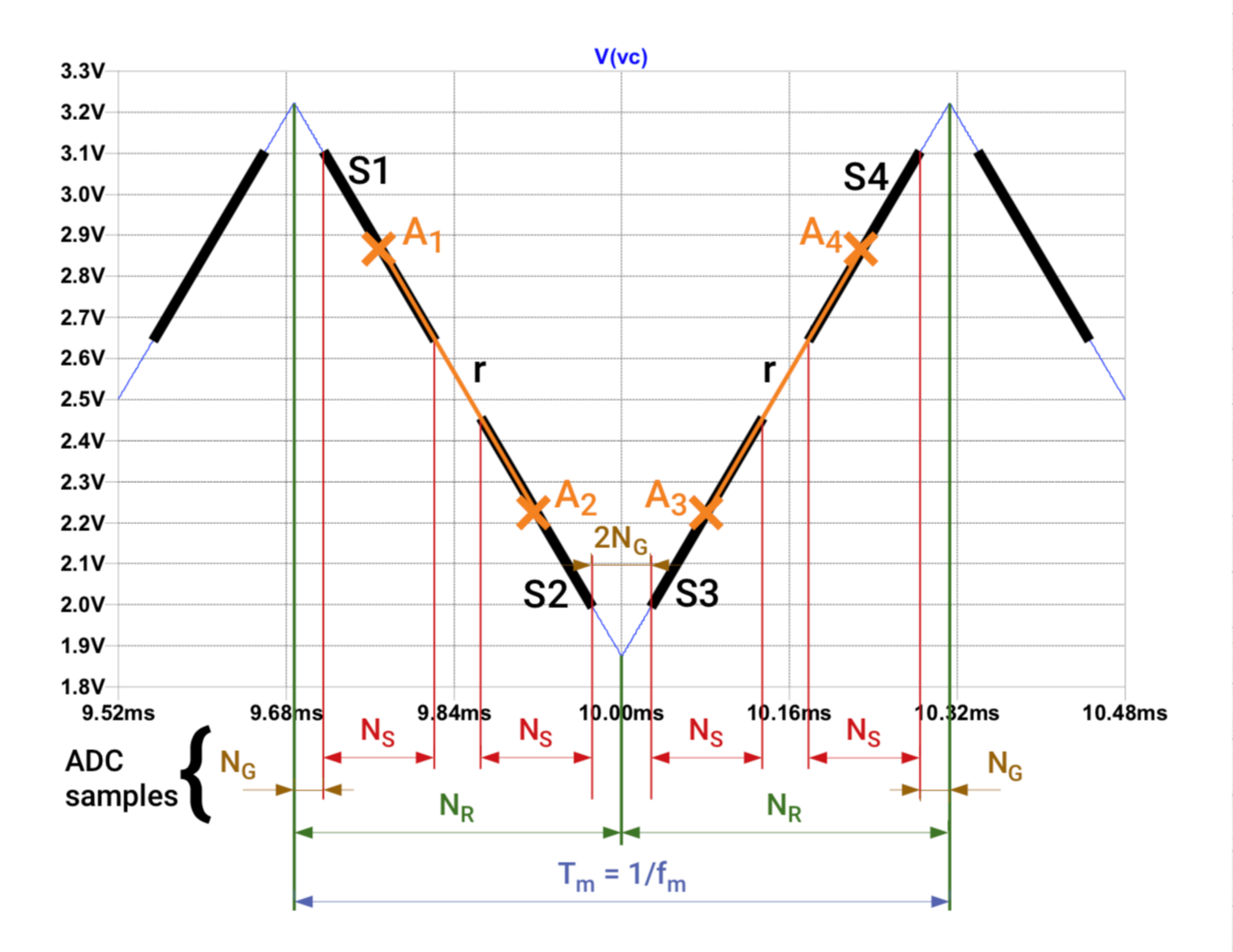
- ✦ Constant current that charges/discharges the plate, driven by a square wave
- ✦ Fixed charging/discharging time
- ✦ Plate voltage Vc is a triangular wave
- ✦ No pre-defined thresholds
- ✦ An Analog to Digital Converter is used to sample the plate voltage
- ✦ Digital calculation of two adjacent ramps with noise reduction
- ✦ Capacitance of the sensor is proportional to slope average

Each segment is oversampled Ns time:

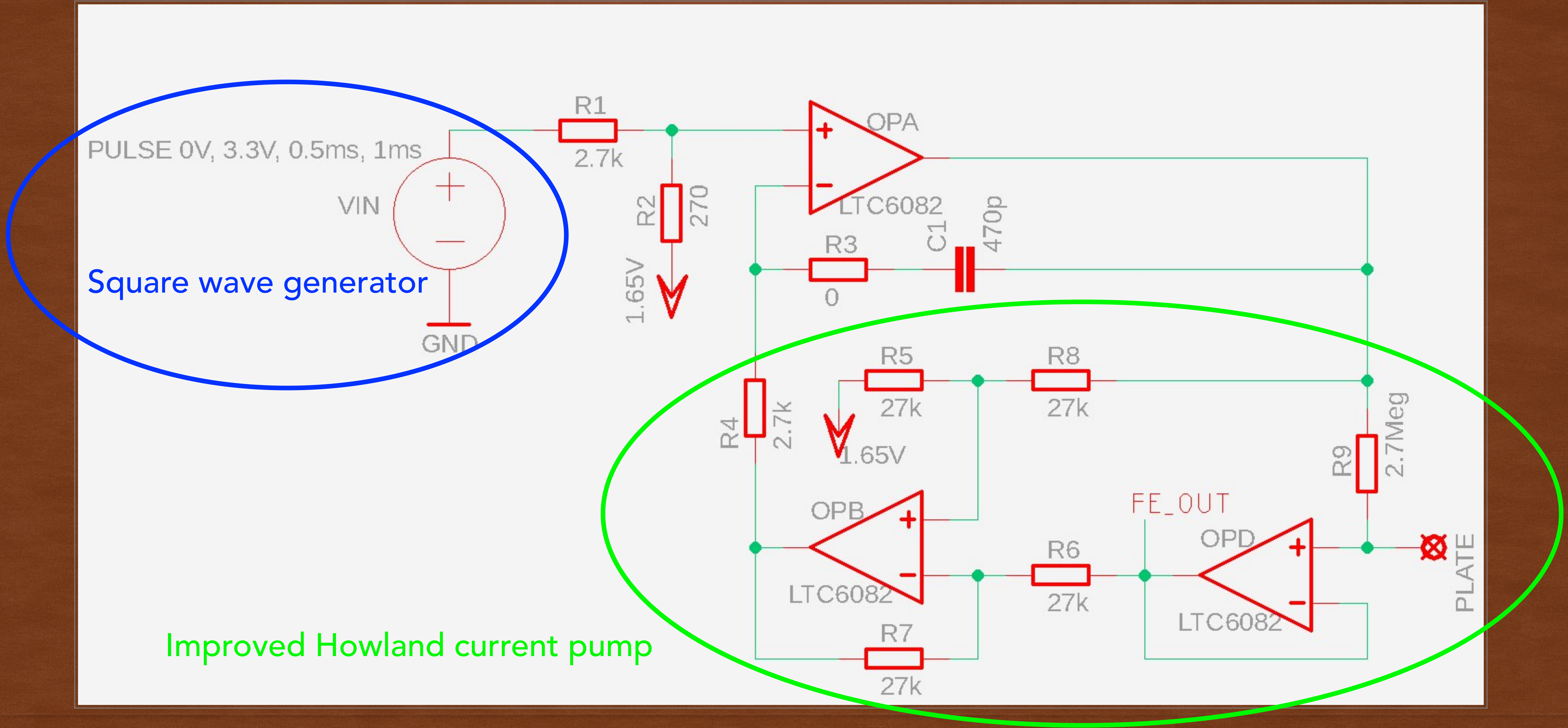
$Ns = 4^n$ (n additional accuracy bits after processing)

- Nr=1000
- Ns=256
- Ng=243
- r=2



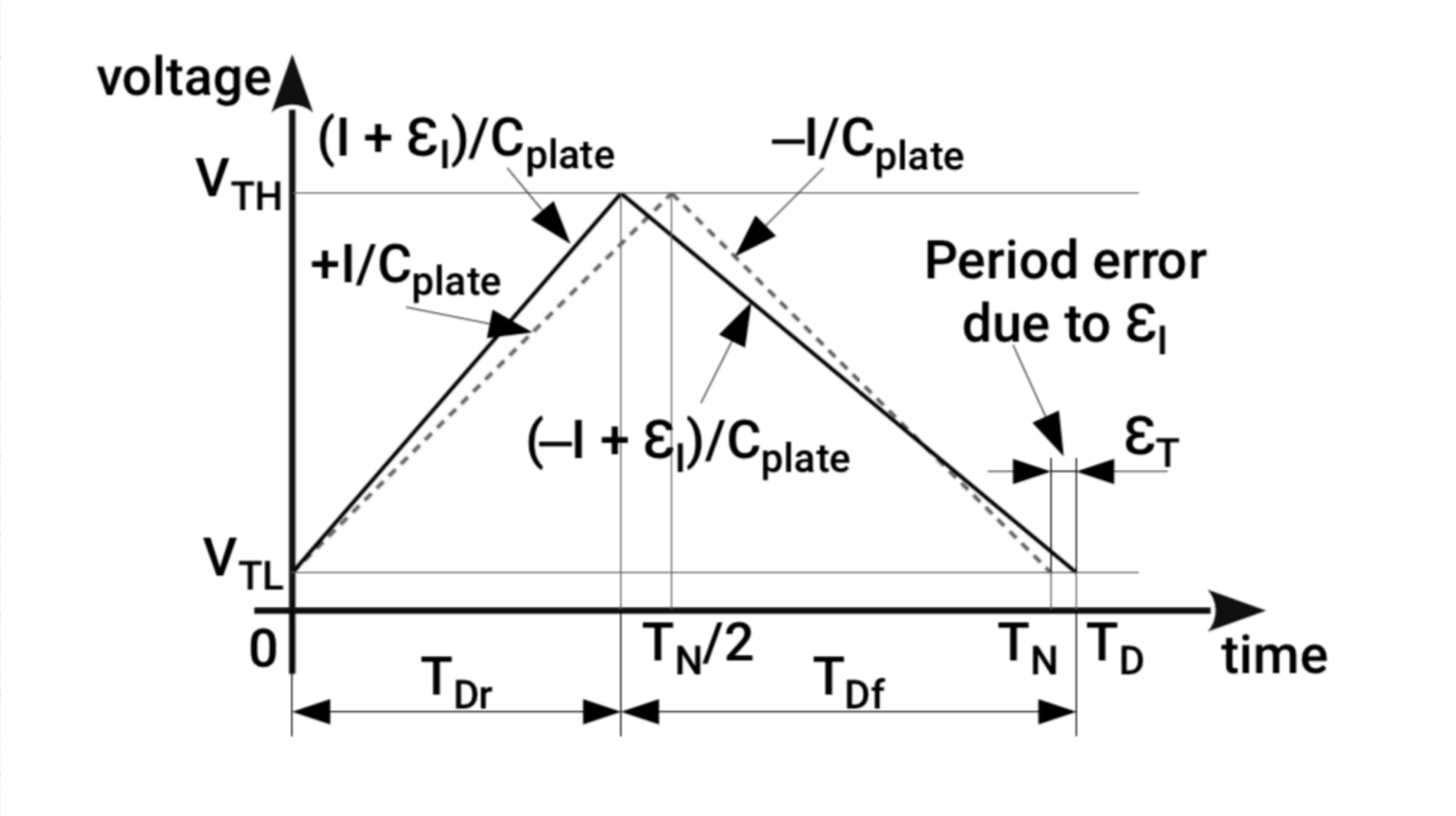


SLOPE MODULATOR CIRCUIT



PERIOD MODULATOR AND SLOPE MODULATOR MEASUREMENT TECHNIQUES AND QUASI-CONSTANT DRIFT CURRENT REJECTION

PERIOD MODULATOR

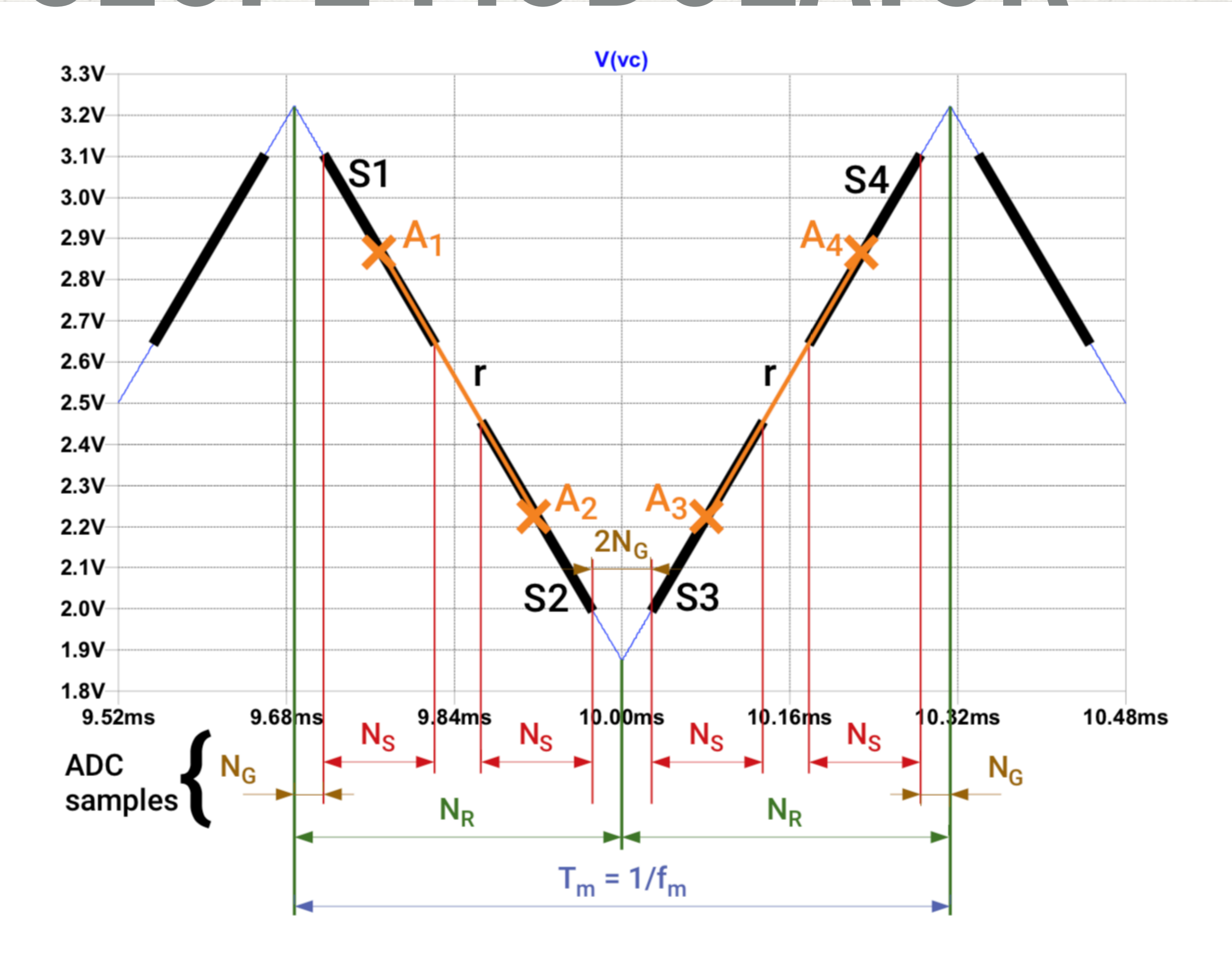


$$C_{\text{plate}} = \frac{I}{2\,(V_{\text{TH}} - V_{\text{TL}})} T_{\text{N}}.$$

$$T_{\text{Dr}} = C_{\text{plate}} \frac{V_{\text{TH}} - V_{\text{TL}}}{I + \varepsilon_I}, \quad T_{\text{Df}} = C_{\text{plate}} \frac{V_{\text{TL}} - V_{\text{TH}}}{-I + \varepsilon_I}$$

$$T_{\text{D}} = T_{\text{Dr}} + T_{\text{Df}} = \frac{2C_{\text{plate}}\,(V_{\text{TH}} - V_{\text{TL}})\,I}{I^2 - \varepsilon_I^2}.$$

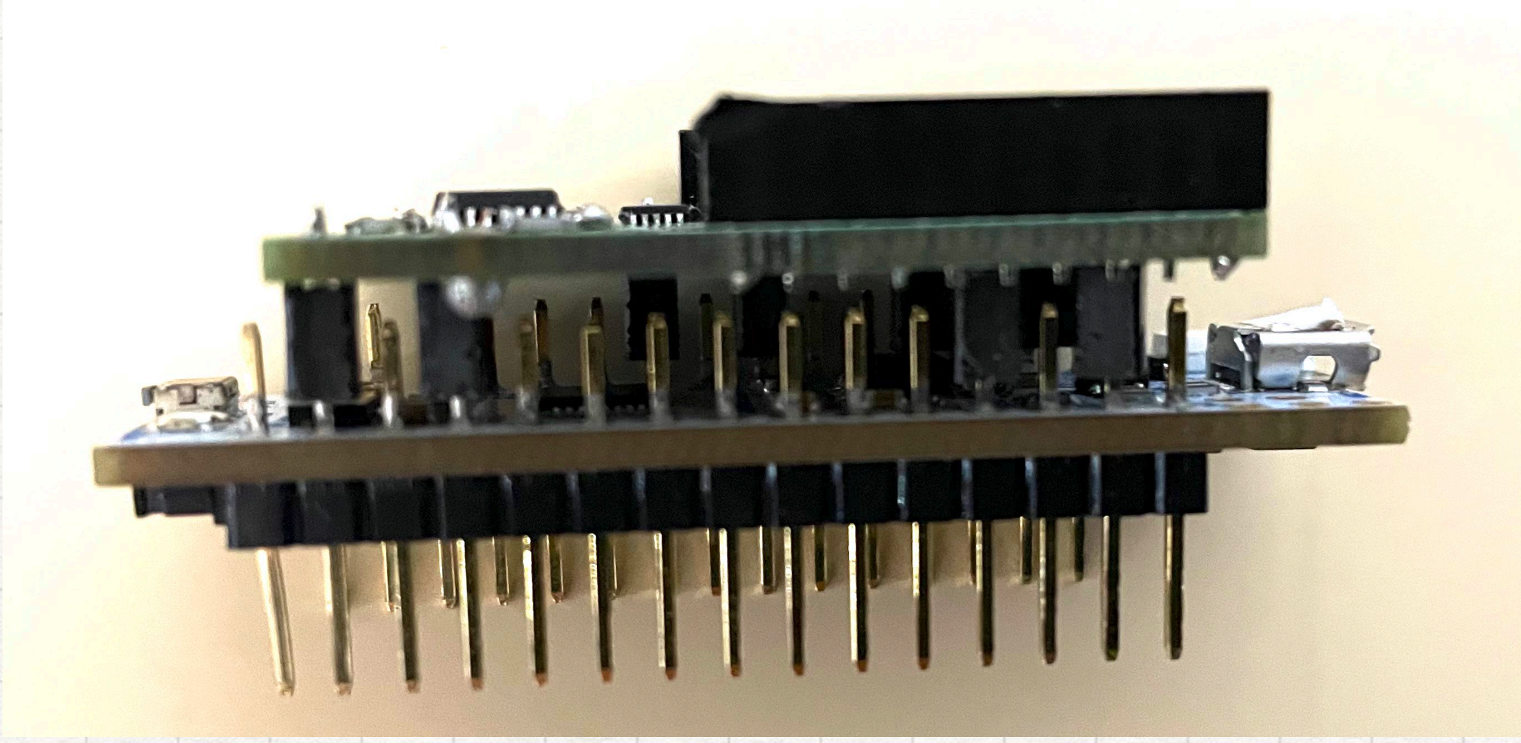
SLOPE MODULATOR



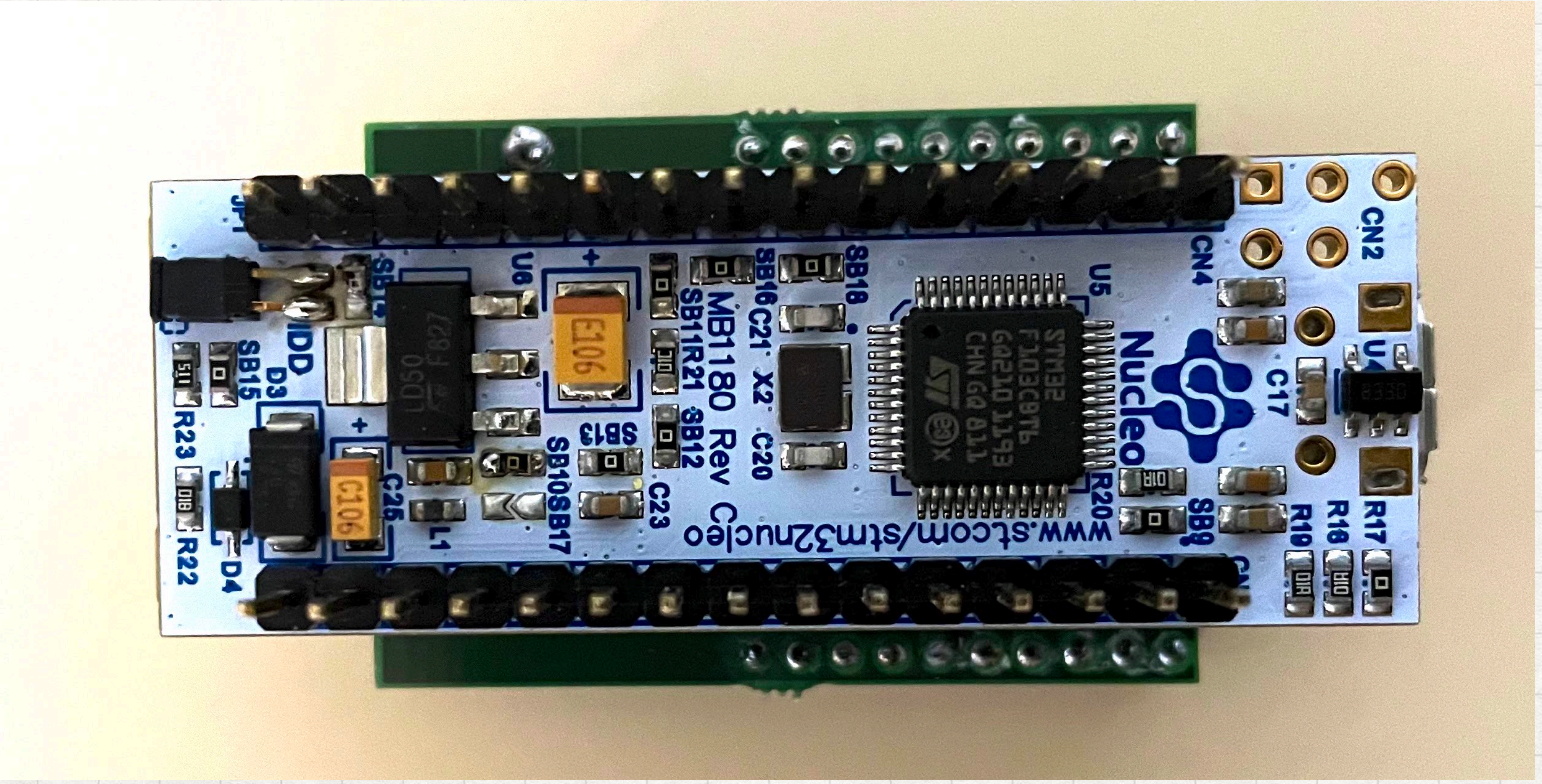
$$S = \frac{\Delta V_C}{\Delta t} = \frac{I}{C_{\text{plate}}}.$$

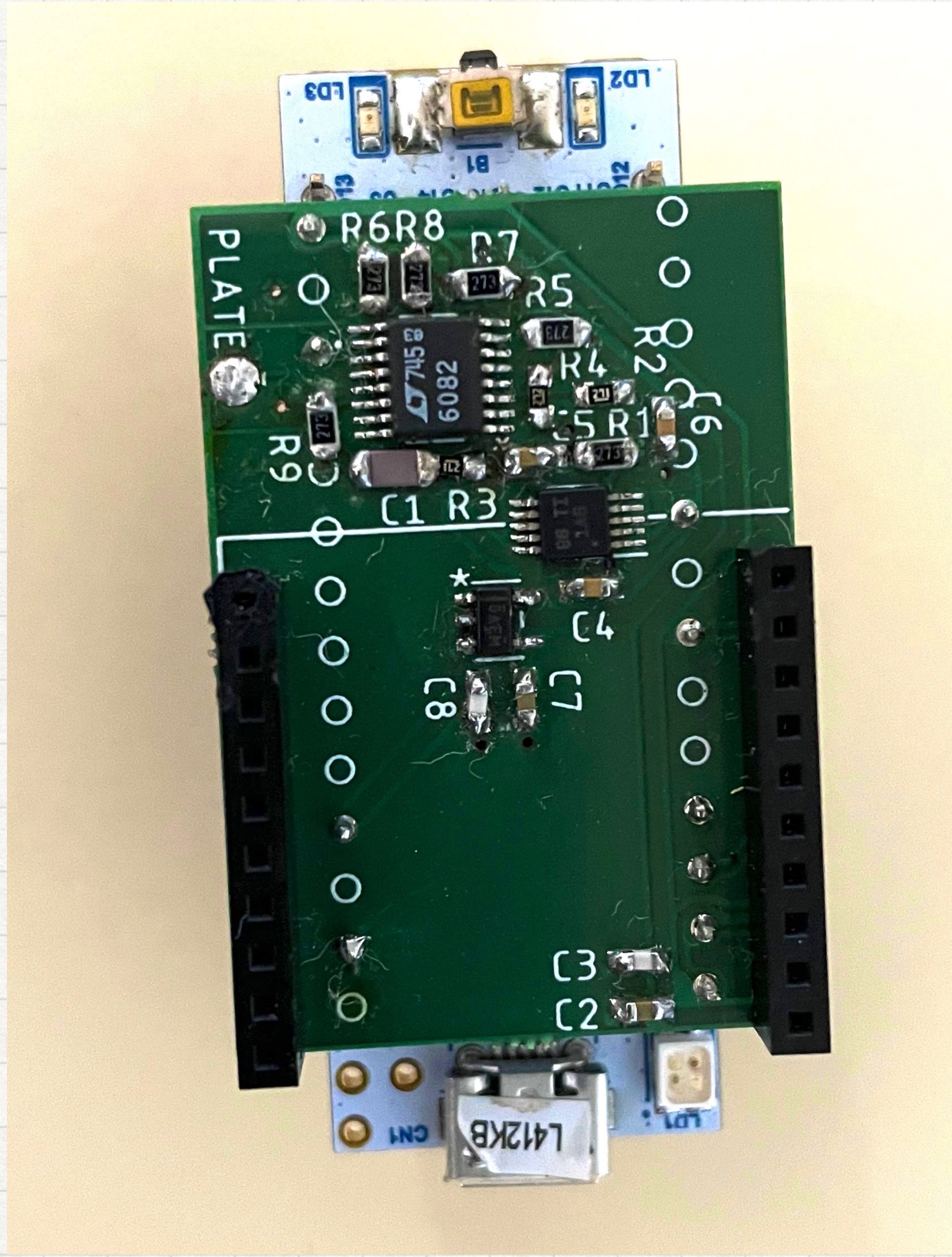
$$S_r = \frac{I + \varepsilon_I}{C_{\text{plate}}}, \qquad S_f = \frac{-I + \varepsilon_I}{C_{\text{plate}}}$$

$$S_a = \frac{|S_r| + |S_f|}{2} = \frac{1}{2}\left(\frac{I + \varepsilon_I}{C_{\text{plate}}} - \frac{-I + \varepsilon_I}{C_{\text{plate}}}\right) = \frac{I}{C_{\text{plate}}}$$



SLOPE MODULATOR PCB+ STM L412KB MICRO CONTROLLER





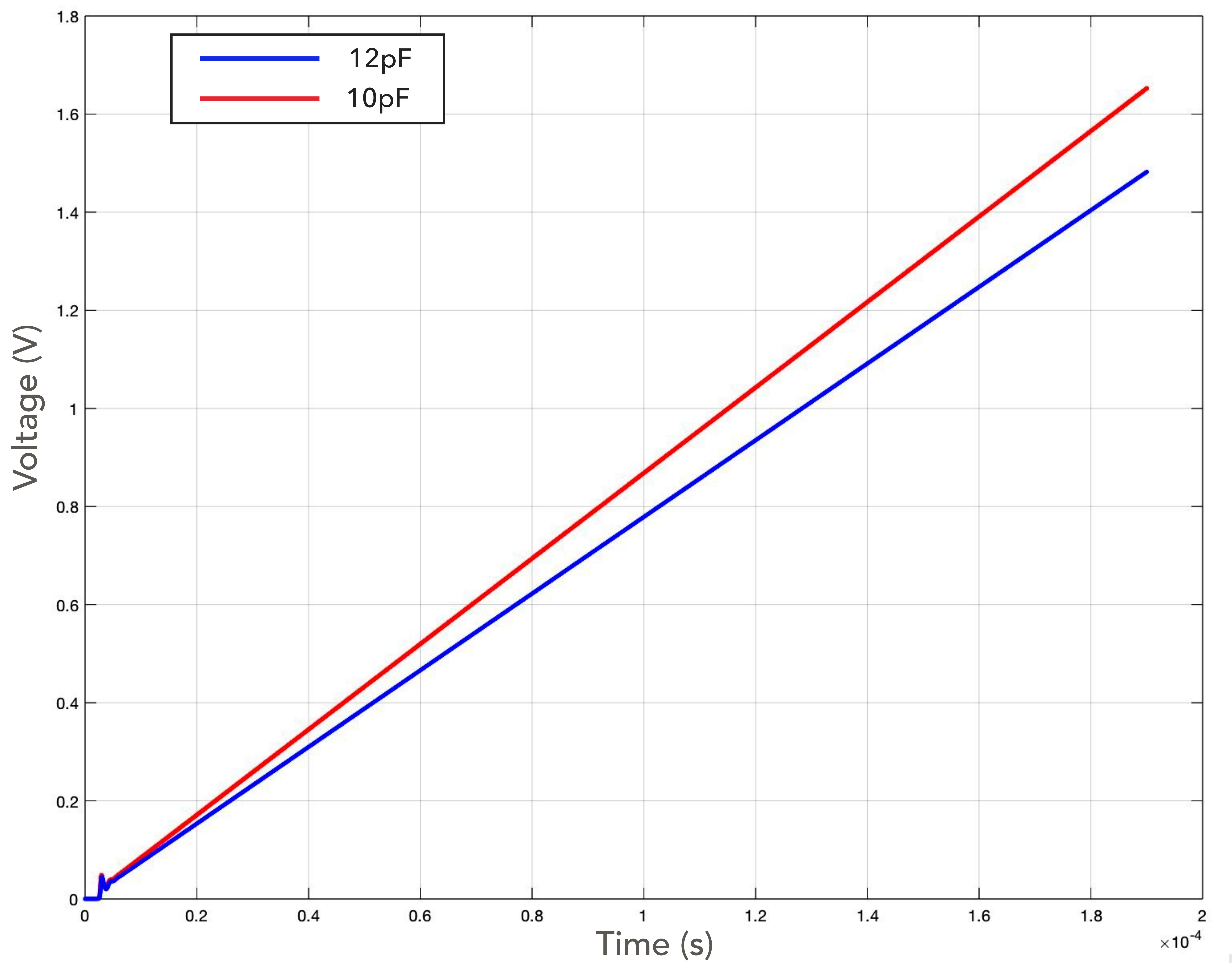
SENSITIVITY CHARACTERIZATION

Sensitivity as a variation of the output signal (slope), for small variation in the capacity of the plate.

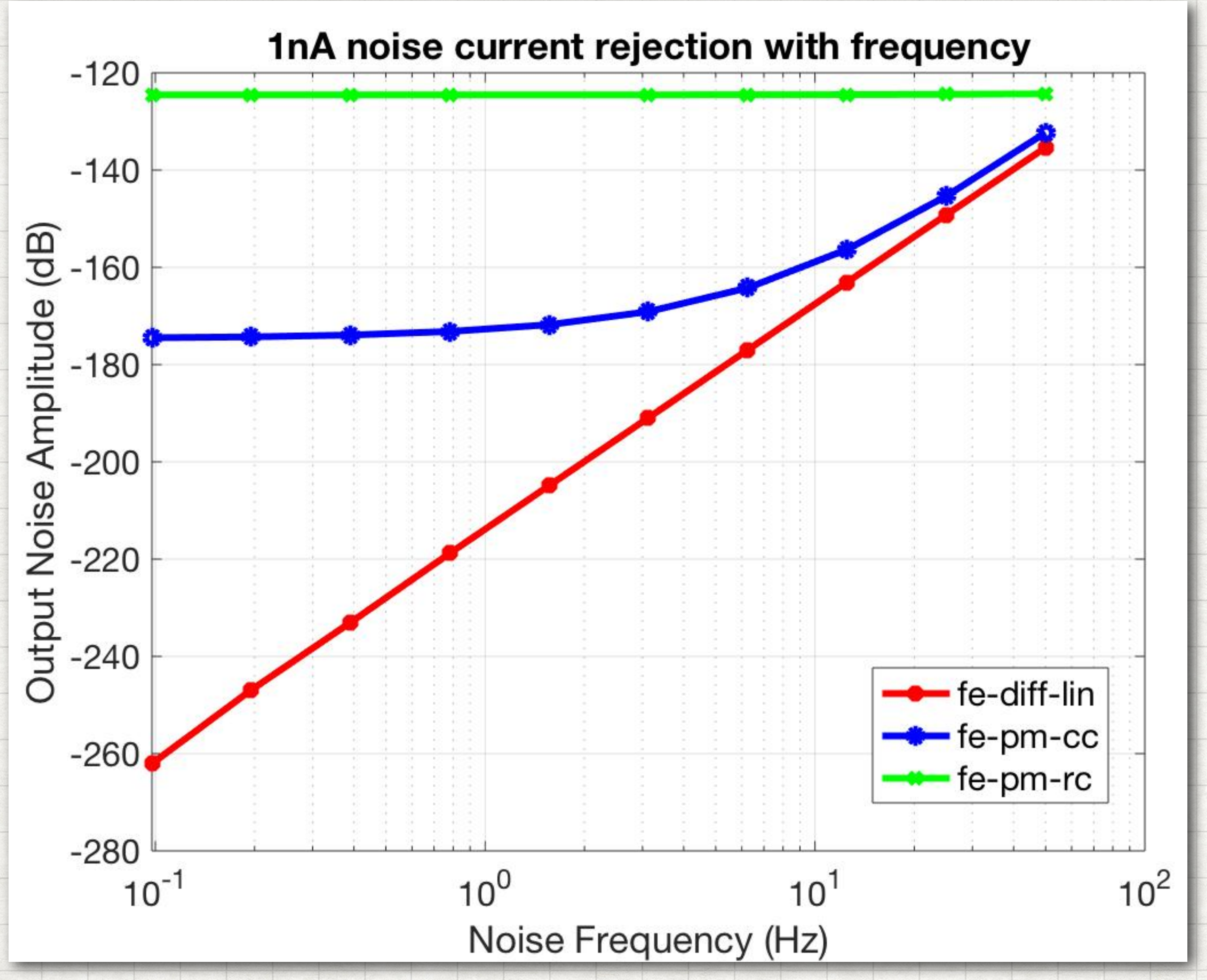
C	C′
10pF	12pF
S	S′
8697.0897V/s	7800.5667V/s

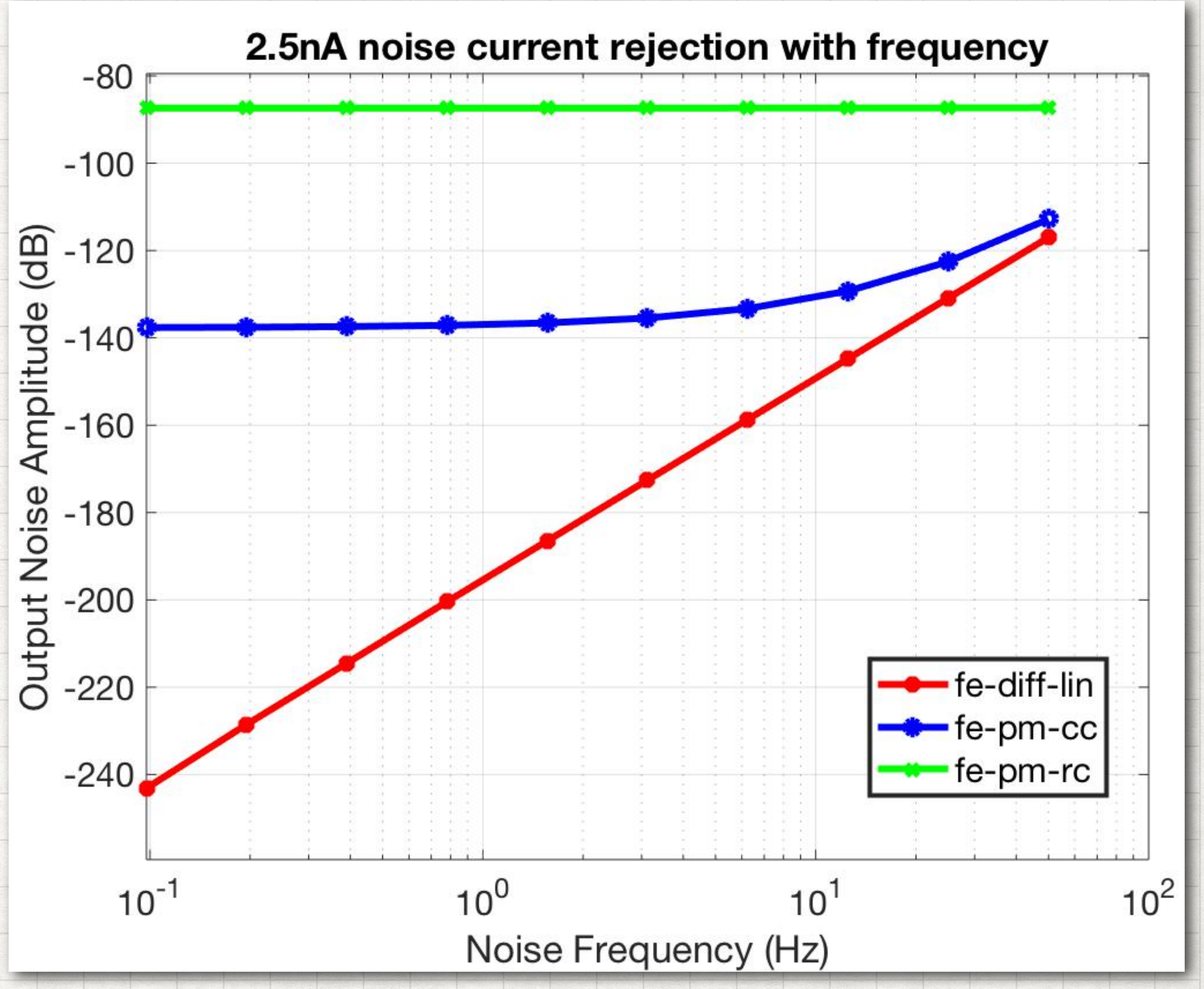
$$Srel\,\% = \frac{\frac{|S-S'|}{S}}{\frac{|C-C'|}{C}} \cdot 100$$

$$Srel\,\% = \frac{\frac{|8697.0897-7800.5667|}{8697.0897}}{\frac{|10-12|}{10}} \cdot 100 = 51\,\%$$



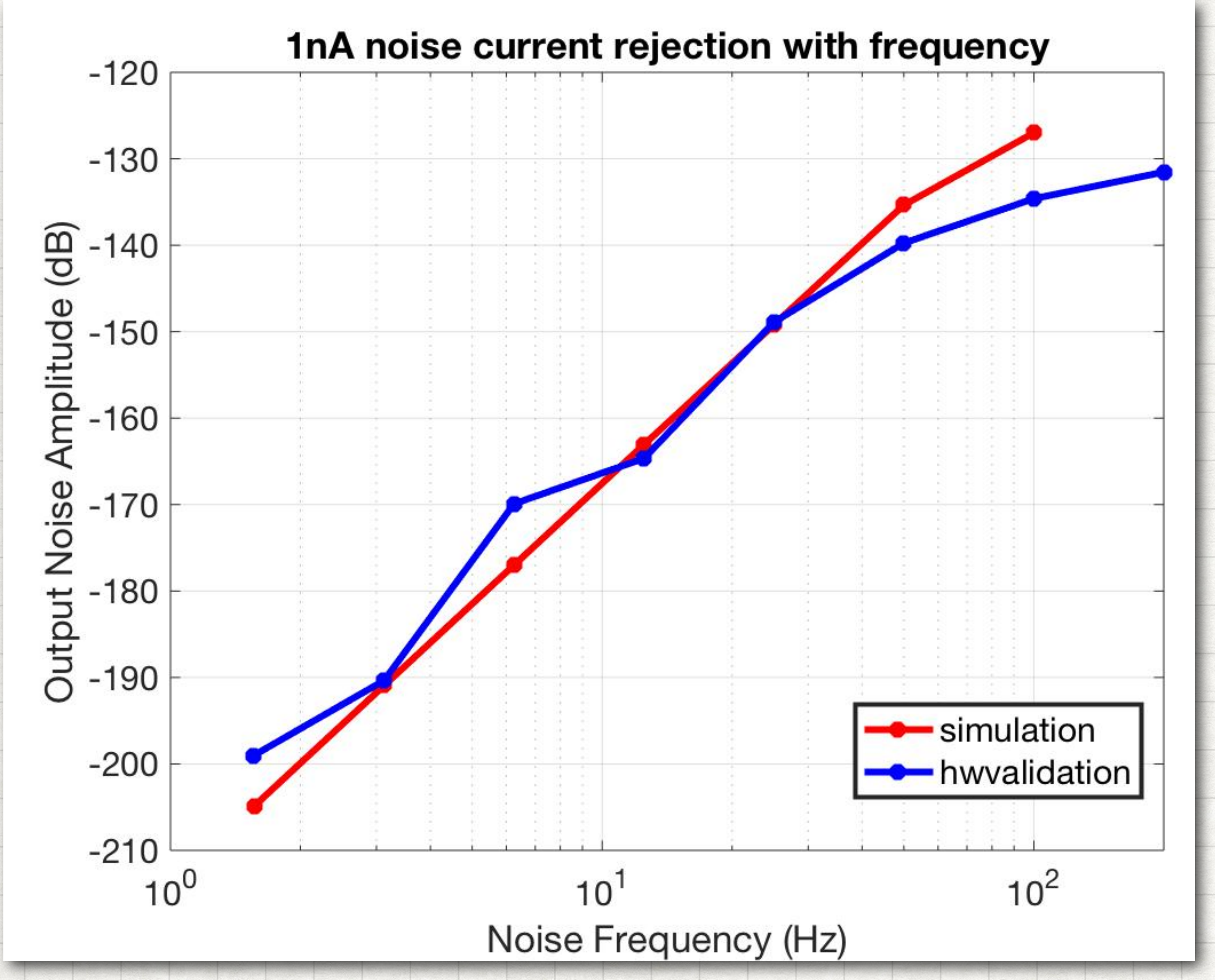
NOISE REJECTION SIMULATION RESULTS

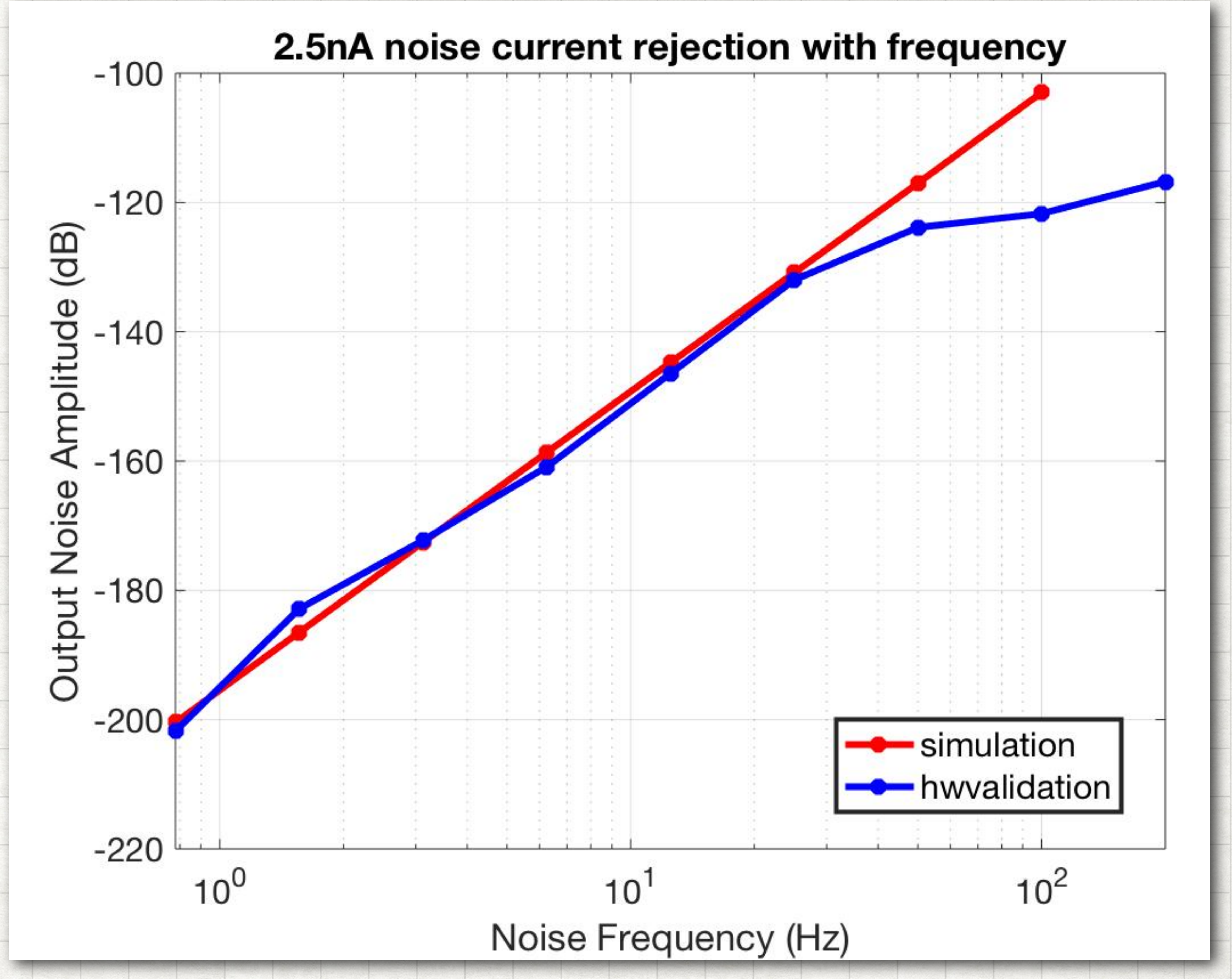




HW VALIDATION

SLOPE MODULATOR





CONCLUSIONS

- Capacitive sensors: incospicuous, low power, low cost, low maintenance
- Limitations:
  - Sensing range comparable to plate dimension
  - Environmental noise affects accuracy and sensing range
- Slope modulator can reject:
  - High frequency noise —> oversampling and decimation, low pass filter
  - Low frequency noise —> differential measurement technique

THANK YOU FOR THE ATTENTION

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