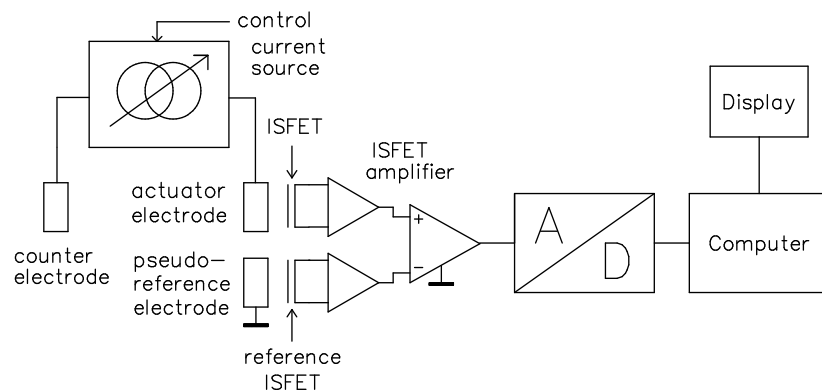


Re-design of the sensor electronics of the coulometric sensor/actuator system II

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1. Introduction

A complete electronic circuitry for controlling the coulometric sensor/actuator device was described by Wim Weultjes and Diana Siemer in 1991. However, because AD-conversion was expensive at that time, a lot of components were added for signal conditioning in order to reduce the AD-converter to an eight bits one. About 75% of the used components were used for signal level conversion and sample and hold action. In addition, for data representation and process control, a commercial microcontroller board was used.

Nowadays, the prices of twelve and even sixteen bits AD-converters are reduced. This results into simpler electronics when the level conversion stage is moved from the analog electronics part to the digital signal processing part. Besides this, modern AD-converters are easily connected to a PC port. Together this resulted into the idea for a new electronic circuitry for interfacing the coulometric sensor/actuator device to a standard PC printer port.

Concerning the level conversion simplifications, no concessions had to be done about the properties of the system. However, the old implementations used electrical insulation of the current source from the ISFET amplifiers in order to avoid a current through the used Ag/AgCl reference electrode. When using a differential set-up, actually no very stable reference is necessary. The fluctuations of a single pseudo-reference electrode used for both ISFET amplifiers will be filtered out when taking the difference as is done with a titration. Figure 1 shows the principle.

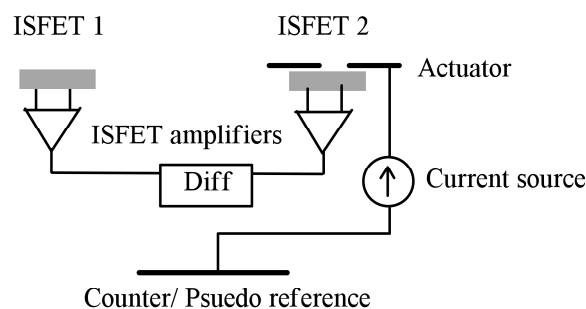


Figure 1: Principle of a differential measurement without a decent reference electrode

The potential change of the Actuator/Psuedo reference electrode due to the applied current is common for both ISFETs, so this change will not be visible in the differential signal.

Appendix A shows the complete schematic drawn in UltiCap from which a PCB like the one given in appendix B can be easily routed using UltiBoard. The whole system, including a 9 Volt battery, can be placed into a 10 ´ 6 cm box and can be connected to almost every computer including laptops.

2. The parallel printer port

The parallel printer port has eight binary outputs and a number of control lines (either inputs or outputs) which can be accessed directly by software. The choice was made to use the eight binary outputs (the data lines) for a DA-converter which controls the current source, and the other (control) lines for reading out a dual serial AD-converter for measuring two ISFETs. The only digital output left was used for switching purposes.

Since the printer port has no power supply lines, an external source must be used. The circuit was designed for a 9 Volt, asymmetric power supply, with the use of a battery as an option.

3. Dual ISFET amplifier

The ISFET amplifier of figure 2 was used successfully in previous projects and was therefore exactly copied here.

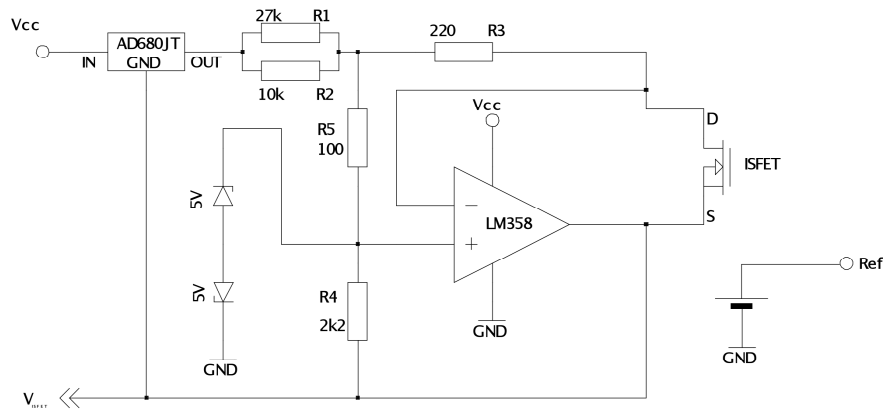


Figure 2: Low power, asymmetrically supplied ISFET amplifier

The reference electrode is not connected to ground, but to a potential which results in an output voltage V_{ISFET} between 0 and 5 volt (directly in the desired input range of the used AD-converter). With a pH range from 0 to 14, and a sensitivity of 59 mV per pH, a range of about 4 volts remains for differences in ISFET offset potentials.

The drain current is equal to:

$$I_D = V_{\text{Ref}} \left[R_3 \left(\frac{R_4}{R_5} + 1 \right) + \left(R_1 / R_2 \right) \left(\frac{R_3}{R_5} + 1 \right) \right]^{-1}$$

which results into a drain-source voltage of:

$$V_{\text{DS}} = I_D \cdot \frac{R_3 R_4}{R_5}$$

For a reference voltage of 2.5 Volt and the resistor values as given in figure 2, the drain current and drain-source voltage become:

$$\begin{aligned} I_D &= 88 \mu\text{A} \\ V_{\text{DS}} &= 0.43 \text{ Volt} \end{aligned}$$

For the operational amplifier a LM358 was chosen because this one has two opamps in a single 8 pins housing.

The AD-converter, an LTC1298 of Linear Technology, is capable of sampling two signals between 0 and 5 volt into a 12 bit number, either separately or subtracted. This number can be read out by a serial protocol over three or four lines. No level conversion between the serial port of the AD-converter and the printer port is necessary because both work with TTL levels.

4. Current source

The counter electrode of the current source is also the reference point. This reference point was designed to stay constant independent on the current. Figure 3 shows the current source, made of a dual opamp TL072 with JFET inputs.

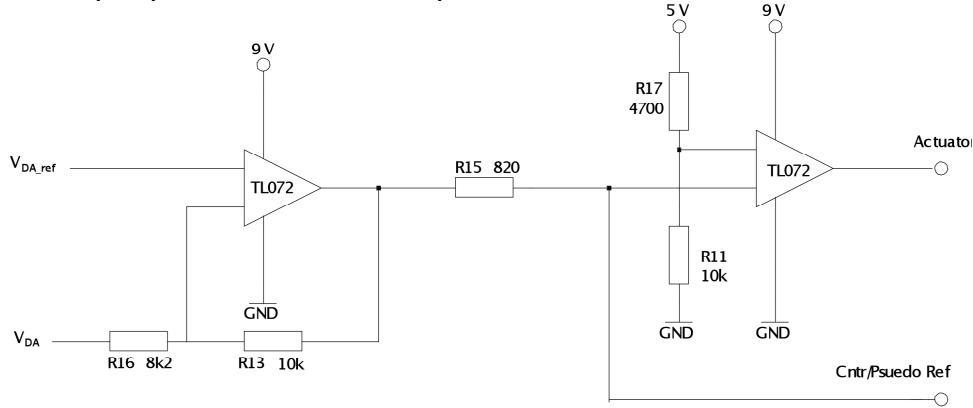


Figure 3: Circuitry for current source

The gain of the opamps is very high, which results in equal potentials at the two input wires of the right opamp. So resistor bridge R11/R17 defines the level of the reference point.

When using a ZN426 8-bit DA-converter for setting the V_{DA} and V_{DA_Ref} input voltages, the output of the left opamp ranges from 4 to 2.5 volt. The output current is determined by the potential accross R15, which ranges from approximately -0.9 to 0.7 Volt. For example, with R15 is 820 Wthis is equivalent to a current range of -0.8 to 1.1 mA in steps of $7.4 \mu A$ with an 8-bit DA converter.

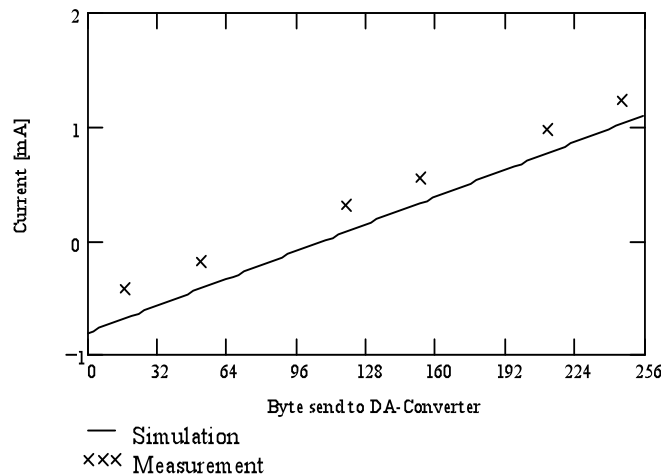


Figure 4: Measured and simulated output current of the current source

Although in principle the output current can be set to zero, an ADG511 quad analog switch is used for switching off the current source. Without such a switch, the discrete output of the DA-converter would never result into a really zero current.

5. Future work

A proto type based on the electronic circuitry of appendix A was realised and tested for proper single ISFET operation with respect to an Ag/AgCl reference electrode. The current source was tested as well, however, a resistor was used as a model for the electrolyte. So the combination of actuator and sensor operation was not tested yet.

One reason for this was that when the current source was switched off (by means of the analog switches), the opamps involved clamped to the power supply and still caused an electrical current through the solution. This happened only for one of the two current directions.

When this minor problem is solved, probably by choosing better locations for the analog switches, the system can directly be used for anodic and cathodic titrations.

Because the ISFET amplifiers were copied from an earlier project, they are not optimised for this system. With a better choice for the components (for example voltage regulators U1 and U2), resistors R3, R4, R7 and R8 can probably be omitted. The zener diodes D1, D2, D3 and D4, which were introduced for limiting the drain-gate voltage, can be omitted as well because of the low voltage power supply.

The LabView Icons given in appendix C, are the starting point for a nice interactive demonstration program. The following options are desired:

- *Single ISFET operation using an Ag/AgCl reference electrode*
 - Interactive calibration procedure (either two and one points);
 - Online pH monitoring with a validity indication;
- *Dual ISFET operation using an Ag/AgCl reference electrode*
 - Interactive calibration for both ISFETs separately;
 - Online difference or dual monitoring mode;
- *Current source*
 - Interactive calibration procedure;
 - Programmable current source;
- *Titration curve generator*
 - Calibration for current source (calibration of ISFETs is not necessary);
 - Titration curve generation. Setting current size and direction, titration time. Plot first derivative of curve as well;
 - Square root of time current generation;

Appendix A: Complete schematic

Appendix B: Possible printed circuit board implementation

Appendix C: LabView icons and Pascal procedures



Initialise.vi

Initialises the electronics for the micro titrator. The current source is switched off and the printer port is set to LPT1 or LPT2 for "port" is 0 or 1 respectively.

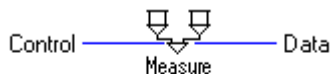
procedure Initialise(newLPT : byte);

Initialises the system for proper operation. The variable “newLPT” defines the printer port.

newLPT = 0 -> LPT1

newLPT = 1 -> LPT2

The current source is switched off by default.



Measure.vi

Gets a single word from the AD-converter and returns this in the variable "Data". The meaning of "Data" depends on the value of the byte "Control".

Control = 0 -> Data is ISFET1 - ISFET2

Control = 1 -> Data is ISFET2 - ISFET1

Control = 2 -> Data is ISFET1

Control = 3 -> Data is ISFET2

function measure(cntrl : byte): word;

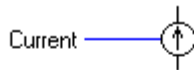
Returns the data word. The variable “cntrl” is a control byte which defines the contents of the returned word:

cntrl = 0 -> ISFET1 - ISFET2

cntrl = 1 -> ISFET2 - ISFET1

cntrl = 2 -> ISFET1

cntrl = 3 -> ISFET2



Set current.vi

Sets the value for the current to the value equivalent to the input byte "Current". Whether the current source is connected to the electrolyte depends on the use of the VI "Current on/off.vi".

procedure set_current(a : byte);

Sets the output of the DA-converter directly to the value corresponding to the byte "a". Whether this value results into a current depends on the procedure "current_source".



Current on/off.vi

Switches the current source on or off. When "ON" is true, the current source is switched on, when "ON" is false, the current source is switched off.

procedure current_on_off(on : byte);

Switch current source on or off.

on = 0 -> Current source on

on = 1 -> Current source off

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