Signal conditioning for electrochemical sensors

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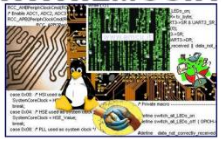


Agenda

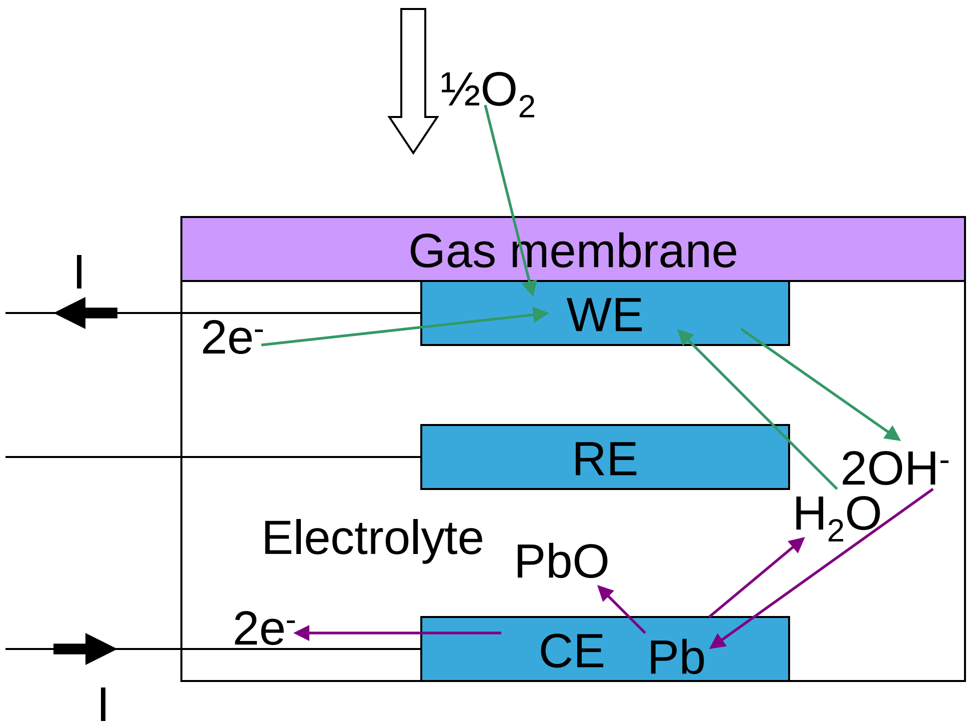
Time	Presentation	Speaker
9:00	Which applications ?	Pierre SENNEQUIER
	What is an electrochemical sensor ?	
	Potentiostat configuration	
	Galvanic configuration	
	From sensor specification to real application	
	Conclusion	

Applications

- Gas sensing
  - Toxic : CO, H_2S, NO_2,…
  - Oxygen (20.9% in air) → risk of suffocation or explosion
  - Refineries, Mining, Semiconductor, Fire fighters, Road construction, …
  - Home (CO new regulations)
- Medical
  - Glucometer

What is an electrochemical sensor

- Different technologies of sensors
  - Electrochemical (amperometric) : Low consumption and linear output
  - Other types of technologies : Metal Oxide Semiconductor, Non Dispersive Infra Red



Oxygen sensor

Oxidation on Working Electrode (WE)

$CO + H_2O \rightarrow CO_2 + 2H^+ + 2e^-$

Reduction on Counter Electrode (CE)

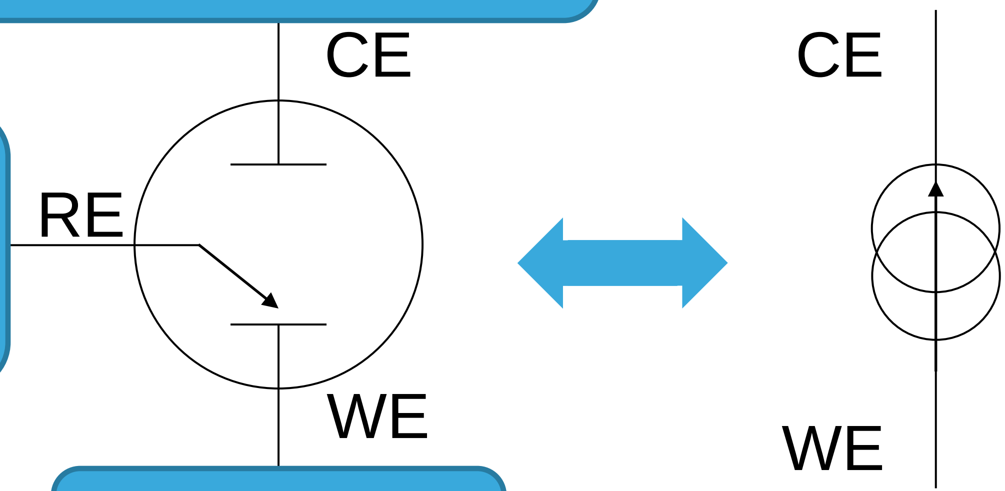
$\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$

Reference Electrode (RE)

Interfacing a 3 electrodes sensor

Must receive the right amount of current to keep the sensor biaised

No current should flow in the RE
Its voltage should be kept constant



Some 10nA/ppm for CO

Its voltage should be kept constant

When using an electrochemical sensor one must :

-Bias the sensor
-Convert the current into voltage (to drive the ADC)

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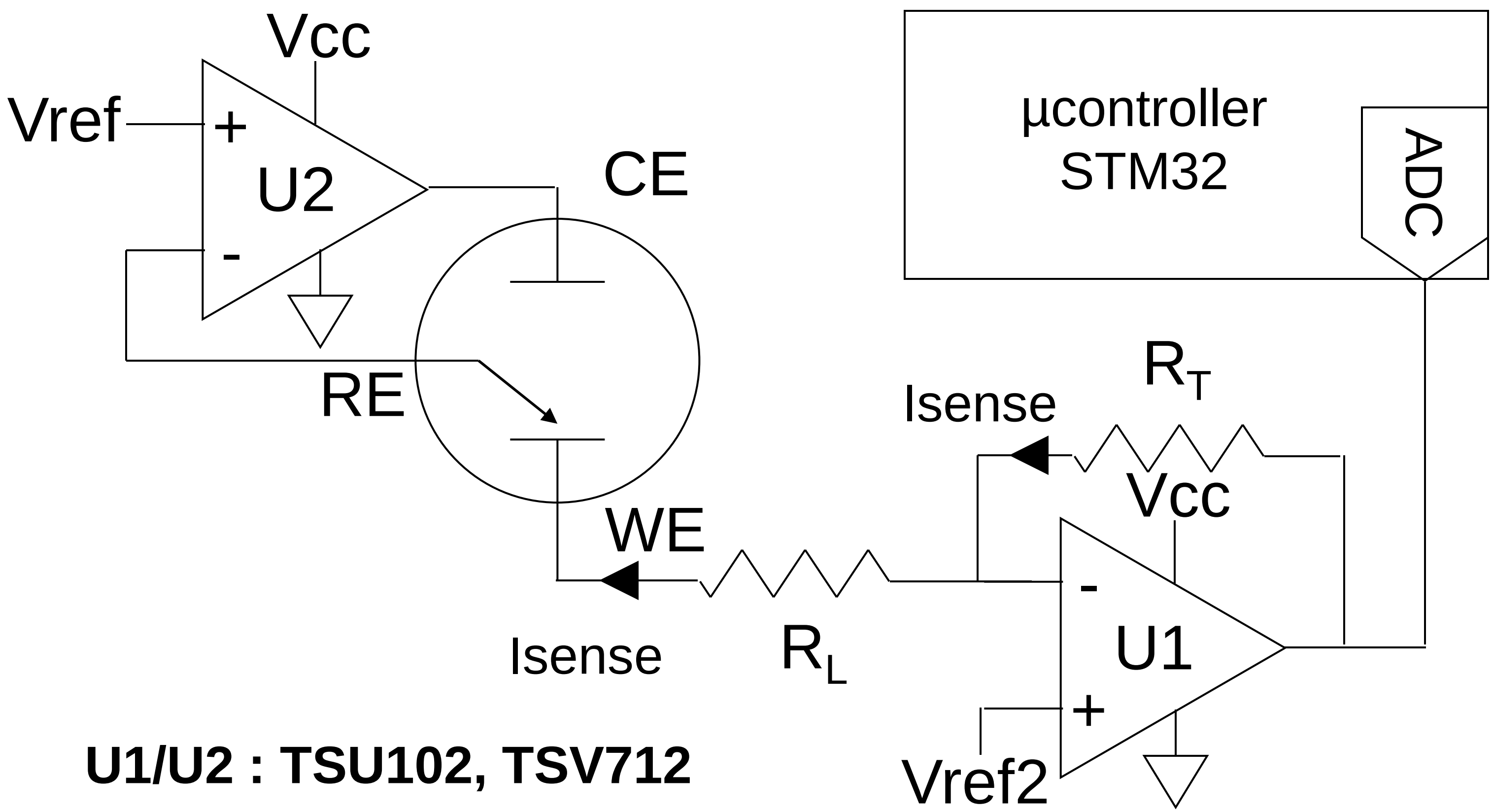
Sensor Characteristics

- Polarity
  - For sensors such as CO, H_2S, SO_2, NO the current enters into the working electrode (oxidation)
  - For O_2 NO_2, Cl_2 the current gets out of the working electrode (reduction)
- Bias
  - Most of the sensors including CO need to be biased with the same voltage on the working and reference electrodes
  - Some may require a positive or negative bias (NO, O_2)
- Sensitivity
  - Genrally some tens of nA/ppm for toxic gases
  - Up to some 100uA for O_2 sensor in air (20.9%)
- Rload
  - Recommended load to be seen by the sensor (generally in the range 10Ω~100Ω)

3 electrodes sensors : Potentiostat



U1/U2 : TSU102, TSV712

Need for ST op-amps !

-Bias the sensor

U2 : RE set to Vref without driving current

-Convert the current into voltage (to drive the ADC)

U1 : $Vout=Vref2+R_T*Isense$

Op-amp key parameters

- Small currents means CMOS device
- Rail to rail op-amps prefered especially for low voltages and sensors that require a biasing different than 0V
- Low consumption (battery powered applications)
- Small package

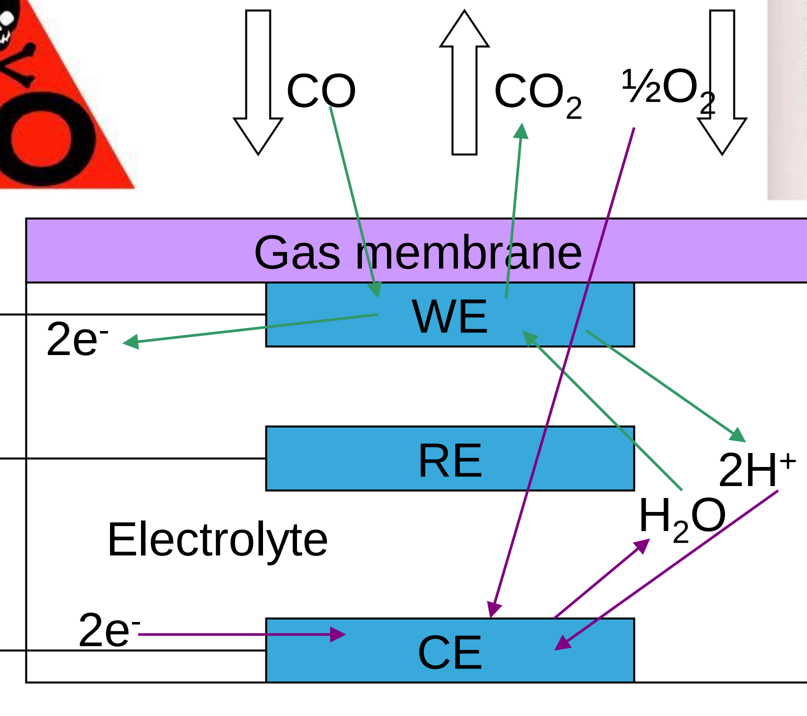
TSZ121/TSZ122/TSZ124
Vio 5uV max

TSU101/TSU102/TSU104
600nA / channel

CMOS
Low Power
Rail to Rail
SC70-5 / DFN8 2x2

TSV711/TSV712/TSV714
9uA / channel, Vio 200uV max

CO detection example



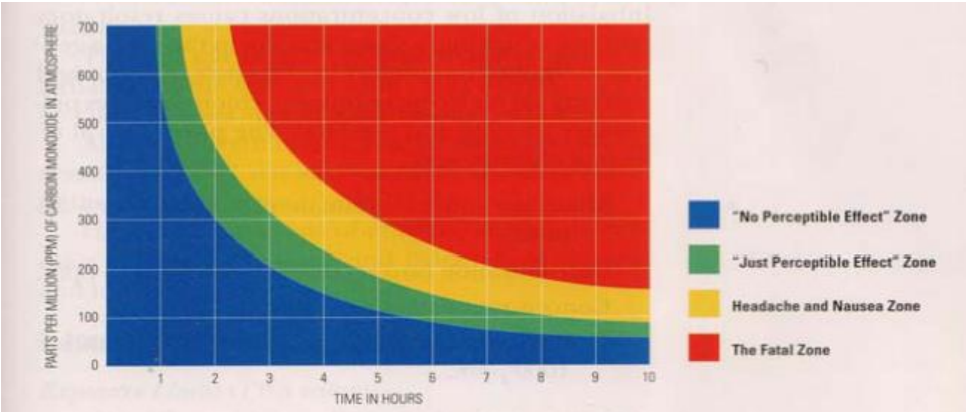


Fig. 1 The Effect of CO on Human Beings

Table 1.1. Comparison of some air quality standards aimed at protection of human health.

Pollutant (unit)	Averaging time	WHO AQG 2005 [33]	EU 2008/50/EC [35]	NAAQS (US-EPA) [36]
CO (ppm)	1 h	30	—	35
	8 h	10	9	9
NO_2 (ppb)	1 h	106	106	100
	Annual	21	21	53
O_3 (ppb)	8 h	50	60	75
SO_2 (ppb)	10 min	188	—	—
	24 h	8	—	—
	1 h	—	131	75
	8 h	—	47	—

Need to detect 30ppm over a long period of time

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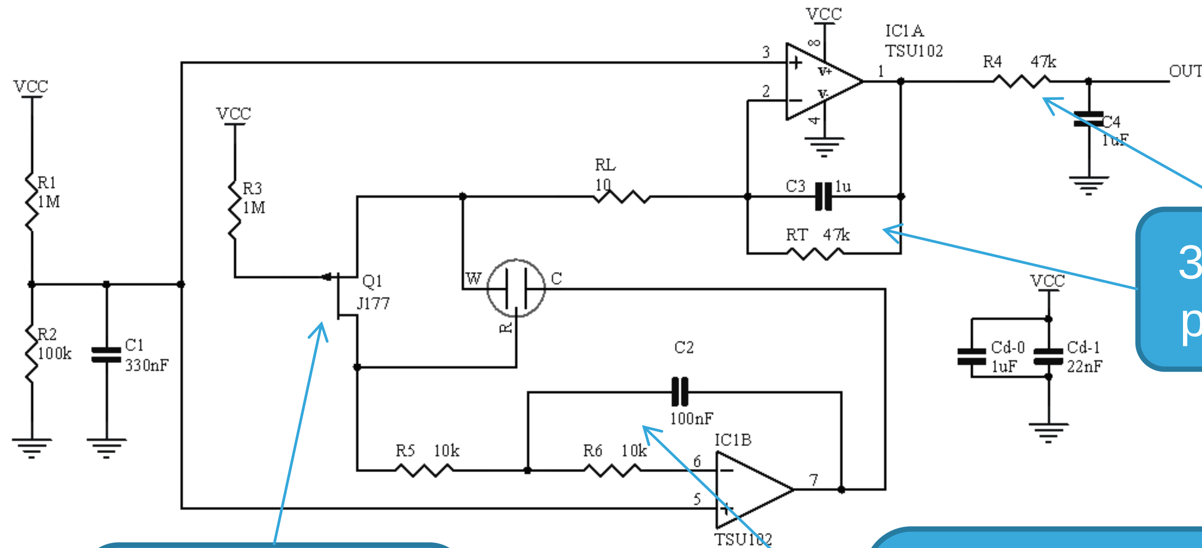
From sensor specification to application

Sensitivity	10 … 30 nA/ppm
Standard Range	0 – 1000 ppm

For Vcc=3.3V, Vicm=300mV (to keep room from saturation)
Maximum output voltage 0.3+47000*30e-9*1000=1.71V (room for over-range)
1ppm means between 0.47mV and 1.4mV on the output (1 LSB of a 12 bit ADC is 0.8mV)



3.4Hz low pass filter

PJFET to keep the sensor biased during power off

Optional compensation network

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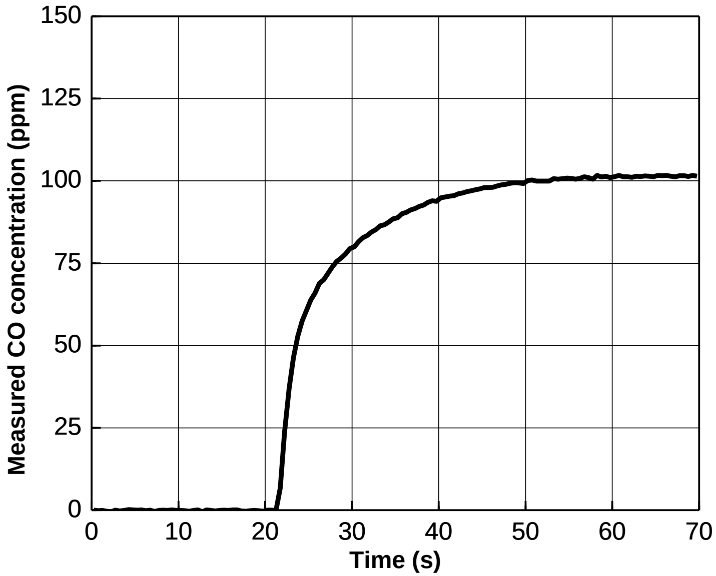
Testing the hardware

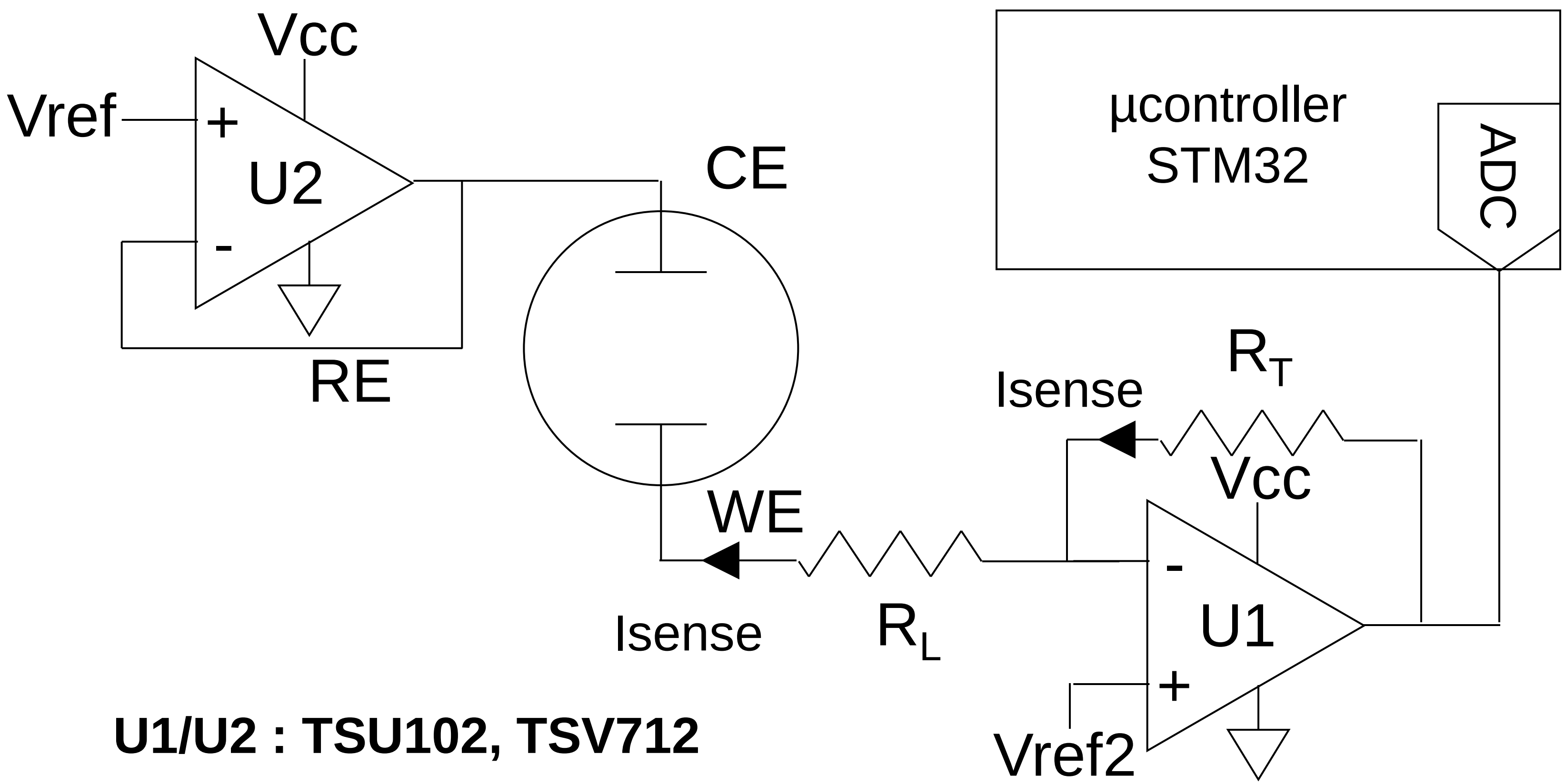
- Check the hardware
  - Sensor removed
    - Verifiy output voltages (shorting RE an CE nodes)
  - With sensor (wait for settling time)
    - Check that there is no saturation
    - Bump test

- Need for calibration
  - Sensor sensitivity (from part to part)
  - Gain, offset (generally two points)



Response to a CO step using TSU102

2 electrodes sensors : Transimpedance



U1/U2 : TSU102, TSV712

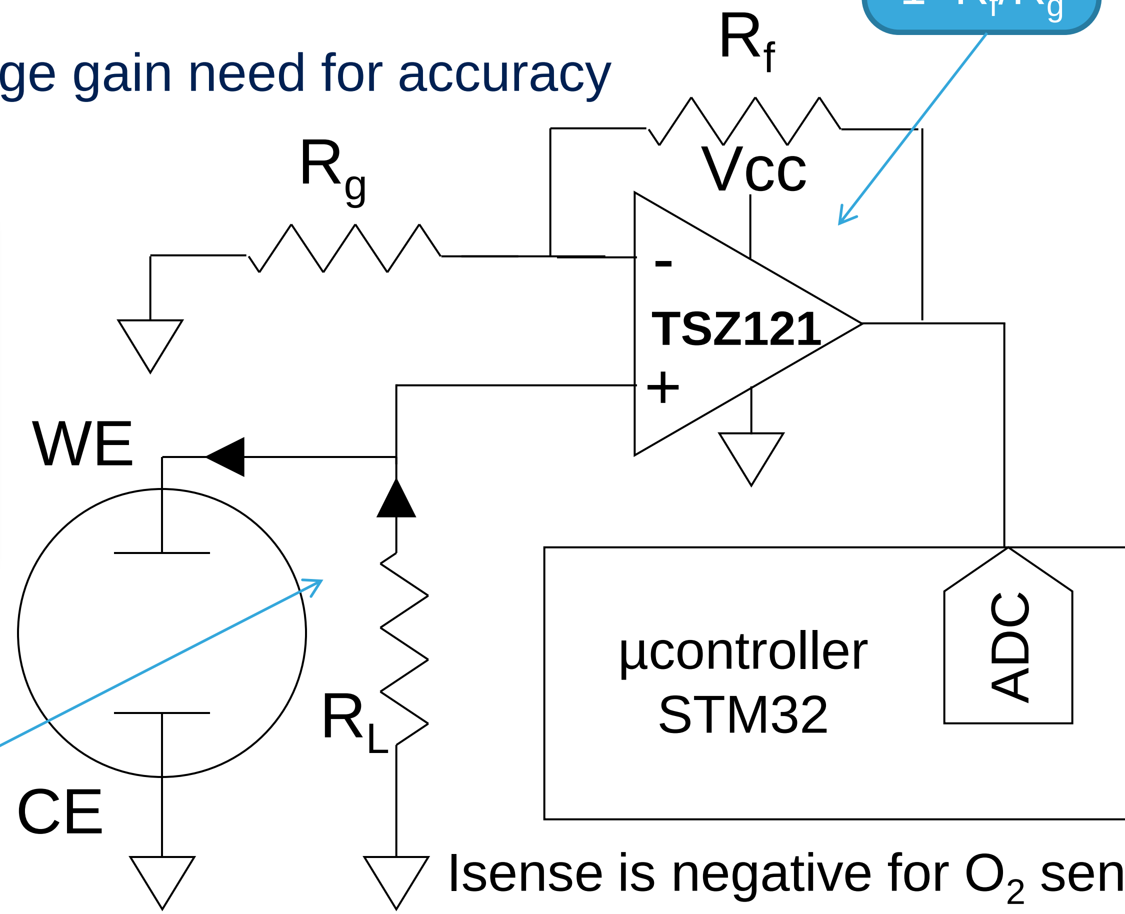
Two electrodes sensors have no RE
This schematics bias CE at Vref, WE at Vref2,
and the output reading is Vref2+RT*Isense

2 electrodes sensors : Galvanic

- I to V conversion done by R_L (100Ω)
- Small signal to amplify ~350uAx100Ω=35mV in air
- Op-amp used in voltage gain need for accuracy

Voltage gain $1+R_f/R_g$

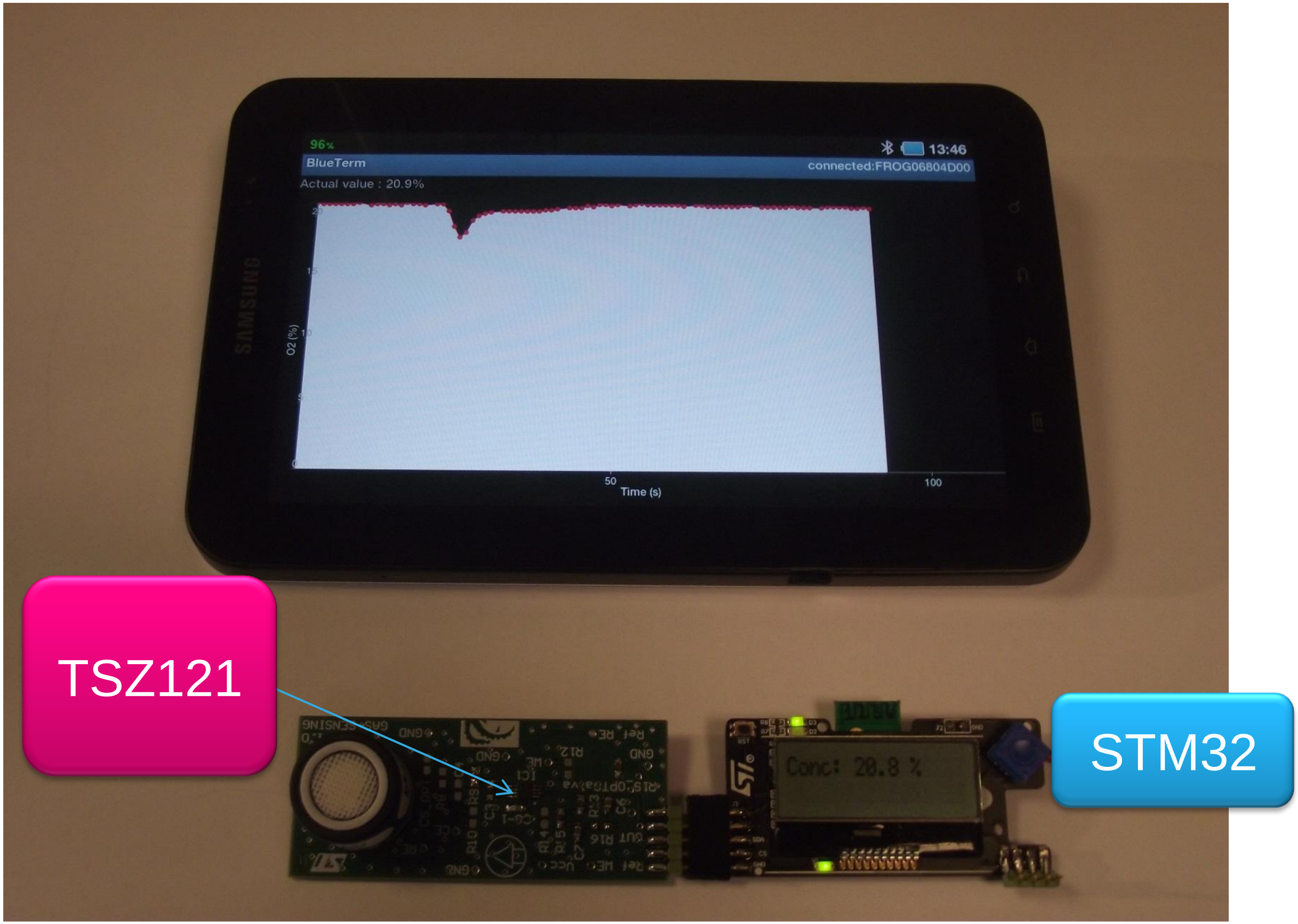
TSZ121
High precision amplifier
5uV max
30nV/°C max
29uA typ



I to V conversion $I*R_L$

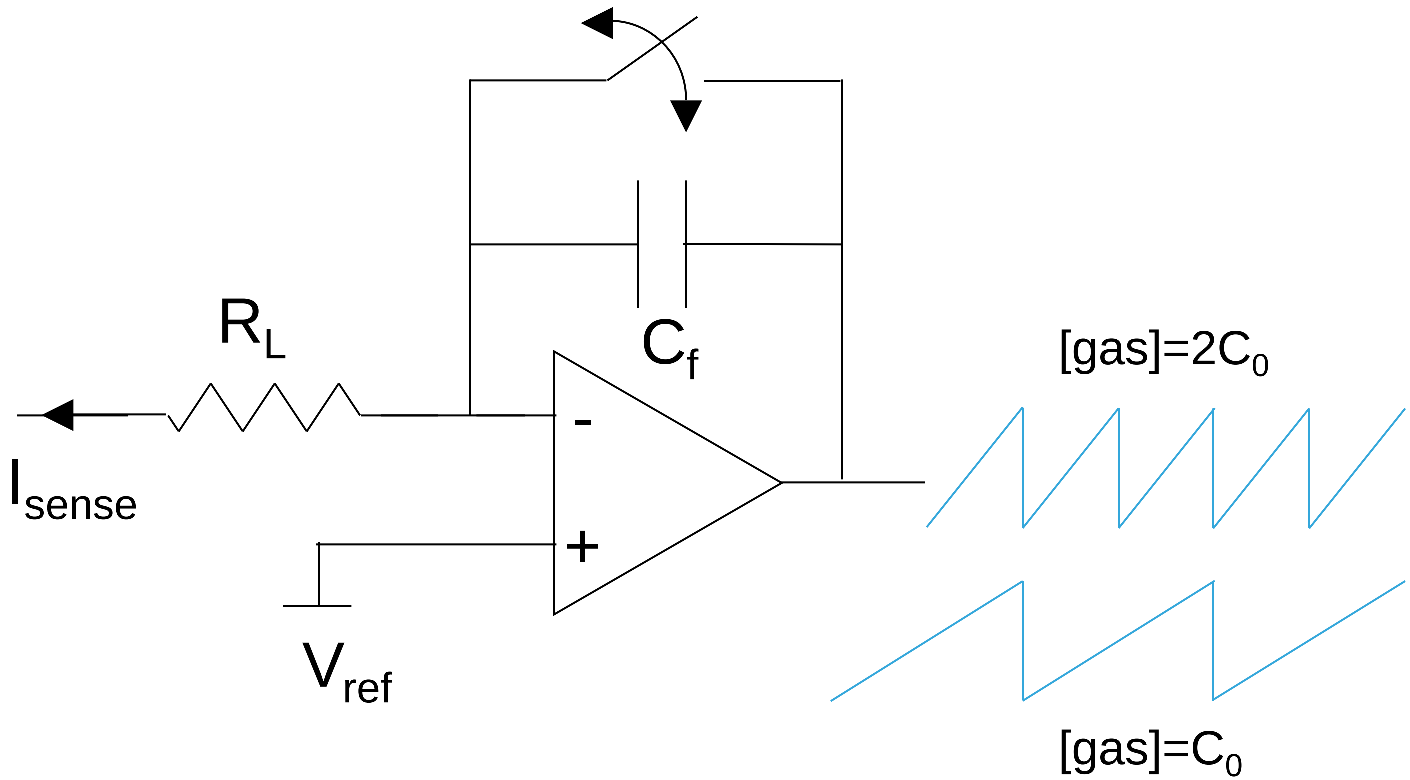
Isense is negative for O_2 sensor

Demo from the lab



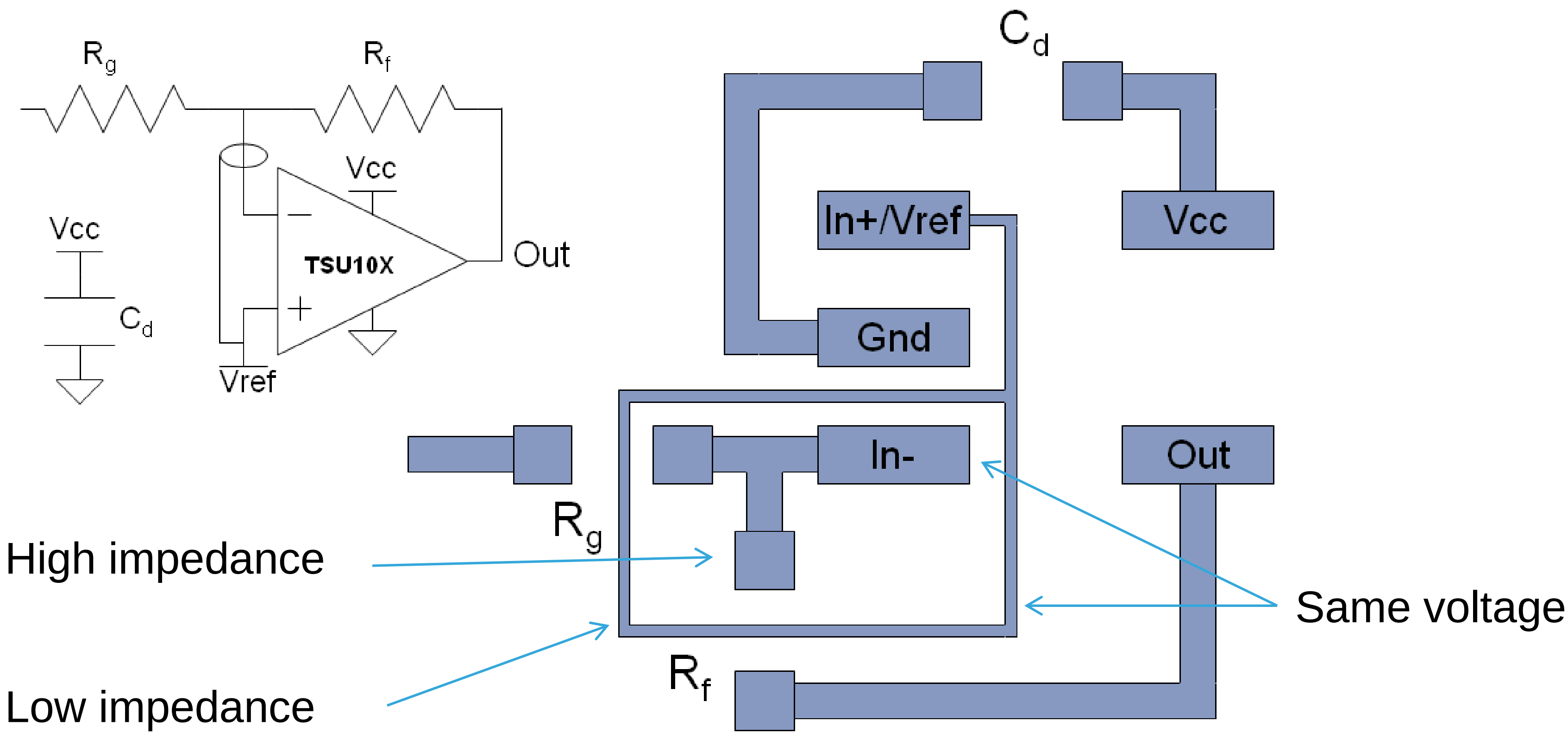
2 electrodes sensors : Integrator

- The number of Cf charges/discharges is proportional to Isense



Other recommendations

- Decoupling capacitors (1uF/22nF close to the IC)
- Guard ring to minimize leakages on high impedance nodes



Conclusion

- Huge and increasing number of products using electrochemical sensors

- Need for one or two op-amps in these applications

- ST has the right right operational amplifiers for these applications
  - TSU102 : nano-power
  - TSZ121 : high precision
  - TSV731 : good compromise between precision and consumption

- We do have additional products making STMicroelectronics your one stop shop for these applications
  - Comparators
  - Analog switches
  - MEMS
  - Microcontrollers
  - ….